Public Risk Perceptions of Ocean Acidification

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This thesis is submitted to Cardiff University in partial fulfilment of the requirements for the degree of Doctor of Philosophy

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Abstract

Ocean acidification has been called the 'evil twin' of climate change and has become acknowledged as a serious risk to the marine environment. This thesis aims to explore public perceptions of ocean acidification as there is limited work on how people understand this emerging risk. It is important to engage the public because ocean acidification will contribute to how carbon emissions are addressed. The mental models approach was used to compare and examine public and expert perceptions of ocean acidification to help inform future risk communications.

Many of the findings were similar to those of climate change; for example, it was not seen as a personal risk but something which would impact on the environment. Results showed that ocean acidification was unfamiliar to the public with low levels of knowledge and awareness found. People could identify possible impacts of ocean acidification but they were unsure about the main cause, stating that pollution from chemicals and industrial waste was one of the main causes. Risk perceptions of ocean acidification were influenced by factors other than knowledge about the risk such as affect, place attachment and environmental identity. A key finding of this thesis was that people were concerned about ocean acidification despite this being an unfamiliar risk issue, perceiving it as a highly negative risk.

This exploratory thesis will help develop more effective risk communications around ocean acidification with these findings in mind. Future work should test ocean acidification frames; whether or not it should be framed as part of climate change. The mental models approach allowed initial understandings of this unfamiliar risk to be explored using mixed methods and helped examine how ocean acidification was conceptualised through social representations theory. Public response to ocean acidification may mean that there would be greater support for policies aimed at reducing carbon emissions.

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GLOSSARY

Biological pump	Refers to the transportation process of carbon dioxide from the atmosphere into the deep ocean by sinking organic matter, without this process atmospheric CO_2 would be much higher
Calcification	The process by which marine organisms build their shells and/or skeletons formed of calcite or aragonite (forms of calcium carbonate – $CaCO_3$)
Carbon capture and storage (CCS)	This technology captures, transports, and stores carbon dioxide underground for the long-term
Coccolithophorids	A type of calcifying organism
Continental margin	This encompasses the continental shelf, slope and rise forming the outer edge of the continental crust
Deep sea	This can be variable referring to either below the surface (upper few hundred metres) or specifically deeper than 1000 or 2000m
Downwelling	Occurs when the wind causes surface water to build up and become denser eventually sinking towards the bottom of the ocean
Eutrophication	In this natural process the environment becomes enriched with nutrients enhancing primary production. It has been accelerated by human activities such as land run-off from fertilisers
Paleo-Eocene Thermal Maximum (PETM)	Event around 55 million years ago when a rapid change in the carbon cycle and climate took place lasting two million years in which there was a significant release of carbon
Phytoplankton	Organism which forms the base of the food chain that uses sunlight to fix carbon dioxide from the environment into organic material
Primary production	It is a measure of the organic materials or chemical energy created by organisms. This is vital for the overall food-web as organisms such as phytoplankton photosynthesise using available carbon
Pteropods	Also known as sea butterflies, surface based organisms
Public	Though the term public is used throughout it is acknowledged that there are many types of public
Saturation state	The degree of calcium carbonate ($CaCO^3$) mineral levels in seawater
Shallow sea	These cover the continental shelves (seabed or edge of continent under the ocean), and are usually defined as up to 200m in depth
Upwelling	Surface water is displaced by the wind and replaced by cold, nutrient and CO_2 rich water is brought up from the depths of the ocean to the surface

ABBREVIATIONS

AR5	Assessment Report 5 from IPCC (2013)
UKOA	United Kingdom Ocean Acidification Programme
NERC	Natural and Environmental Research Council
NASA	National Aeronautics and Space Administration
DEFRA	Department for Energy, Farming and Rural Affairs
EPOCA	European Project on Ocean Acidification
BIOACID	Biological Impacts of Ocean Acidification
CHOICE-C	Carbon cycling in China seas - budget, controls and ocean acidification
UNFCCC	United Nations Framework Convention on Climate Change
CLAMER	Climate Change and European Marine Ecosystem Research
PETM	Paleo-Eocene Thermal Maximum
SIDS	Small Island Developing States
RCP	Representative Concentrations Pathways
SARF	Social Amplification of Risk Framework
SRT	Social Representations Theory
MPA	Marine Protected Area
GHG	Greenhouse gases
CDR	Carbon Dioxide Removal
SRM	Solar Radiation Management
OA	Ocean acidification
CCC	Committee on Climate Change
IGB	International Geosphere-Biosphere Programme
IOC	Intergovernmental Oceanographic Commission
SCOR	Scientific Committee on Oceanic Research

Chapter 1: Introduction

1.1 Introduction

The effects of climate change on the marine environment are already visible in parts of the world. Climate tipping points in the Earth system have been identified (Lenton et al., 2008) where a small change can result in a state change to the system. Duarte (2014) highlighted three sources of uncertainty that could result in other tipping points being reached in the ocean; human drivers (consumption patterns), natural processes and other changes and elements in the system. The most recent IPCC report (IPCC, 2013) dedicated a section to the impact of climate change on the oceans, establishing a variety of stressors the ocean faces including the effects of ocean warming, deoxygenation and ocean acidification (OA). However, this only serves to solidify the importance of these issues and does not contribute to solutions, especially in relation to the uncertainty of OA. This relatively unknown risk has become more prominent since the publication of the Royal Society Report in 2005, which led to an increase in the volume of publications (Gattuso & Hansson, 2011) with much of the literature focused on researching particular species, regions and potential impacts. The impacts of anthropogenic climate change on the marine environment are numerous, but the combination of three stressors; warming, deoxygenation and OA, could potentially have serious consequences on the oceans.

The focus of this piece of work is on OA, a global issue caused by the increase in anthropogenic carbon dioxide (CO_2) concentrations in the atmosphere, which is absorbed by the ocean resulting in a decreased pH level and other chemical changes. This chemical alteration has impacts on wildlife with calcifying organisms such as coral reefs having been highlighted as those most likely to be affected (Tyrrell, 2011). This may also have serious consequences for those people who rely on the oceans for their livelihoods and food source; the ocean provides more than one billion people with their main source of protein (Turley et al., 2012). As this is an emerging risk issue there is low confidence about what the effects may be due to lack of current research and understanding, with concern about the potential impact of OA on societies that rely on the resources of the ocean.

As CO_2 emissions start to impact the marine environment, with potentially severe consequences for both the natural and human environment, exploring public perceptions of OA is important to establish how emerging risk issues are understood. It is important that the public is informed of emerging risks by raising awareness, and by developing appropriate risk communications based upon robust evidence of their current understandings and risk perceptions (Pidgeon & Fischhoff, 2011). The role of the public and wider society in informing policy measures and responses to OA, and allowing them to make a contribution, is essential. By engaging people with OA, their understanding and concerns around the issue can be considered and incorporated into future research and policy development helping ensure there is support for any measures put in place to mitigate or adapt to OA.

1.2 Aims of work and research contributions

The aim of this research is to examine public risk perceptions of OA. This research uses a mental models approach, which aims to develop effective risk communications by comparing expert assessments with public views on OA. A mental model refers to the idea that people will use their beliefs, and any knowledge and associations that they have to create an image or 'mental model' in their mind of a particular risk (Bruine de Bruin & Bostrom, 2013). The purpose of this research is to explore how OA is conceptualised by both experts and the public, and to determine what the similarities and differences are in their understanding and knowledge about OA.

There are three main research questions:

1) **What are expert perceptions of ocean acidification?**

2) **What are public perceptions of ocean acidification?**

3) **What are the differences and similarities between the experts' and the publics' perceptions of ocean acidification?**

Public perceptions work on OA is still very limited, with little public engagement within the UK. There is a need to involve the public with OA as the issue becomes more widely discussed in relation to CO_2 emission targets and the wider topic of climate change. As OA is seen as a subset of climate change, it is important to assess the literature on public perceptions of climate change as this will most likely be closely linked to that of OA. By

exploring how the general public conceptualises OA, future risk communication or engagement with the risk issue can start to be addressed with more emphasis placed on the importance of emerging risks. To answer the research questions set out following the mental models approach the thesis is structured as follows:

1.3 Structure of thesis

Chapter 1. Introduction: The thesis is introduced and set into context laying out the aims and research questions to explore public risk perceptions of ocean acidification.

Chapter 2. Literature Review: An overview of ocean acidification is given before reviewing the literature around risk perceptions and marine climate change, public perceptions of marine climate change impacts and ocean acidification. The chapter then moves onto establish how social representations theory can help to examine conceptualisations of OA amongst the public.

Chapter 3. Expert Methodology and Mental Model of Ocean Acidification: This chapter starts by outlining the methodology used to examine experts' perceptions of OA, which used expert interview data (N=7) and literature, and the analyses involved. It then shows how the expert mental model of ocean acidification was created with an overview of its components. Five areas of the expert model were identified (Causes, Process, Impacts, Interactions and Responses), and showed that there were key areas of agreement as well as a range of uncertainties, especially around the impacts of OA. Lastly, it was clear that the scientific literature is fast-moving for this complex risk, which was explored at the end of the chapter.

Chapter 4. Public Interview Methodology and Analysis: In this chapter, the mental models interview and process behind this is outlined before covering the data collection and analyses used. The chapter then gives a detailed explanation of the public model and how ocean acidification was perceived by people in the interviews. OA was found to be an unfamiliar risk issue but one that made people feel concerned despite low levels of knowledge. This chapter summarises how OA was understood through social representations, as well as how public perceptions compared to expert perceptions.

Chapter 5. Public Survey Methodology and Results: In this chapter, the design of the survey is given, then it describes data analyses used to explore a range of psychological factors and the prevalence of perceptions identified in the interview phase. Similar results were found to the findings in the public interviews, with low levels of awareness about

OA but people reporting high levels of concern. Lastly, three regression analyses were conducted to explore knowledge, concern and acceptability of OA to determine what influenced people's perceptions of OA.

Chapter 6: Discussion: The research questions are answered in this chapter followed by a discussion of the results found in the empirical chapters, and how these fit into other risk perception literature. It then goes onto suggest how OA could be approached in communications before setting out some further research directions and closing with the conclusion.

Chapter 2: Literature Review

2.1 Ocean acidification

Producing around half of the oxygen in the atmosphere, and absorbing approximately 30% of anthropogenic carbon emissions and 90% of heat generated by global warming over the past few decades, the oceans play an important part in the carbon cycle and have temporarily lessened the effects of climate change (Turley & Gattuso, 2012). The oceans are an important resource for food and livelihoods, particularly for those who rely on coastal ecosystems: fish provided over 3.1 billion people with almost 20% of their average per capita intake of animal protein in 2013 (FAO, 2016). However, there is a cost to the oceans' role as a major carbon sink, as the uptake of atmospheric carbon dioxide (mainly from anthropogenic emissions) is resulting in a change in ocean chemistry in a process called ocean acidification (OA). The chemistry behind OA is clear: CO_2 is absorbed by the ocean, which results in the reduction in seawater pH, carbonate ion concentration, and saturation states of calcium carbonate minerals (see Figure 1). Specifically, CO_2 entering the ocean dissolves and becomes carbonic acid which then forms bicarbonate ions and hydrogen ions causing the water to become more acidic. Depending on local factors such as riverine run-off where water is nutrient-rich, pH may in fact remain the same or even go up (Gattuso & Hansson, 2011), but generally the trend shows a decrease in pH through this process.

There have been historical events of OA caused by natural occurrences including the Aptian Oceanic Anoxic event (OAE1a ~120 million years ago), the end-Permian mass extinction (252 Mya) possibly caused by a giant volcanic eruption of flood basalts (resulting in 96% of life becoming extinct), and the Paleocene-Eocene Thermal Maximum (PETM) 55 Mya (Zeebe, 2012). The PETM is the closest similar event to today as it was a rapid onset event, though the cause is still uncertain, with one highly contentious possibility being a comet impact (Schaller, Fung, Wright, Katz & Kent, 2016). Wright and Schaller (2013) determined that the event was effectively instantaneous based on the layers in clay cores in New Jersey but Pearson and Thomas (2015) on re-interpretation of the drill core, argued that the onset was likely to have occurred over millennia instead (see also Pearson & Nicholas, 2014). All of these events, including the PETM, have been more gradual compared to the current OA event and

though there are natural causes of OA as evidenced through these past events, the focus of this research is on anthropogenic OA.

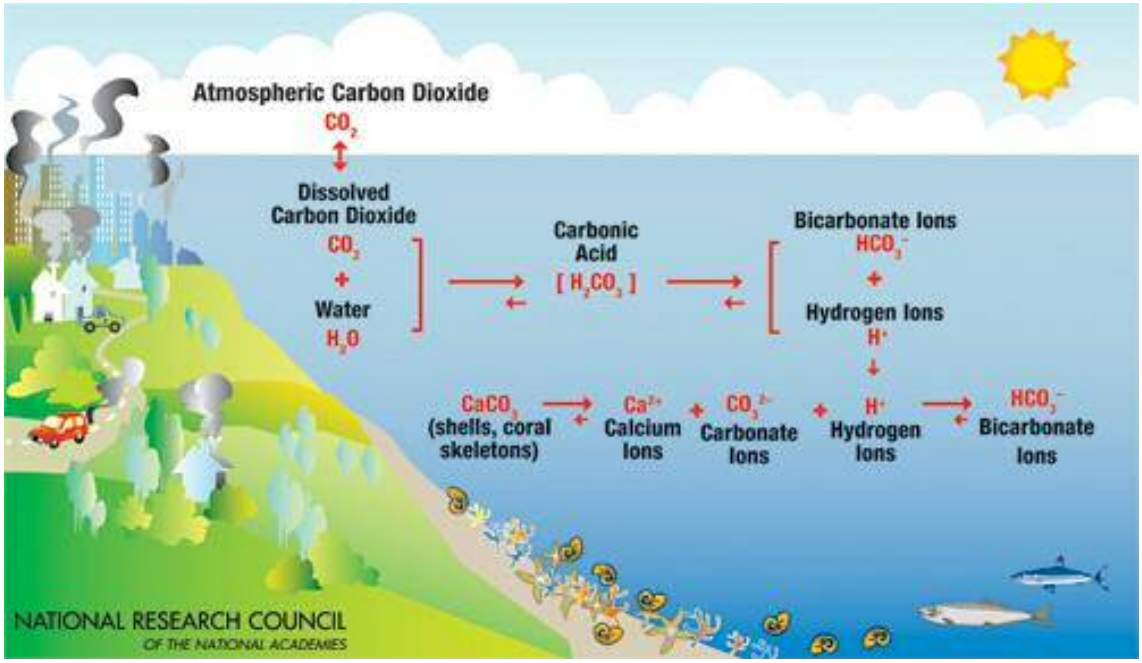


Figure 1. Carbonate chemistry of OA (The National Academies of Sciences, Engineering, and Medicine, 2011)

It is widely acknowledged that the current OA event is primarily driven by emissions from fossil fuels, cement manufacturing and deforestation since the industrial revolution (Royal Society, 2005). It is clear from past events that OA caused mass extinctions and major environmental changes (Hönisch et al., 2012), and it is important to try and establish what the impacts of OA will be on the environment today. The UK Ocean Acidification research programme (UKOA) was set up with joint funding from Department for Environment, Food and Rural Affairs (DEFRA), Natural Environment Research Council (NERC) and the Department of Energy and Climate Change (DECC[1]), as this risk has been recognised as potentially having serious impacts on the marine environment. As well as UKOA, other research groups globally have been established to explore the risk of OA, including; EPOCA (European Project on Ocean Acidification) in the EU, BIOACID (Biological Impacts of Ocean Acidification) in Germany and CHOICE-C (Carbon cycling in China seas - budget, controls and ocean acidification) in China (for a full list and description of the groups see Laffoley & Baxter, 2012).

[1] DECC was merged with the Department for Business, Innovation and Skills (BIS) creating the Department for Business, Energy and Industrial Strategy (BEIS) in July 2016.

2.1.1 Key impacts of OA

A recent meta-analysis reviewed 228 studies, providing a comprehensive overview of biological responses to OA (Kroeker et al., 2013). Grouping a wide range of marine organisms together, the results showed decreased rates of survival, calcification, growth, development and abundance of organisms. There has been a strong focus on decreased calcification rates as being one of the main impacts of acidification, which is reflected in the number of studies conducted (Gattuso & Hansson, 2011). Calcification is the process by which marine organisms build their shells and/or skeletons formed of calcite or aragonite (forms of calcium carbonate – $CaCO_3$). The shells and skeletons dissolve when there is a low carbonate ion concentration (see Figure 1). Particular organisms, such as corals, which are heavily calcified, are most affected by acidification (Tyrrell, 2011) with fish, seagrasses and diatoms being less affected or even benefiting from acidification. Specific to the UK, the impact on marine aquaculture (e.g. mussel farms) would potentially be similar to those already mentioned; growth abnormalities, declining growth and reduced survival rates of bivalves for example (Callaway et al., 2012).

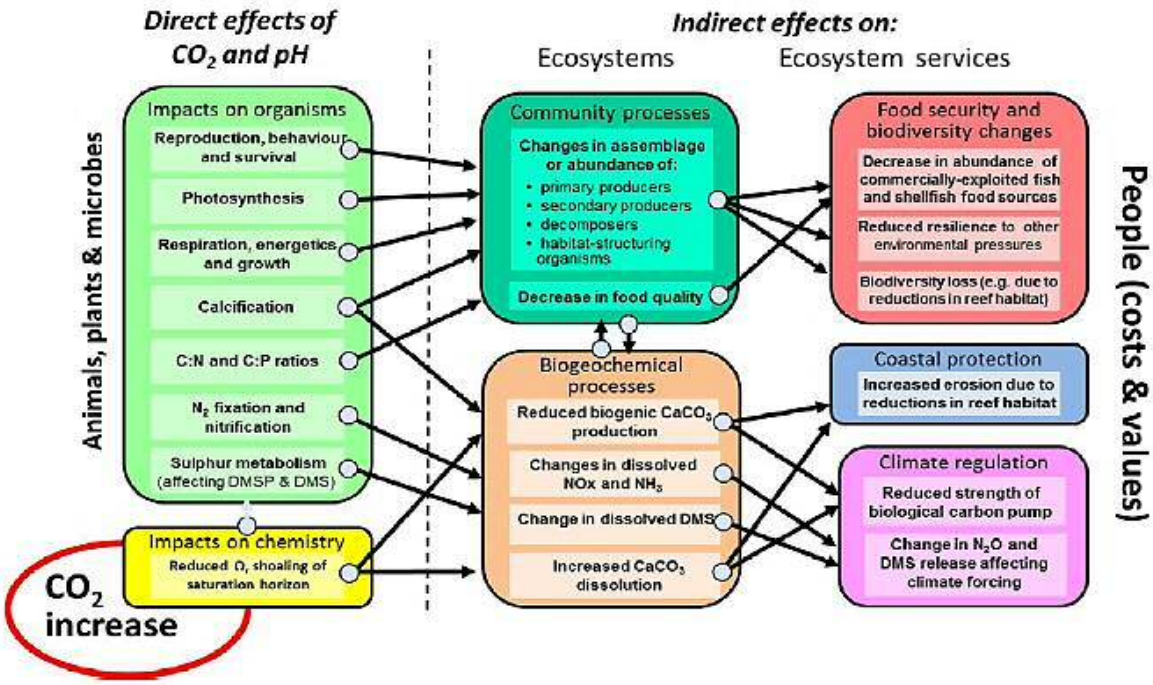


Figure 2. Summary of impacts of OA on organisms, ecosystems, services and society (Aze et al., 2014, p. 15)

As a wide variety of organisms were included in this meta-analysis, there was a substantial variance in responses as expected. Sensitivities between organism types are a main factor, while nutritional quality of food (Turley et al., 2010) and the source population are also contributory factors.

The pH tolerability range for marine organisms is still not clear and cannot be easily defined for specific organisms as these factors also affect the impact of acidification. Additionally, sensitivity (vulnerability of organisms to OA) appears to be increased when there is an interaction with warmer water temperatures. A large volume of published research has focused on the impacts of OA, and though it would be possible to outline many of these in detail, this is not the focus of this piece of work. Figure 2 provides a summary of impacts as shown in Aze et al. (2014), as part of the Convention on Biological Diversity (CBD) technical series. It is very difficult to develop a model showing the full complexity of impacts including numerous interactions, which influence these too[2]. In summary, organisms are impacted in a range of ways as described, which then have implications for ecosystems and food-webs. For example, coral reefs are crucial nurseries for a variety of organisms and with the degradation of habitats, this protection will no longer be available for those that rely on reefs to survive.

Alongside these impacts, there will be changes in numerous biogeochemical cycles. For instance the carbon cycle will be affected as the warming of the oceans means less CO_2 will be absorbed making it a less effective carbon sink resulting in further atmospheric warming. The main point to take away is that the impacts of OA are complex, numerous and uncertain and though there is a large body of research exploring these, there are still many unknowns. Further problems arise because OA is only one stressor with ocean warming, eutrophication (where the environment becomes enriched with nutrients) and deoxygenation some of the key stressors that interact with OA. Multiple stressors must be explored, with research being carried out in a variety of environments and habitats to try to gain a comprehensive understanding of OA (Breitburg et al., 2015).

[2] The model shown includes a number of chemical processes which shall be explained here. In the first balloon titled 'Direct effects of CO_2 and pH' energetics refers to how energy is exchanged or redistributed in numerous processes (e.g. exertion used to feed). C:N and C:P ratios refer to the ratio of carbon to nitrogen and carbon to phosphorus which are generally constant across global oceans and helps modellers to understand biogeochemical processes and how these may change. N_2 fixation and nitrification through the nitrogen cycle are being altered through human activities and can result in OA. Sulphur metabolism may be altered affecting DMS (dimethylsulphide) produced by dying phytoplankton cells decomposing or DMSP (dimethylsulphonloproplonate). The second balloon titled 'Impacts of chemistry' mentions reduced Ω ($CaCO_3$) and shoaling of saturation horizons meaning saturation of seawater will change with calcification becoming harder in undersaturated waters. The remaining balloons continue exploring how changes in the biogeochemical processes already mentioned may cause indirect changes.

The impacts covered in Figure 2 are primarily biological. There is little mention of how society would be affected, and why OA is an important issue to explore. It should be clear that the impacts mentioned already would affect people around the world. This is true for many islands and other vulnerable regions globally, including the UK. The UK has a direct interest in its Overseas Territories, as these regions have strong tourism industries driven by the attraction of warm-water coral reefs as in the Pitcairn Islands (with one of the largest marine nature reserves in the world), and OA would affect biodiversity for which the UK is responsible (Williamson et al., 2013). Small islands are at risk from numerous climate-related hazards and have adapted to some of these issues. However, sea-level rise and OA are new and islanders do not have traditional adaptation techniques (Weir, Dovey & Orcherton, 2016). Residents of these islands rely on fish as a primary source of protein, with the coral reefs and biodiversity providing a strong tourism industry, which is an essential part of the economy. The UK itself is also at risk from OA, though it is hard to determine exactly what the impacts might be and how serious they could be. Goods and services from the UK marine environment include multi-million pound fisheries, aquaculture industries and raw materials (fishmeal, fish oil and seaweed), which are necessary to feed fish species that are being intensively produced (Turley, Findlay, Mangi, Ridgwell & Schmidt, 2009). As well as these production services there are significant economic and cultural services such as bird watching, diving and sea angling which also supports small businesses (Beaumont, Austen, Mangi & Townsend, 2008). A decline in biodiversity would affect all the mentioned services and more.

2.1.2 Responding to climate change and OA

OA is certain to increase as CO_2 emissions and the atmospheric concentration of CO_2 increase, with the interaction of the aforementioned factors influencing the severity of acidification. In order to ensure OA is appropriately responded to, there is a need to present viable solutions to this risk issue that will reduce and limit CO_2 emissions. The IPCC has set out a number of scenarios for future representative concentrations pathways (RCPs) for time-dependent projected changes in atmospheric greenhouse gases (GHGs). These four pathways are representative, as they have similar radiative forcing and emissions characteristics, and consist of RCP 2.6 with a strict mitigation scenario, RCP 4.5 and RCP 6.0 as intermediate scenarios, and one scenario with very high GHG emissions (IPCC 2014). Gattuso et al. (2015) reviewed how the IPCC scenarios RCP 2.6 (low CO_2 emissions) and RCP 8.5 (business as usual) would impact on the ocean and concluded that many organisms were already affected, with RCP 2.6 still resulting in

several high risk impacts occurring globally before 2100. They concluded that global climate agreements needed to ensure that impacts on the ocean were minimised. Turley et al. (2010) recommended a threshold of 500 ppm be avoided with 450 ppm as a precaution to avoid large-scale risks. A range of possible responses have been proposed to take action against OA, which Billé et al. (2013) grouped into four categories: (i) preventing OA (reducing and removing CO_2 emissions and other GHGs); (ii) strengthening ecosystem resilience (e.g. introducing Marine Protected Areas (MPAs)); (iii) adapting human activities; and (iv) repairing damage (such as liming oceans to counteract OA). The main way to mitigate OA is to reduce CO_2 emissions, and though climate change mitigation also requires this response, there are other ways that climate change is being responded to which would not have any direct effect on OA.

It is only more recently that OA has been considered an important aspect of climate change, as researchers believe that awareness of OA and the responses required to act need to become more prominent in the public and policy maker domains. They believe that the oceans should be considered alongside climate change when deliberating CO_2 targets and how to achieve them (Zeebe, Zachos, Caldeira & Tyrrell, 2008). Climate change and OA are separate issues, but are both mainly caused by the increase in CO_2 emissions. The UNFCCC (United Nations Framework Convention on Climate Change) focuses on mitigation and adaptation of climate change but does not recognise OA as a separate issue (Harrould-Kolieb & Herr, 2012). By not acknowledging OA as a separate problem from climate change, some solutions adopted to deal with climate change may have little effect on OA. CO_2 must be reduced to mitigate both these issues; however, there may be more focus on reducing other GHGs if the aim is solely to mitigate climate change. It is important that OA is recognised as a separate risk and that the effects of OA are likely to impact on the severity of climate change, for example through global warming. This debate about whether climate change and OA should be considered together or as separate issues will be discussed throughout this thesis.

The IPCC defines mitigation (of climate change) as "A human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)" (IPCC, 2014, p. 1266). The first international treaty (the Kyoto Protocol) was adopted in 1997 and came into force in 2005. 192 countries ratified the treaty (not including the US) with the agreement running up until 2012 (UNFCCC, 2007). This led the UK to pass the Climate Change Act (2008) which aimed to cut 80% of GHG emissions by 2050, with 5-year interim targets

monitored by the Committee on Climate Change (CCC), who are an independent body. After lengthy negotiations, the Paris Agreement (2015) came into force in November 2016 with 153 countries having ratified the treaty at this point in time, initially including the US and other large contributors. The main target set out in Article 2.1a states:

> "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change." (UNFCCC, 2015).

The Paris Agreement was seen by many as the last chance to take serious action and limit the impacts of climate change. Since coming into force, the US presidential elections came to a close with outgoing President Obama of the Democratic Party (who was committed to limiting climate change and ratified the agreement) being replaced by Donald Trump of the Republican Party. His threat to withdraw during the election campaign from both the Paris Agreement and President Obama's Clean Power Plan to regulate power stations and reduce carbon emissions deeply concerned international leaders (Nisbet, 2016; BBC, 2016). At the start of June 2017 Donald Trump announced that the US were withdrawing from the Paris Agreement generating uncertainty about what the future will hold (The White House, 2017).

Some scientists believe the target of a safe 2°C global temperature increase is likely to be missed (Jordan et al., 2013) as climate change worsens over time. Increases in greenhouse gases and warming on a global scale will result in the trends already seen such as more extreme events, sea level rise and warming oceans. Adaptation measures are being adopted as an additional response to climate change as we are already committed to a level of climate change because of emissions already released. Adaptation means that there will be an accommodation to the current climate or the climate expected in the future and its effects, by taking measures like protecting coastal zones from flooding or increasing mangroves and seagrass protection to help retain benefits associated with ecosystems (IPCC, 2014). Though it would be preferable to try and reduce carbon emissions, particularly to minimise the impacts of OA, there are adaptation measures that can be taken. For example bleaching of coral reefs will only be worsened by OA but other stressors could be reduced such as restricting fishing or tourism in the region to delay the impacts expected. Adaptation to OA is explored more in section 2.1.4.

2.1.3 Geoengineering

Technologies such as geoengineering are being discussed as a third response to climate change after mitigation and adaptation. Geoengineering refers to large-scale interventions to manipulate the Earth's climate system in an attempt to moderate anthropogenic climate change (Royal Society, 2009). There are two main techniques of geoengineering: Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM). SRM would have no direct effect on OA and its impacts, as this technique entails reflecting sunlight back into space to reduce warming (Williamson et al., 2012). It would indirectly have an effect on OA as limited warming means some interaction effects would be lessened. Concentrating on CDR techniques would be more likely to have a direct effect on OA. One of these techniques involves ocean fertilisation, whereby nutrients are added to the marine environment encouraging CO_2 to be absorbed by the ocean, becoming stored as carbon in the deep ocean (Williamson et al., 2012). The effectiveness of these techniques is uncertain and the impacts on organisms are not known. Other stressors such as temperature would also still be an issue. Additionally fertilisation would initially affect only the surface water as the process is slow and it would take time to decrease the impact of OA in the mid and deep ocean. Geoengineering technology has yet to be developed, with ongoing debates and research about its effectiveness, costs and risks.

One further important consideration will be the response from the general public. Pidgeon et al. (2012) found an extremely low baseline awareness of geoengineering in the public, as expected. Once explained, CDR techniques were preferred to SRM techniques with geoengineering supported more by those who were concerned by climate change, and believed it was human-caused. This study was exploratory but illustrates that risk perceptions of these techniques can be formed without a full understanding of their implications; with respondents only getting a brief introduction to the topic. A further study used deliberative workshops (facilitated group discussion) to examine responses to climate change with a focus on geoengineering (Corner, Parkhill, Pidgeon & Vaughan, 2013), in which a key theme that emerged was the idea that human intervention was 'messing with nature'. How new technology is framed and presented to society is critical, as solutions to climate change and OA will rely on support from the public if future implementation is ever to take place.

2.1.4 Localising OA

Alternative solutions to geoengineering to mitigate the impacts of OA would be either adaptation or remediation (Turley & Boot, 2011). By choosing to adapt to OA, the consequences of lower pH are accepted and management strategies are adopted. Remediation would attempt to avoid a low pH level locally or regionally. Locally there may be the potential to focus on other important factors which contribute to acidification, perhaps including the use of geoengineering. This local approach has been successful as shown by Welch in 2009, who examined the effects of OA on a shellfish hatchery in Whiskey Creek, Oregon. Researchers found an 80% mortality rate in 2006 and 75% in subsequent years. In 2008, they linked these mortality rates to upwelling, where CO_2 rich water is brought up from the ocean depths to the surface. In order to prevent this water being taken into the hatchery, water monitoring began and improved mortality rates of the larvae were seen as water intake was now controlled. As the shellfish industry is economically important to this area, this story was picked up by other actors and became widespread. Kelly, Cooley and Klinger (2014) believed this coverage contributed to policy change in Washington, alongside the scientific literature on the impact of OA on the Pacific Northwest (in particular see Feely, Sabine, Hernandez-Ayon, Ianson & Hale, 2008). The narrative story in the news coverage not only demonstrated the human impact of OA, but localised the issue and decreased psychological distancing. Being further backed up by scientific data also made it easier for policy development. Despite this data, at the time other areas on the Northwest coast did not do anything to limit the impacts of OA perhaps because there was not a clear human impact as there was for Whiskey Creek. Since then, Cooley, Ono, Melcer & Roberson (2016) outlined a number of community-level actions that have been used in affected states in the United States; moving from easy to difficult actions. Easier low-cost actions included educating others, filling knowledge-gaps, and emphasising the relevance of OA. More difficult actions included supporting industries, managing for resilience, and ultimately cutting OA. Focusing on local solutions, however, does seem to be a viable option, as engagement with the issue remains a problem, even in areas where it has impacts.

2.2 Risk Perception

Public understanding of climate change is crucial as it contributes to people's response to government policy and initiatives designed to help adapt to and mitigate climate change (Bord, O'Connor & Fisher, 2000). The recent Fifth Assessment Report (AR5) made the

strongest statement yet that humans are responsible for climate change: "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century" (IPCC, 2013). There have also been successive global record temperatures each following year, with 2016 announced the warmest year on record since records began (NASA, 2016). Despite the scientific consensus of climate scientists and extensive evidence of the impacts of climate change, such as coral reef damage and impacts in the Arctic (Hughes, Day & Brodie, 2015; Hinzman et al., 2005), the public are yet to become engaged and take meaningful actions to mitigate their emissions (Whitmarsh, 2009a). Before reviewing the literature on risk perceptions for climate change (including the marine environment), it is necessary to define what is meant by 'risk' and 'risk perception' in this context. Various areas of theory have been developed within risk research to understand how people form mental representations of unfamiliar risk issues (e.g. nuclear power in Spence, Poortinga, Pidgeon & Lorenzoni, 2010). Here we review how these are important when considering the unfamiliar risk of OA.

In most contexts 'risk' refers to "the possibility of physical or social or financial harm/detriment/loss due to a hazard within a particular time frame" (Rohrmann & Renn, 2000, p.14). A hazard could be a situation (like climate change), substance (e.g. chemicals), or an event which can lead to harm, and 'risk perception' refers to people's judgements and evaluations of these hazards. There are a number of theories that have tried to explain what influences the formation of a risk perception to a hazard including the psychometric paradigm introduced by Fischhoff, Slovic, Lichtenstein, Read, & Combs (1978). They measured quantitative judgements of perceived risks and benefits of some activities and technology along with the acceptability of these hazards. Key findings from this work were that people thought some current risk levels were unacceptably high and that there was a relationship between perceived benefits and acceptability of risk. A two-dimensional factor structure showed activities and technology on one dimension with those at the high end showing unknown and new risks. The second perceived risk dimension of dread was an important predictor of public perception and acceptance of a hazard, with the higher end associated with higher dread, e.g. lack of perceived control and catastrophic potential. As OA is an unknown risk, the psychometric paradigm may help to explain public risk perceptions of OA by assessing acceptability of this risk and the risks or benefits associated with it. This paradigm was conceived in the belief that the perception and acceptability of risks is based on social and cultural factors (Slovic, 1987)

with people's experience of hazards typically coming from the media (though also from friends, family and experience).

Heuristics associated with probability estimates can influence risk perceptions and decisions that need to be made about risk, such as how severe a hazard may be and to what extent there may be a risk to people. Judgements have to be made where there is uncertainty in the consequences of decisions made, and these may need to be quick decisions. Heuristics are useful shortcuts to help decision-making and form a judgement more easily, though these are not always useful. They are important to consider when exploring people's risk perceptions of unfamiliar risks, as heuristics and affective evaluations can help provide a greater understanding of risks such as OA. Tversky and Kahneman (1974) described three heuristics that may be utilised in decision-making situations. The representativeness heuristic may be used when someone is asked to judge the probability that object A belongs to category B; if A resembles B in some way, the person will be more likely to assume this to be the case. The availability heuristic describes the process by which a person, asked to judge the probability of an event, will assume that the probability is higher if they can recall such an event. Lastly, anchoring and adjustment may influence decisions made if someone is asked to estimate the value of an object. They will start with an initial value (anchor) then adjust this value based on any further information. These adjustments tend to be insufficient for accurately assessing the value using the information available.

Another heuristic useful for providing a decision-making shortcut is the affect heuristic. All perceptions are thought to contain some affect (Zajonc, 1980) as illustrated by Damasio (1994) with the somatic marker hypothesis. He believed that thoughts are mainly images 'marked' by positive and negative feelings likened to somatic or bodily states. Images that are marked in such a way help to guide judgements and decision-making. Epstein (1994) outlined two information processing systems; a rational system (analytical and deliberative) and an experiential system (automatic and intuitive). 'Affect' can be defined as "a specific quality of 'goodness or badness' experience as a feeling state (with or without consciousness), demarcating a positive or negative quality of a stimulus" (Slovic, 2010, p.22). People use an 'affect pool' in which objects or events are represented in people's minds to speed up decision-making through the experiential system (Slovic, Finucane, Peters & Macgregor, 2007). Alhakami and Slovic (1994) (as cited in Slovic & Peters, 2006) found that an inverse relationship between perceived risk

and benefit of using pesticides (for example) was linked to the level of positive or negative affect associated with the activity. This implies that risk is judged on both what people think and feel about the activity. Finucane, Alhakami, Slovic and Johnson (2000) explored this further and found that participants were less able to analytically deliberate a decision under time pressure and make an effective judgement. They also found that when information increased a perceived risk or benefit there was an inverse impact on the other attribute (perceived risk or benefit decreased).

Risk as feelings (Slovic, Peters, Finucane & Macgregor, 2004; Loewenstein, Weber, Hsee & Welch, 2001) refers to responses that are fast and instinctive and 'risk as analysis' to responses that are slow and deliberative and these two information processing systems influence decision-making. These heuristics all contribute to decision-making and help to form risk perceptions.

The formation of risk perception can also be influenced by culture and identity as outlined in cultural theory whereby an individual's perception of risk reflects and reinforces their commitment to how they view society should be ordered and governed (Douglas & Wildavsky, 1983, Mamadouh, 1999). As they are embedded in society an individual's values, attitudes and worldviews are shared with others through the social structures in place around them. Kahan outlines the concept of cultural cognition which he views as one approach to measure cultural theory of risk as set out by Douglas and Wildavsky. It builds on cultural theory as it measures cultural worldviews by incorporating social and psychological mechanisms helping to explain how culture influences risk perceptions (see Kahan, 2012). The social amplification of risk (SARF) also integrates the psychometric paradigm and cultural risk perception literature (Kasperson et al., 1988) and can help explain how people form their risk perceptions to OA through amplification or attenuation. A key aim of SARF is to explain why certain hazards judged by experts to be fairly low risk come to be amplified through social processes, while other risks judged to be more serious are attenuated. For example, the risk of climate change is thought to be amplified or dampened depending upon how resonant the issue is with a particular group such as environmentalists or businesses (Renn, 2011). A risk event and its characteristics are shared through numerous risk signals (e.g. imagery), and interact with numerous processes that amplify or attenuate the risk. For example, if a risk event such as a nuclear power plant accident occurred, the message would be communicated from an initial source. The message would then be passed through various amplification

stations (including scientists, mass media and politics), who would transform the risk signal through their interpretation. They might make the risk more salient if it is interpreted by this social group in this way. The signal would in turn be intensified or attenuated by individual stations (including heuristics and attitudes) with seemingly appropriate behaviours or responses occurring which might lead to further impacts (Kasperson, Kasperson, Pidgeon & Slovic, 2003). As OA is a novel risk the public will interpret the messages about OA based on other stations and act accordingly. The authors refer to SARF as having ripple effects like dropping a stone into water. The original risk event affects the initial group then spreads to a secondary level and if amplified can have further impacts. If the risk event is minimised or restrained then this ripple effect can be avoided. Attenuating risks means people can handle the numerous risks they encounter on a day-to-day basis though it can result in serious consequences from some risks being underestimated (Kasperson et al., 2003).

2.2.1 Climate change and the public

Risk perceptions predict behavioural intentions and can help determine if people would be likely to take action on environmental risk issues such as climate change (O' Connor, Bord & Fisher, 1999). Perceptions of climate change are highly complex (see Wolf & Moser, 2011; Weber, 2010) with a range of factors influencing engagement with this issue.

The rationalist approach assumes that educating people will increase their understanding and willingness to take action if assumed deficits in their knowledge are filled by providing expert knowledge. Bulkeley (2000) argues that this is too simplistic an account, and not the most important barrier to engagement. Though scientific knowledge about climate change was important to the people studied in Bulkeley (2000), local knowledge and values also contributed to how they understood climate change. More recently, Shi, Visschers, Siegrist and Arvai (2016) found that different types of knowledge influence concern in different ways. If values were controlled for, then increased knowledge about causes but not physical characteristics were found to be linked to increased levels of concern. Understanding the anthropogenic causes of climate change was also the strongest predictor of risk perception in studies in Latin America and Europe (Lee, Markowitz, Howe, Ko & Leiserowitz, 2015) with these authors suggesting that as education improves and people have more experience with changes in weather patterns awareness of climate change will increase globally. A recent literature review showed

how public perceptions of climate change have changed over time (Capstick, Whitmarsh, Poortinga, Pidgeon & Upham, 2015). In the 1980s and 1990s there was a growth in awareness and concern globally as there was more evidence and media coverage on climate change. As media attention increased in the mid-2000s, this awareness was more widespread and there was consensus that action was needed. However, in the latter 2000s and early 2010s doubts and scepticism increased in the public as climate change became a politicised issue (Whitmarsh, 2011). There is a well-established literature exploring a number of barriers to public engagement with climate change (Lorenzoni, Nicholson-Cole & Whitmarsh, 2007; Gifford, 2011, Clayton et al., 2015), including distrust in information, ideologies, lack of action from government or industry and lack of knowledge. For example, scientists are found to be the most trusted on information about climate change with industry and government less trusted by the public (Poortinga & Pidgeon, 2003). Although people trust scientists, climate change is of secondary concern relative to people's daily lives and issues like the economy, health and family (Lorenzoni & Pidgeon, 2006; Scruggs & Benegal, 2012). This finite pool of worry means that issues such as climate change are minimised whilst issues perceived as more threatening, such as terrorism, become of more concern (Weber, 2006).

Public understanding of science is crucial in raising awareness about a wide variety of risk issues, including those considered too complex, uncertain or associated with scientific jargon. People do understand uncertainties about climate change (Darier & Schüle, 1999), but are suspicious of information used to create awareness of the issue. One area where this can become problematic is when a particular concept is difficult to imagine, perhaps because of its novelty or because the terminology is too scientific. The process of OA itself is considered extremely complex, and the level of certainty around the impacts is low, making it clear that engagement with the issue will need serious thought. Similar to OA, climate change is a highly scientific and abstract concept that is mistakenly conflated with other environmental risks such as the depletion of the ozone layer and extreme weather events (Kempton, 1991). Climate change is a well-established example of a risk, which once was considered far too complex for the public to comprehend; public awareness of climate change has improved over time with high levels of concern consistently found in the last 10 – 15 years in the UK. Reynolds, Bostrom, Read and Morgan (2010) updated their original mental models study on climate change (Read, Bostrom, Morgan, Fischhoff & Smuts, 1994) and found that the hole in the ozone layer – misunderstood by some participants in their original study as a driver of climate

change - was still mentioned but not to the same degree, indicating this misconception had been reduced. One recent survey conducted in March 2016 found that when asked directly about their concern about climate change, 70% of people were very or fairly concerned (DECC, 2016).

Despite the established literature of public perceptions of climate change, which have been tracked and surveyed as media coverage ebbs and flows on environmental issues, different facets and impacts of climate change on particular environments has been an area much less researched. The impacts of marine climate change is an important area of research that is still fairly new; rather than focusing on the climate as a whole, scientists are interested in public perceptions of more specific aspects of the environment. As the research literature has grown in identifying the effects of climate change on the ocean, interest in establishing the level of public knowledge has also increased. The literature on marine climate change impacts is important here, as it moves away from the overall abstract concept of climate change and can provide further insights into how people engage with a particular environment. Perhaps by exploring impacts on particular environments, public support and action to cope with climate change can be engendered.

This chapter will now turn its attention to what is already known about public perceptions of the marine environment and OA, reviewing the literature on specific risk factors that are most relevant in this thesis.

2.3 Public perceptions of marine climate change

2.3.1 Awareness and knowledge

The lack of urgency to tackle global climate change is in part due to the lack of motivation to take action either on an individual level, business or governmental level, as well as a lack of pressure on government or business from the public (Lorenzoni et al., 2007). It is clear that the marine environment is important; particularly the oceans (Turley & Gattuso, 2012). However, McKinley and Fletcher (2010) interviewed a group of marine practitioners from governance organisations around the UK and found that they believed that the public feels disconnected from the marine environment and this was linked to poor awareness of marine issues. The marine practitioners also thought that the public should be involved in marine decision-making and that raising awareness and concern was important. By involving the public, the practitioners believed that citizens will

become more engaged with the issues, encouraging changes to lifestyle choices and behaviours.

A study by CLAMER (Climate Change and European Marine Ecosystem Research) in 2011 (Buckley, Pinnegar, Dudek & Arquati, 2011) surveyed 10, 000 respondents in the EU to assess public perceptions on marine climate change impacts, including OA. The data in this survey focused on anthropogenic marine impacts, and was reported by Gelcich et al. (2014). They found that the public perceived the immediacy of marine impacts influenced by human activity (like pollution and overfishing), and thought that these had already occurred or would occur within their lifetime. Over a third of survey respondents thought that the consequences of OA would become obvious within 20 years. When asked about knowledge of marine issues, only 14% were informed about the occurrence of OA (the lowest level of all marine issues), however 58% were concerned. In the UK sample 30% of respondents were unable to come up with a timescale for how the consequences of OA would progress in comparison to 18% for the wider EU sample (Buckley et al., 2011). These statistics are interesting especially considering that only 14% believed that they were informed about OA.

Chilvers, Lorenzoni, Buckley, Pinnegar and Gelcich (2014) conducted a mixed methods study to assess how the public in the UK assessed and understood marine climate impacts. The survey data was taken from the wider European survey (Buckley et al., 2011; Gelcich et al., 2014) but only incorporated the UK sample. The survey data and deliberative workshop group in East Anglia showed that people did not see individual distinct marine climate change impacts (like temperature, OA and sea-level rise), but rather these were seen as interconnected with environmental issues more generally, and with each other. Respondents did express high levels of knowledge for the most cited marine impacts, sea-level rise being the most mentioned (Chilvers et al., 2014). Unsurprisingly the five impacts that people felt least informed and concerned about included OA which ranked last for ‘informedness’; concern about OA ranked at the top of these five ‘least informed’ impacts on the marine environment. This may suggest that a lack of knowledge about OA could be linked to concern as laid out in the psychometric paradigm; that is, people do not necessarily need high knowledge about a particular hazard to express concern (Fischhoff et al, 1978; Slovic et al., 2007).

The low public awareness of the issue must be addressed to ensure support for future governmental policies and the use of new technologies to reduce carbon emissions

specifically. While research in this area is lacking, there is some work which has begun to explore perceptions of OA and marine climate change impacts more generally. Opinion polls carried out by the Ocean Project and AAAS (American Association for the Advancement of Science) in 1999 and 2003 respectively, showed respondents were aware that human activities impacted on the ocean, but did not see urgent action as being necessary (Tran, 2009). Understanding the water and carbon cycles were seen as important to aid people's comprehension of the ocean and improve their climate science literacy; those who were more knowledgeable were more supportive of policies to protect the ocean. Jefferson, Bailey, Laffoley, Richards and Attrill (2014) surveyed the UK public to assess their perceptions of the marine environment; more specifically marine health and knowledge of subtidal species. Issues such as litter and other indicators of cleanliness scored highest, as did contaminated seafood when examining marine health perceptions. The authors go on to suggest that these are clearly linked to human impact on the marine environment. When respondents were asked to select risks to the health of marine environments, the most severe risks such as the effects of climate change were not selected possibly because of their unclear association with human health (Jefferson et al., 2014). A lack of knowledge amongst respondents on the diversity of species in UK waters was also found, which varied depending on marine experience as well as social values (whether a person was classified as a pioneer, settler and prospector as laid out in Maslow's group model (see Rose, Dade and Scott, 2008)). Those who understood nature more generally (pioneers) were more aware of negative implications than those who did not.

Research also shows that knowledge and awareness of oceans is tied to public support for improving ocean health. For example, knowledge is important for developing perceptions but Steel, Smith, Opsommer, Curiel and Warner-Steel (2005) found that although coastal residents considered themselves more knowledgeable than non-coastal residents both groups had low levels of knowledge, contrary to their expectation that coastal residents would be more knowledgeable. NEP (New Environmental Paradigm) measures were also included and were found to positively correlate with level of knowledge about the oceans. Steel et al. (2005) believe that those who identified more with the NEP were more motivated to seek information about the ocean and coast. They also believe that it would be harder to improve levels of knowledge in those with a low socio-economic status (SES) than in those whose knowledge level is affected by where they reside. Lastly, the information source that respondents in this study referred to also impacted on their

knowledge levels, as those who used newspapers and the internet improved their knowledge on the ocean and their resources, whereas television and radio negatively impacted on their knowledge. It is hard to establish how these sources were used. However, research has already shown that in order to ensure information provided is effective in engaging the public, it should be tailored for the target group; rather than simply increasing knowledge, implementation and adaptation strategies should be clarified (Lorenzoni et al., 2007).

2.3.2 Science Education

The paucity of research on the understanding of marine science and ocean issues as well as the inadequacy of ocean science in the education curricula motivated Guest, Lotze and Wallace (2015) to measure levels of ocean literacy in Nova Scotian school students to assess what knowledge they had, how important the marine environment was to them as well as how they used it. Out of around 700 respondents, they found that ocean knowledge was low (below 50%) though knowledge on certain topics varied. For example, questions on ocean and marine life scored highly but were low for chemical and physical topics (including OA; out of eight topics only 0.83% of respondents chose to answer an open-ended multiple choice question on OA with responses that were brief and sometimes confused; "What causes ocean acidification?"). The most chosen question was "What causes tsunamis?" with 37% answering this, but the next highest proportion of respondents (15%) chose not to answer the multiple choice question at all. Guest et al. (2015) believe that concepts such as OA need to be incorporated into ocean education curricula, as the region has a strong connection to the sea. Danielson and Tanner (2015) surveyed undergraduate students on their understanding of OA and found that environmental studies students were more aware of OA and its cause than biology or chemistry students, indicating that low awareness is still an issue even in those with general science degrees. The students thought that they should have an understanding of climate change from their degrees, but the authors suggested that OA may not be perceived as an impact of climate change, or that it is too novel a topic.

There are experiments that illustrate the effects of OA that could be used by educators such as those outlined by Kelley, Hanson and Kelley (2015), which demonstrate the biochemical process of OA using chalk and shells. Science education seems to be believed to be necessary to provide knowledge on more specific ocean issues like OA (Fauville, Säljö & Dupont, 2013), as understanding the function of the oceans more

generally (and associated issues) should allow people to take more informed decisions. An earlier study by Fauville et al. (2011) supports this hypothesis, as they found an increase in knowledge once participants had completed their study. First, they presented students with an interactive animation detailing the background of OA including information on what OA and pH are, the calcification process, and how it is affected by OA. They also gave the students information on the food-web and the effects of time and changes in CO_2 levels on the ocean and its resources. Secondly, they designed a virtual OA laboratory to show the effect of OA on sea urchins in larval form. Students observed the development of the organisms in different conditions, which they had set up themselves. Improving knowledge about risks to the marine environment and increasing information made available to the public is likely to educate the public and increase awareness levels (as this study shows) but addressing the information-deficit gap will not necessarily result in engagement. However, engagement can be achieved through rational-cognitive, affective means, and practical actions (Wolf & Moser, 2011) and as a consequence knowledge alone is not necessarily enough to motivate action.

Lack of knowledge is perceived as the most obvious barrier to engagement with an issue, especially when it is a complex risk issue such as climate change or OA. It is an important contribution to public engagement to encourage understanding of the risk but despite the public knowing what climate change is and the measures they can adopt to mitigate their carbon emissions, the most effective actions are not carried out. There is still low uptake of high impact actions (such as changing travelling or eating habits) and low impact behaviours are adopted instead, most commonly recycling and conserving domestic energy, e.g. switching off lights (Whitmarsh, Seyfang & O'Neill, 2011).

Though there are high levels of public awareness of climate change in general, research on the impacts of marine climate change is still in the early stages. The CLAMER report mentioned earlier found that 18% thought that climate change was the biggest global threat (Buckley et al., 2011) and though there appeared to be low knowledge or awareness of OA there was a high level of concern. Understanding why these concern levels were found is important, as it will help establish people's perceptions of this emerging risk issue. In the UK, when respondents were asked to rank a selection of issues based on how concerned they were, ocean health was ranked last; 32% rated it as important or very important (Potts, O'Higgins, Mee & Pita, 2011). When this was explored in more depth across the sample of seven European countries, environmental problems of pollution,

litter, and oil and gas exploration were perceived as the most important threats to ocean health. Hynes, Norton and Corless (2014) examined public attitudes towards the marine environment in Ireland and found a reasonable level of knowledge of the main threats in this area. In comparison to other surveys, respondents were more generous with their responses, showing they generally felt issues were more of a concern. Out of 11 issues, OA was rated fourth most threatening with only industry pollution, litter, and oil and gas extraction perceived to be more of a threat.

A UK study which interviewed visitors to the UK National Maritime Museum who were asked about their awareness of marine environmental issues, rated pollution as the most important issue with 40% of respondents mentioning it. Interestingly climate change came second but with only 17% citing it as an important issue (Fletcher, Potts, Heeps & Pike, 2009) which suggest this risk is not particularly important to people. It is important to take into consideration the context here, as the sample was quite specific with over half stating they were visiting the museum due to personal interest in maritime heritage.

2.3.3 Trust

People's trust in government to take action and manage the marine environment will be an important factor for future policy support. Poortinga and Pidgeon (2003) explored the role of trust in risk perceptions across five different risk issues (radioactive waste, mobile phones, GM food, climate change and genetic testing), and found that in general there was a distrust in government across all these issues. However, they suggest that a healthy type of distrust called 'critical trust' can be found. For example, if someone has a high degree of general trust alongside a high level of scepticism they will rely on information from an institution but also question its correctness. Support for a policy might still be present despite this form of distrust.

Hynes et al. (2014) found that the respondents they surveyed on marine issues were sceptical of the government and industry to manage the marine environment but trusted scientists' competency. Potts et al. (2011) found government organisations were mistrusted to manage the ocean environment and believe that there is the opportunity for scientific concerns to be represented in policy reform. This may increase support and trust for policy to move forward and improve the marine environment.

2.3.4 The influence of affect, perceived risks/benefits and acceptability of hazards

The psychometric paradigm shows people do not necessarily need high knowledge about a particular hazard to express concern. OA elicits high levels of concern despite there being low levels of knowledge. Exploring affective imagery that underlies risk perceptions illustrates the importance of affect in judgements of climate change (Smith & Leiserowitz, 2012). Lorenzoni, Leiserowitz, De Franca Doria, Poortinga & Pidgeon (2006) surveyed participants in the US and Great Britain and found the affective images of people's associations with climate change were on average, negative. UK participants most frequently cited images relating to the weather possibly due to personal experience, which may help anchor the abstract concept of climate change (Smith & Joffe, 2013). Though the link between impacts of climate change and weather in the UK population is well-known (Whitmarsh, 2009b), Whitmarsh (2008) found that direct experience with extreme weather such as flooding events does not seem to engage people with climate change any more than those who have not suffered flooding. This may simply have been because the issues were seen as separate. However, evidence is mixed on this as Spence, Poortinga, Butler and Pidgeon (2011) found that people who have experienced flooding were found to be more concerned about climate change and felt that personal action on climate change would be effective and have an impact. Another piece of work provided evidence that flooding experience was important as those who had experienced flooding were more supportive of policy for both adaptation and mitigation measures than a nationally representative sample (Demski, Capstick, Pidgeon, Sposato & Spence, 2017). Experience-based or affective decision-making for climate change or other risks can make communications more salient and personally relevant (Marx et al., 2007) if done in an appropriate way.

The use of affect through dramatic visual imagery may not always be an effective way of engaging people however, as shown by Lowe et al. (2006) who found that those who read a scientific report about climate change were no more concerned about climate change than those who had watched the film "The Day After Tomorrow" released in 2004. Fear campaigns or fearful messages about climate change are counterproductive and tend to disengage people (O'Neill & Nicholson-Cole, 2009). Climate change communications need to be positive in order to engage people successfully and using visual representations can be a powerful way of communicating complex issues in a meaningful way (O'Neill & Smith, 2014). OA has been used in work exploring the use of icons (defined as something that enables a person to relate to or feel empathy towards) to engage people

with climate change (O'Neill & Hulme, 2009). In the O'Neill and Hulme study OA was used as an expert-led icon (developed from scientific literature review) but participants were not engaged because it was difficult to understand, vague and impersonal. Examining how affect interacts with conceptualising OA will be useful as it is clear that both climate change and OA are abstract terms but ones with the potential to elicit negative affect.

Affect evoked by hazards can help people assess the associated risk. Perceived risks and benefits are important in shaping people's response to new technology and activities (Fischhoff et al., 1978). This includes acceptance of nuclear energy, for example, which is evaluated negatively by people concerned about climate change (Spence et al., 2010) though people also report that they will 'reluctantly accept' nuclear energy if it will help mitigate climate change (Pidgeon, Lorenzoni & Poortinga, 2008). It is clear that renewable energy sources are much preferred by the public (Demski, Butler, Parkhill, Spence & Pidgeon, 2015).

As part of his outrage model Sandman (1989) felt that outrage was the main reason why the experts and public viewed hazards differently, with outrage resulting if a controllable risk event had serious consequences and could be attributed to those who had failed to manage the risk. Human-made hazards would be more likely to cause public outrage as Siegrist and Sütterlin (2014) showed in work that explored how people were influenced by the nature of the hazard. When framing a hazard as human-caused rather than nature-caused people were more concerned by the former even if the result was the same in either scenario (e.g. the same number of birds were killed by an oil spill). One explanation for this finding is that human-caused hazards to the environment might be seen as 'messing with nature', as seen in discussions of geoengineering and climate change responses (Corner et al., 2013). When discussing oceanic disposal of CO_2, participants interviewed by Palmgren and colleagues expressed concerns about the impact this would have on marine organisms in the ocean and saw it as "…messing with some form of life…" (Palmgren, Morgan, Bruine de Bruin & Keith, 2004). Tampering with nature was also shown to be an important factor in perceived risk for new technology in early studies by Sjöberg (2000) and as a result may be an important factor in risk perceptions of OA.

2.3.5 Values and worldviews

There are clear cultural worldviews and ideologies linked to how people perceive climate change and these should be similar for OA. Hazards have been described as "threats to

people and what they value" (Hohenemser, Kasperson and Kates, 1985: 25) as risk is not just about harm to the person but to things they value like nature or community. Values - typically defined by social psychologists as a 'guiding principle in the life of a person' also shape climate engagement as they have an effect on how climate change information is interpreted (Corner, Markowitz & Pidgeon, 2014, p. 412). Values are important because they influence which risks people attend to and those that they choose to tolerate, or conversely avoid or ignore. This in turn is important for how we might seek to communicate risks to those with particular sets of values or worldviews.

As set out in the cultural theory of risk (Douglas & Wildavsky, 1983), those who fit into an egalitarian worldview perceive more environmental risks than those who are more individualistic (Xue, Hine, Loi, Thorsteinnson & Phillips, 2014). Policy preference is also influenced by values as those who identify as egalitarian were found to be most supportive of climate policy in an American sample (Leiserowitz, 2006).

The value-belief-norm (VBN) theory is a key theory on environmental values, which explains pro-environmental behaviour (Stern, 2000). It includes value theory, norm-activation theory, and the NEP where a causal chain moves from personal values to beliefs about the environmental worldview, consequences and actions a person will be motivated to carry out, and lastly to affect their behaviours (Schwartz, 1994; Dunlap, Van Liere, Mertig & Jones, 2000). While the NEP is commonly used to measure pro-environmental values, however, environmental identity has been found to be a stronger predictor than the NEP in many studies. People with a strong environmental identity were more likely to carry out a set of pro-environmental behaviours than those with a weaker environmental identity (Whitmarsh & O'Neill, 2010). Accordingly, we can conclude here that risk perceptions are formed not only of psychometric characteristics but also how individuals perceive risks based on their values (Slimak & Dietz, 2006).

2.3.6 Place Attachment and Psychological Distancing

As well as the role of environmental identity, place attachment and place identity can contribute to public communication and engagement with climate change (Scannell & Gifford, 2013). Place attachment refers to the formation of an emotional connection with a particular location (Altman & Low, 1992) and place identity refers to when a place becomes part of one's self (Proshansky, 1978). Place attachment has also been shown to be two-dimensional (Williams & Vaske, 2003); personal meanings of place can be broken down into place identity and place dependence (functional attachment where a place can

support activities). It is important to consider how attachment affects support for new mitigation and adaptation projects, for example, as shown in Devine-Wright and Howes (2010). When asked about proposed wind farms, place identity was found to be threatened for those strongly bonded to a place increasing opposition to such plans. As a result. I would expect that for people who have a strong emotional connection to the ocean OA will be a more serious issue.

Climate change is often a psychologically distant issue both spatially and temporally (Spence, Poortinga & Pidgeon, 2012). OA is clearly a global issue and while the theory does allow issues to be scaled up to a global level much of the research on place attachment typically has a local focus (Devine-Wright, 2013). Local messages have been shown to be more effective than global messages to engage people with climate change and engagement greater in those with strong place attachments to their local area (Scannell & Gifford, 2013). However, Spence and Pidgeon (2010) showed that information framed as distant or local did not cause differing attitudes to climate change mitigation. They did find psychological distancing as distant climate change was perceived, as more severe than local climate change impacts. Brügger, Dessai, Devine-Wright, Morton and Pidgeon (2015) highlighted a number of caveats that help explain why attempts to use proximising to increase support for climate change may not succeed. For example, if a person cares about a place proximising should be effective, but if the information is personally salient they may become overwhelmed and not act as perhaps intended. The authors also refer to the implications from construal level theory for proximising. Construal level theory proposes that in order to experience an event that is distant, abstract mental construals are formed and as distance increases, construals become even more abstract (Trope and Liberman, 2010). The closer an event or situation is, the less contextualising is required as it is more concrete, while formation of mental representations will require more effort for events that are further away.

Psychological distance is commonly found in relation to climate change, as associations with this are often distant issues e.g. ice-melting (Lorenzoni et al., 2006) and likewise this is expected to be found to affect perceptions of OA.

2.3.7 Expert risk perceptions of the marine environment

Compared to the problems scientists consider the most important (mainly climate change and destructive fishing, as well as OA) there is a clear difference in risk perceptions with the public. Ekstrom et al. (2015) conducted an analysis of coastal communities in the US

who are reliant on shelled molluscs and are likely to be affected by OA. They found that there were gaps in people's scientific understanding of changes in the ocean chemistry, the impact on organisms, and those reliant on these organisms, resulting in difficulties trying to prepare for OA and find appropriate solutions. This limited understanding also included the effect of other interactions (such as higher ocean temperature and eutrophication) which could influence the severity and impact of OA. Ekstrom et al. (2015) believed that social scientists were necessary to help engage the public and policymakers, and also contribute to development of solutions and tailored strategies for local communities. However, Rudd (2014) found ocean research priorities were very different between over 2000 scientists surveyed globally (including social scientists). These significantly varied depending on the type of scientist asked. Overall OA was ranked third out of 10 in research priorities but social scientists did not rank this in the top 10 but instead focused on behaviour and management. Despite these differences and the challenge in ensuring successful cross disciplinary research, it is important that there is interdisciplinary work in order to formulate effective policy and decision-making.

Delivering a clear message about OA and its problems is crucial for policymakers. OA is of concern to scientists but as the science is still fairly new with regards to impacts this may be problematic. Gattuso, Mach and Morgan (2013) surveyed 53 experts who had participated in an IPCC workshop to assess statements prepared by several of the experts present about OA and its impacts through an online survey. A strong consensus was found for most statements such as anthropogenic carbon emissions being the main source causing OA (though there are other contributors), that the effects will be felt for centuries and also that geoengineering (SRM techniques) will not help reduce anthropogenic OA. Impacts were more uncertain as was the statement about being able to define a threshold for ocean acidity either globally or locally. Without certainty on impacts and a clear threshold on acidity among the research community, policymakers are unlikely to set out clear targets towards mitigating or adapting to OA until they have a clear message of the implications of OA. This is also the case for climate change where critical thresholds need to be outlined for what is an acceptable risk or 'dangerous' climate change (see Lorenzoni, Pidgeon & O'Connor, 2005).

Developing suitable communication materials for the public is important, as there is already evidence that public views differ from expert views in relation to marine risks. Some research in New Zealand emphasises the difference in expert and public views on

risks to the marine environment. Experts rated OA as being the biggest threat to marine habitats in this area, although were also the most uncertain about this threat (MacDiarmid et al., 2012). As previously discussed, the impacts of OA are not yet known, however those asked believed there was a high potential for widespread impact with a possible 57 out of 59 habitats being affected. A recent survey carried out by Eddy (2014) also found that experts identified OA as the main threat to the marine environment in New Zealand, followed by warming sea temperatures. In contrast, the public believed fishing and pollution to be the most threatening and failed to identify the top risks as outlined by the experts. This supports the findings described by Jefferson et al. (2014) as visible, less important issues are more prominent to the public than the abstract invisible ones that are more important.

2.4 Public perceptions of OA

There has been work exploring stakeholder perceptions of OA, and from this work it is clear that fishermen and the shellfish industry are aware of OA and are very concerned about it. As mentioned earlier OA has affected the Northwest Pacific (Feely et al., 2008) where oyster hatcheries are important for the shellfish industry (Washington State Blue Ribbon Panel Report on Ocean Acidification, 2012). Mabardy, Waldbusser, Conway and Olsen (2015) surveyed people in the US West Coast shellfish industry to assess level of concern through negative impacts of OA and participants' understanding of the risk. 94% of respondents had heard of OA with over half having experienced the impacts of OA; 97% experienced financial impacts and 68% emotional impacts. Concern about OA was high with 64% extremely – very concerned about OA in respondents who had not experienced OA and 93% who were equally concerned if they had personally experienced the impacts of OA. Finally, over three-quarters of the sample were extremely – very concerned about OA regardless of their level of understanding.

Donkersloot (2012) carried out roundtable discussions in Southern Alaska to gather the thoughts and experiences about OA from industries, fishing families and communities to ensure that they could help inform public policy on OA. In these discussions there was recognition of a need for OA research to continue and expand including monitoring, with fishermen acknowledging their unique positioning to assist with research. Respondents felt as though action needed to be led by them but also highlighted the need for politics to deal with the issue, as OA is a global issue. Lastly, although the economic case for OA more generally is important, the impacts are more personal for families, cultures etc. such

as those involved in the discussions. OA is a prominent issue for those who are directly involved in affected industries but this does not transfer to wider society.

One of the few pieces of research specifically focused on public perceptions of OA was carried out in Alaska. This region is more vulnerable to OA because of the cool water temperatures and the ocean circulation pattern. The region also has a strong fisheries industry, which is of key importance to the economy. Frisch, Mathis, Kettle and Trainor (2015) surveyed Alaskan residents (N=311) and found that many individuals had a low level of literacy regarding OA and the associated risks. Three-quarters of respondents had heard of OA and cited CO_2 as the main cause with the second most cited being human activity. Frisch et al. (2015) also found that 52% of the sample was concerned about OA and concern increased in those already concerned for future projections of 100 years into the future. When comparing this to the levels of concern and awareness about OA to those who work in the shellfish industries there is a difference, with Alaskan residents not as concerned or aware of the risk. Mabardy et al. (2015) believe this is because stakeholder groups recognise OA and have first-hand experience with it whereas the residents surveyed in Frisch et al. (2015) have not experienced it.

The levels of awareness found in this sample are very different from those found by Capstick, Pidgeon, Corner, Spence & Pearson (2016) who report that only one in five had heard of OA with only 37.5% citing CO_2 as the cause (34.1% cited pollution as the main cause). A second wave was completed to assess if the release of the IPCC report (IPCC, 2014) could have an impact on awareness, but this found similar results to the first wave with only a slight increase in awareness about OA (Capstick et al., 2016). This work surveyed a UK-based sample whom it could be argued have less of a reliance on the ocean than the Alaskan sample, which may account for the difference in awareness of OA, although the issue was also far more widely reported in Alaska. Both conducted their initial surveys in autumn 2013 and employed both open-ended and close-ended questions to explore public understanding and concern of OA. Capstick et al. (2016) did provide a wider choice of response options for knowledge items than Frisch et al. (2015) but also had a much larger sample size (N = 2501). Capstick et al. (2016) also found high levels of concern in OA as well as strong negative associations (e.g. harm to organisms and/or humans) with OA.

There is still limited research on public perceptions of OA with work in the US focused on those with direct associations with affected areas. There is not widespread awareness

of OA; one nationally representative survey found that only 23% of Americans had read or heard about OA with only 32% of this sub-sample aware that the absorption of CO_2 was the cause of OA (Leiserowitz, Smith & Marlon, 2010).

2.5 Exploring ocean acidification using a Mental Models approach

OA is an emerging risk with ongoing research exploring the impacts and the potential consequences this could have on the marine environment. Social sciences are well-placed to determine what perceptions of this risk are and in ways which will help define future communication strategies. Despite the low awareness levels found for this relatively unknown risk, high concern levels were found among those surveyed in the UK (Capstick et al., 2016; Potts et al., 2011).

The present study will use a mental models approach to explore public perceptions of OA in more detail; this is the first piece of work to use this approach in relation to OA. Mental models were first proposed by Craik in 1943 who believed that people had an internal model of the world and they could use this model to decide on the most appropriate way to respond in future situations (Craik, 1943). An alternative definition of a mental model refers to the idea that people will use their beliefs, any knowledge and associations that they have to create an image or 'mental model' in their mind of a particular risk (Morgan, Fischhoff, Bostrom & Atman, 2002). The mental models approach allows for expert and public risk perceptions of a risk to be compared, in order to highlight areas of agreement, important knowledge gaps, and key misunderstandings. A key point of the methodology is that the findings and models obtained from the public are investigated before any risk communication, or information about a risk, is developed, to 'correct' their mental model (e.g. fill in key gaps, current misunderstandings, challenge erroneous beliefs) or before being evaluated to establish how successful the communication has been. It is important to inspect mental models first in order to establish people's level of knowledge and understanding of OA. Assessing what people know about a particular risk issue and what they need to know ensures risk communications are designed with this in mind. The lack of public support on risk issues has frequently been blamed on deficits in knowledge or poor understanding of the issue, however there are numerous reasons that the public may disagree on a risk issue. For example, they may be suitably knowledgeable about a risk issue but may not trust the government to act appropriately. There are also a number of other issues that are more important to individuals (e.g. health, economy), so messages are potentially missed or ignored as the issue is of little concern to them. Exploring how

the public conceptualise a risk issue will help more successful and engaging risk communications to be designed.

This research will follow the five-stage approach outlined by Morgan et al. (2002); though this research will only cover the first three stages as the final two stages were beyond the capacity of this project and focus more on the application of the approach:

(i) Develop an expert model

(ii) Conduct mental models interviews with members of the public

(iii) Carry out a survey aimed at the target population

(iv) Draft risk communication

(v) Evaluate communication

This mixed-methods approach has been used extensively to develop risk communication strategies (Breakwell, 2014) for a range of hazards including radon (Atman, Bostrom, Fischhoff & Morgan, 1994), chemicals from dry cleaning and the electronics industry (Niewöhner, Cox, Gerrard & Pidgeon, 2004), nuclear waste disposal (Skarlatidou, Cheng & Haklay, 2012) and sea-level rise (Thomas, Pidgeon, Whitmarsh & Ballinger, 2015). Prior to developing and testing these communications, public perceptions of each of these issues as well as expert perceptions were investigated, but there may be issues with this process from the very first stage.

2.5.1 Problems with the mental models approach

The initial part of this strategy is to develop an expert model, which can be done from both a scientific literature review and/or expert interviews. However, defining what constitutes an expert and whether they will provide a clear model of the hazard or risk issue at hand can impact on how the initial model is created and understood. The issue of expertise is discussed in section 3.2.3. The expert model created will likely contain areas of uncertainty and disagreement and it is not clear how best to cope with this when constructing the influence diagram following the guidance in Morgan et al. (2002). Though they state that the process should be iterative and experts should review the work (p. 42), the level of uncertainty around OA makes this a challenge as will become clear in chapter 3. The expert model cannot be presumed to be correct as it only provides a

brief insight into what was said at the time and OA is still an unfamiliar and rapidly growing research area.

As discussed earlier, risk perceptions are affected by both the analytical approach and the experiential approach, with rational information and feelings being used to construct a response to risk (Slovic et al., 2004). Affective evaluation of risks such as climate change or OA could be a useful complement to mental models work when designing risk communications (Lorenzoni et al., 2006), which is one of the key aims of this type of work. Mental models work tends to consider the knowledge aspects of a particular risk and as OA is an unfamiliar risk issue, affective evaluation is a necessary inclusion.

Traditionally this approach has mainly focused on producing risk communications and information to increase public knowledge but it is clear that addressing this 'knowledge-deficit' is only one part of engaging people. There are numerous other factors and barriers that have an influence as seen in other mental models work such as Thomas et al. (2015), who explored public perceptions of sea-level change. They found that people had low concern about sea-level change and that it was a psychologically distant issue, both of which need consideration when formulating risk communications. Schuldt, McComas and Byrne (2016) also identified three barriers to communicating about ocean health issues – psychological distance, unfamiliarity and politicisation.

2.6 Social Representations Theory

The unfamiliarity and low awareness in the public for OA has already been established (Capstick et al., 2016) and this piece of work will explore this more closely. Social representations theory (SRT) fits in well as a way of examining conceptualisations of the risk of OA, a complex and highly technical issue. This theory was originally proposed by Moscovici (1988) to help explain how and why society creates social representations and the common sense that evolves from this (Joffe, 2003). The theory was originally developed to explain how people go through the process of trying to understand an unfamiliar risk or idea (Breakwell, 2014). When people encounter a possible risk they develop a risk representation by recognising a hazard and the associated characteristics. As set out in Breakwell (2010) a person develops their mental model at this stage but the affective component is also active at this point. People explore the social influence processes and incorporate the likelihood that they are at risk from the hazard in question. Put simply, SRT can help explain how an individual creates their mental model or

representation of an unfamiliar hazard (Breakwell, 2010), which makes it useful for understanding how people come to understand the topic of this thesis.

SRT is a useful theory as it stresses the need to move beyond information processing and the well-known deficit model of public understanding of science. The representations developed rely on social interactions as well as the mass media to help create representations of a novel risk (Joffe, 2003). OA has already been shown to be of concern to people and produces a negative affect (Capstick et al., 2016). Although emotions are not directly included in this theory by Moscovici, he does acknowledge that they play a part in the creation and development of social representations (Moscovici, 1988). Höijer (2010) concluded that emotions can be viewed as a cultural-cognitive product associated with social norms and values, and that representations are inseparable from emotion.

The aim of all representations is to "make something unfamiliar, or unfamiliarity itself, familiar" (Moscovici, 1984: 24). This is done through anchoring and objectifying an unfamiliar risk. Anchoring refers to the process of making the unknown known by linking it to a well-known risk to compare it to and make sense of it. Objectification occurs when the unknown is made into something concrete and it can be perceived by the senses (Breakwell, 2014).

The equally complex issue of climate change has been explored through social representations by Smith and Joffe (2013). Participants were asked to provide their initial associations to global warming and the symbols, metaphors and images that they mentioned were regularly found to match those in the press. In early mental models work the ozone layer and weather have both been used to objectify and make the abstract concept of climate change concrete (Kempton, 1991; Bostrom, Morgan, Fischhoff & Read, 1994). The abstract concept of climate change is being objectified but does seem to result in misunderstandings and confusion. SRT is useful as it allows us to obtain insight into how risks are perceived and structured. The social representations formed illustrate how these can be confused when people try to make the unfamiliar familiar, especially for complex issues. SRT will help to make sense of the complexity of OA as perceived by the public and allow for engagement on a more meaningful level when exploring the public data.

It could be argued that as OA is an emerging risk there are no social representations of this risk because these are socially constructed. However, SRT is still useful in relation to mental models and perceptions of risk because it aims to describe a dynamic process

which allows existing representations to be applied to this emerging risk issue. These can help to contextualise the mental models that people may hold, or are constructed during the mental model interviews about OA. As with the early mental models work exploring climate change (Kempton, 1991; Bostrom et al., 1994), social representations are expected to be adopted to make OA less abstract and more concrete. Mental models interviews enable anchoring to take place and social representations to form following prior associations.

2.7 Hypotheses

As set out in the introduction the main aim of this thesis is to establish what public perceptions of OA are following the mental models approach and will answer three key research questions. This thesis is exploratory as there is very little previous work focused on public perceptions of OA and none using a mental models approach. The work on OA perceptions (Capstick et al., 2016; Frisch et al., 2015) alongside the research on climate change perceptions (e.g. O'Connor et al., 1999; Weber, 2010; Lorenzoni & Pidgeon, 2006) help inform a set of hypotheses outlined below:

1) **What are expert perceptions of OA?**

   It is expected that OA will be a highly complex and uncertain risk issue though there should be consensus about the main cause and response to OA (Gattuso et al., 2013). As seen in the literature there is uncertainty around the impacts of OA, and also what influence other stressors such as warming of the ocean or eutrophication will have on OA (Breitburg et al., 2015**)**. These certainties and uncertainties should be found to form part of the expert mental models.

2) **What are public perceptions of OA?**

Based on previous work in Capstick et al. (2016) it is hypothesised that there will be low knowledge and awareness about OA due to the unfamiliarity around the risk issue. As seen with information on climate change, information on OA from scientists should be trusted by people more than that of industry or government (Poortinga and Pidgeon, 2003). Though mental models will focus on knowledge other factors such as affect are expected to be important in forming conceptualisations of OA. In particular, it is expected that OA will produce a negative affective response in respondents and high levels of concern (Potts et al., 2011). Other psychological factors such as place attachment and acceptability of OA will also influence risk

perceptions as in climate change (Scannell & Gifford, 2013; Spence et al., 2010). For example if people are more attached to the ocean they may find OA more unacceptable as seen in Devine-Wright and Howes (2010) where place attachment influenced support for wind farms.

3) **What are the differences and similarities between the experts' and the public perceptions of ocean acidification?**

As there is no previous work that has explored OA in this way it is difficult to anticipate what will be found when examining each group's perspective. It is expected that the public will identify other causes of OA deemed incorrect by experts e.g. pollution from waste. As in Capstick et al. (2016) they should also acknowledge CO_2 as a cause of OA. For impacts associated with OA, people are expected to provide a range of impacts that match up with the experts but it is not expected that they will select the most effective response to reducing OA.

Ultimately the findings in this thesis will contribute to developing more effective risk communications of OA and help to determine what information the public needs to know and how this would be best communicated. The implications for the findings of this research will be discussed in the final chapter and allow for some recommendations to be made for risk communications.

2.8 Outline of research phases

This work was carried out to establish how people understand OA based on public perceptions research on climate change and emerging and unfamiliar risks. Each phase contributed to the findings presented in this thesis and were closely related to the other research phases. This piece of research follows the mental model approach and includes three phases, each building on the empirical findings of the previous stage(s) as outlined by Morgan et al. (2002). The first phase uses both relevant literature and expert interviews to construct an expert model of OA. This established a comprehensive overview of how experts conceptualised OA, allowing for areas of agreement and uncertainty between the experts and the public to be highlighted once public perceptions had been examined. The second and third phases both explore public perceptions of OA, first through mental models interviews and then through a wide-scale survey. The second phase of this research was informed by the expert model with the public interviews designed around the topics outlined during the expert phase. The second empirical phase aims to determine

what public perceptions of OA are and how they relate to expert perceptions of OA. Lastly, the public survey provides a measure of how prevalent beliefs about OA are in the wider population. In particular the public interview findings helped to inform the design of the survey conducted in the third stage of this research. Using both qualitative and quantitative approaches is exceptionally useful for exploring highly unfamiliar topics such as OA. It allows for each set of research findings to be corroborated and to establish how unfamiliar risks are understood from each perspective.

As well as exploring OA following the mental models approach with each phase determined through this methodology, this focus of this work was also based on other mental models work and public perceptions literature of environmental risks (e.g. climate change, nuclear power, GM food). Earlier work on OA showed that there was low awareness about OA with emotion and concern playing an important role in perceptions of OA (Capstick et al., 2016). Moving beyond the traditional mental models approach was necessary to ensure a complete picture was developed. Adopting SRT provided a way of examining how social representations were used and created especially during the mental model interviews with members of the public, before ascertaining how widespread these representations were in the wider population. Each of the three phases can help to inform the development of effective risk communications and inform future policy.

This research used a mixed methods approach where qualitative and quantitative research techniques are combined in different phases of the research process (Tashakkori & Teddlie, 2010). A debate about whether this is a reasonable approach has ensued for decades with two main arguments at its centre; that the type of research method is tied to a particular epistemology and that qualitative and quantitative research are separate paradigms and cannot be combined (Bryman, 2008, p. 604). Though by some accounts there is a clear distinction between the epistemological positions of qualitative and quantitative research, this does not mean each is necessarily associated with incommensurable approaches to data collection and research strategy (Bryman, 1988). There are many circumstances where combining the two will help to overcome possible drawbacks of use of any one of these types. For example, though there is previous work on public perceptions of OA (Capstick et al., 2016) the survey results can only generalise the findings based on simple response options but are unable to establish in any detail

why a certain response is given and if there are other crucial factors which helped form a particular view of OA.

The use of mixed-methods has become more common, as the benefits of adopting this approach have become clear. Poortinga, Bickerstaff, Langford, Niewöhner and Pidgeon (2004, p. 74) used a mixed methodology in their work on the foot-and-mouth crisis, stating that "studies have shown that combining different research methods can provide a more comprehensive view on risk issues than can any one methodology alone." The expert phase and the public phase adopted here allows for the use of quantitative research to corroborate qualitative research findings (or vice versa) resulting in stronger conclusions (Johnson and Onwuegbuzie, 2004). In this study, using qualitative approaches (expert and public interviews) and quantitative approaches (a survey of the public) enables expert and public understandings of OA to be explored and compared in different ways. This thesis will now move on to explore each phase in turn, starting with expert interviews.

Chapter 3: Expert Methodology & Mental Model of Ocean Acidification

Chapter Overview

This chapter will lay out the first phase of this research project including the methodology and results. It will explore the expert mental model of ocean acidification that was developed from a literature review and interview (N = 7) from experts in the field of ocean acidification research. Firstly, the rationale is outlined for this phase and how it fits into the other phases of this project. This chapter will then go on to explain the methodology behind this approach and how the data analyses were conducted. The second part of the chapter shows how the expert mental model of ocean acidification was developed, with a final model presented and broken down clearly. Lastly, a reflexive account will be given, describing how this phase was influenced.

3.1 Rationale

The first step of this approach is to develop an expert model, which this chapter will now move on to explore. The expert interviews were used, along with a literature review to develop a mental model of OA that was as accurate as possible but also contained areas of disagreement and uncertainty. This first stage is necessary as it provides an overview of expert perceptions of the risk, which will help to shape the interview protocol for the second stage; conducting mental model interviews with members of the public.

3.2 Methodological Approach

3.2.1 Interviews

Semi-structured interviews are the most widely used qualitative technique in psychology for data collection (Willig, 2013). They allow for a range of open-ended questions to be asked and for the interviewee to give more insight into particular areas if they would like to do so. Potter and Hepburn (2005) set out a range of issues associated with qualitative interviews which essentially highlight the fact that the interview is a social interaction and that some researchers fail to treat interviews as such when designing the protocol, transcribing or carrying out their analysis of the data. This traditional view of interviews in which an interviewee passively responds to the interviewer's questions, and that the right questions will ensure the necessary data can be acquired, has been subject to particular scrutiny. The interview is now perceived as an opportunity for participants to construct their reality interactionally (Gubruim & Holstein, 2002, p. 14). Recognising where the interviewer has influenced the data or analysis will help ensure the right level of detail is given when reporting and representing the interviews conducted. It is clear that interviews are seen as valuable and versatile by a range of disciplines, as well as in the commercial world, to explore numerous areas of interest (Gaskell, 2000). For the purposes of this work they were integral to the first two phases when constructing mental models of OA; for experts in phase one and the public in phase two.

3.2.2 Expert Interviews

Expert interview data was used to complement the literature review on OA. Expert interviews are designed for a specific group, such as experts in an institution who have specialised knowledge that is relevant to the topic under investigation (Flick, 2014, p.227). The debate around who the 'experts' are, and if they really know what they are

talking about became clear in the recent months during the EU referendum, which saw the UK vote to leave the EU.

> *"People in this country have had enough of experts" (Michael Gove (Justice Secretary), Sky News, 3rd June, 2016)*

During the campaign both sides cited experts providing their knowledge, expertise or professional opinion on what might happen to the economy, science and research, migration and so on. It is important to establish what an expert is as many of those put forward to share their views seemed to become discounted by many voters during this referendum. The debate about whether the worth of expert views has been damaged is worth discussing later in this thesis when considering what this might mean for risk communications.

There is no agreed definition of what an 'expert' is (Lowe & Lorenzoni, 2007), and it can be defined in numerous ways. It could refer to someone who has a wealth of specialised knowledge in a particular field, as already mentioned, or it could be someone who has vast experience or interaction with an area. Collins & Evans (2002, p. 254) set out three levels of expertise:

No expertise – person does not have the expertise to carry out analyses or fieldwork

Interactional expertise – person has enough expertise to interact and conduct analyses

Contributory expertise – person has enough expertise to contribute to the science of the field

Those interviewed all fall into the final category, as they were all senior scientists with substantial published work in their specific area of ocean sciences. For this work, those interviewed also fall under the initial description by Flick (2014) as those with specialised knowledge in OA.

3.2.3 Data Collection

Data was collected by another researcher within the team working on a related project assessing public perceptions of OA, of which I was involved (Capstick et al., 2016). The expert interviews were carried out in order to provide a basis for the public survey that was conducted, and to enable a more detailed subsequent analysis of expert views, but the data were not formally analysed except for within my own research. As the interviews

were not designed or carried out by myself, this restricted the content of the data and they may have been conducted in a different way to how I would have completed the interviews. Despite this, they are fit for purpose as they cover the material that would likely have been obtained allowing for the opportunity to assess the views of key experts (i.e. senior scientists on each of the UKOA consortium projects). How this may affect the analysis will be discussed in the next section of this chapter after briefly covering where the expert interview data came from and how it was collected.

3.2.4 Sample

Because the research was specific to the UKOA project, which encompassed seven discrete projects spanning different disciplinary approaches (including Paleoclimatology, Oceanography and Earth System Modelling), the main target interviewees were senior scientists on each of those projects (Table 1). The UKOA Research Programme ran for five years and was jointly funded by DEFRA, NERC and DECC. The programme aimed to understand marine organism's response to OA, collect data and communicate findings useful to policymakers, and to try and determine predictions of carbonate chemistry changes with more certainty (UKOA, 2016). The interviews (N = 7) were conducted by Stuart Capstick between May - July 2013 as part of the UKOA programme.

Expert	Expertise
Interviewee 1	Earth System Scientist
Interviewee 2	Marine System Modeller
Interviewee 3	Earth System Modeller
Interviewee 4	Marine Biologist
Interviewee 5	Marine Ecologist
Interviewee 6	Marine and Atmospheric Scientist
Interviewee 7	Paleoclimatologist

Table 1. Expert participant areas of expertise

3.2.5 Interview protocol

The protocol was designed to be a mental models type interview; it started with general questions about OA before moving on to more specific topics. The initial questions for example asked interviewees about their area of expertise, what OA 'is', and areas of consensus as well as what is uncertain. The rationale behind asking about certainties and uncertainties was seen as important by the researcher who carried out the interviews, as it established what the overall understanding of OA was by the respondents in the initial stage of the interview. In relation to climate change, this is a key theme in many ways and also enables us to know what the OA scientific community is clear and less clear about.

By asking all the interviewees the same initial questions (e.g. areas of certainty and uncertainty) this also gives an overall picture of what 'the experts' as a whole think. For example, everyone agrees that the chemistry is clear and uncontested (an increase in CO_2 concentrations dissolved in the ocean changes bicarbonate ions, decreases carbonate ions causing a pH decline), but there are different views about the likely seriousness of OA for marine organisms (Kroeker et al., 2013).

To design the protocol, background reading (e.g. Royal Society, 2005; Barker & Ridgwell, 2012) revealed salient areas within the literature and these were also brought up in the interview. A major research area was the consequences of OA for organisms and ecosystems; coral reefs and coccolithophores in particular were highlighted (Tyrrell, 2011), and respondents were asked about the potential general consequences of OA. It was also clear from the literature that geographical variations would likely be seen in the severity and types of impacts. As well as this applying to various oceans around the world this would also include different parts of the ocean – i.e. surface, deep and seabed (Orr, 2011). Questions also asked experts how they thought society would be impacted (with a focus on the UK context) which resulted in some interviewees stating that this type of question was out of their area of expertise. However, it was important to try and determine their views on what the wider societal or policy implications could be (see Appendix A).

As each person was from a different specialist background there was also an attempt to get details more pertinent to their own specific area of research. The success of this approach was variable though it did allow information from that specific expertise to be garnered. A final area that these interviews focused on was climate change, regarding the relatedness of climate change and OA and how this link (or 'non-link') would affect the interpretation and transmission of science more generally (as OA is an emerging climate risk).

3.2.6 Secondary Data

Secondary data analysis occurs when pre-existing qualitative data from previous research studies are re-used. Such data can be used for a couple of purposes: either to explore new or extra research questions or to verify previous research findings (Heaton, 2008). It could be argued that this set of data is secondary data as the 'primary' purpose of the interviews was to help inform the design of the public survey and as the interviews were not designed

or conducted by me. However, as the data was not formally analysed, the analysis carried out here was the primary analysis though there are elements of secondary analysis.

Data sharing would be considered as informal, as the primary researcher was from the same research group, willing to share his data with me and had no part in the analysis (Heaton, 2008), though there are ethical considerations which shall be discussed. The two research projects overlapped and shared research members within these projects who were permitted to share data. Heaton (2000) formulated a typology of secondary analysis with criteria that distinguished six types of secondary analysis that may be utilised by the researcher. This was revised to five types in further work shown in Table 2 below (Heaton, 2004). Based on this typology this work does not fit exactly into any of the categories outlined.

Supra analysis	Transcends the focus of the primary study from which data were derived, examining new empirical theoretical or methodological questions
Supplementary analysis	A more in-depth investigation of an emergent issue or aspect of the data which was not considered or fully addressed in the primary study
Re-analysis	Data are re-analysed to verify and corroborate primary analyses of qualitative datasets
Amplified analysis	Combines data from two or more primary studies for purposes of comparison or in order to enlarge a sample
Assorted analysis	Combines secondary analysis or research data with primary research and/or analysis of naturalistic qualitative data.

Table 2. Types of secondary analysis of qualitative data (Heaton, 2004, p. 38)

It is clear from the descriptions of these types that my use of the data potentially fits into only the first or second types of analysis; supra-analysis and supplementary analysis.

Supra-analysis fits because the data was used for a different purpose in this research by creating a mental model of expert conceptualisations of OA rather than simply using the information to help design a public survey conducted externally to this piece of research. On the other hand, supplementary analysis fits because both projects were interested in establishing what public perceptions of OA are but approached the question in different ways. This analysis explored the data in detail to create a rich picture of how experts perceived OA which informed the design of a survey at a later point and also incorporated items from the original survey.

However, I would argue that this analysis is the primary analysis, as the data was only collected by another researcher and no proper analysis was conducted, but was supplemental to the main project purpose. There are still limitations to the data collected, which will affect the analysis. Firstly 'data fit' as data was collected for another purpose, though based on the protocol a mental models style interview was used. A second issue is the 'problem of not having been there' and that someone else carried out the interviews, designed the interview and had a different approach (Heaton, 2008).

3.2.7 Ethical considerations

There are ethical concerns with using data collected by another researcher for another purpose. These have not been explored in enough detail in the literature for qualitative data and in cases of secondary analysis could be problematic (Kelder, 2005). In this case, the main issue is that of informed consent and the need to ensure confidentiality is maintained and no harm is done. In the interviews, all participants were made aware that the data obtained would potentially be utilised in future reports, publications and other outlets. With regards to confidentiality, participants consented for their data to be used in such a way. In this thesis, the findings will be reported in line with the 'strictest' of the possible consents allowed (i.e. "I would prefer that my institutional affiliation is not used as a generic identifying feature" and "I would prefer to remain anonymous"). Once qualitative data has been anonymised parts of it are generally considered able to be made public in theses, publications and reports.

3.3 Data Analysis

An initial literature review was carried out to gain an understanding about what OA was and to assess the scientific knowledge about the risk at the time. The main topics that became evident from the literature reviewed between autumn 2013 and spring 2014 were

the causes, impacts and effects of OA. As this body of research is constantly shifting, with new findings published on a daily basis, the inclusion of expert interview data was deemed necessary in order to create a more accurate expert model. The OA literature was very technical and the focus was on very specific topics with few review papers. Mental models interviews and analysis enabled a 'big picture' to be formed.

All expert interviews were reviewed with notes taken on each one but a full transcription was not conducted. The full transcriptions, once completed by a professional employed by the other project, were shared with me, allowing me to read the transcripts through and take more notes to further inform my conceptualisations of this risk and conduct a more in-depth analysis. Incorporating the literature that had been reviewed, the expert interview data as well as further literature up to summer 2014 allowed me to create a clearer picture of this uncertain risk.

3.3.1 Grounded Theory and Thematic Analysis

The analysis approach was semi-grounded as it was deductive (structured from scientific literature) and inductive (grounded) in which themes were identified from the raw data. Grounded theory, introduced by Glaser and Strauss (1967) refers to theory that is generated through a close inspection of qualitative data such as from interviews. It is impossible to state that theory is simply generated by exploring the data as little sense could then be made of it. Researchers will have their own influence and ideas regardless of whether they apply any other theoretical background. Pidgeon and Henwood (1997) describe the process that takes place when theory appears to be 'emerging' as "a 'flip-flop" between ideas and research experience" (p. 255) with a continuous interplay between the data and the researcher's own thoughts. During this analysis the process described above was evident, as it was hard to distinguish that which had come from the literature and the interviews, as well as my own ideas and interpretations when developing theory and the expert model of OA.

Thematic analysis is best suited to creating a conceptualisation of a particular phenomenon (Joffe, 2012), in this case the risk of OA. It is a method used to identify, analyse and report themes or patterns within the data (Braun & Clarke, 2006). A theme captures something important about the data in relation to the research question which can be consistently found in the entire dataset. However, there are obstacles to ensuring quality is maintained throughout the analysis. Boyatzis (1998) outlines three possible issues:

(1) Projection – researcher may read into or attribute something to another person that has come from themselves, such as emotion, value etc.: This was not a major issue as the main interest was scientific knowledge rather than personal views and opinions outside of this knowledge though there is always the risk of projecting a reason for concern or the scale of the risk.

(2) Sampling – using a convenience sample means the data may be quite unique so a bigger sample or one with more diversity would be better unless a particular group is required: A group of experts within the relevant field were interviewed with a variety of backgrounds to ensure diversity within their combined knowledge. As well as the interview data, the literature was important in gaining a fuller picture.

(3) Mood and style – this type of analysis is meant to be subjective so the researcher must ensure their own fatigue, emotions or frustrations are not applied to the data as it may influence the coding and ultimately the analysis: Again, as the focus was on knowledge this was less of an issue though of course there is likely to be an element of the researcher in the analysis regardless.

3.3.2 Coding

Meta codes of the wider aspects of the risk were used with codes emerging from the interview data. Codes capture a description of basic units of meaning with inductive codes capturing the meaning within a segment of text and deductive where a segment contains something the researcher is specifically interested in (Willig, 2013). The meta-codes identified from the literature (e.g. causes, effects) allowed for data to be assigned to these areas accordingly, however there were many codes that emerged from the data such as 'ecosystems alter' that were assigned further sub-codes e.g. 'migration of species' and 'commercial species affected'. The coding framework (Table 3) provides an overview of these meta-codes and the breakdown into codes and sub-codes alongside examples from the interview data (which are also reflected in the literature). In short, the transcripts were coded to allow for analysis of the themes and concepts that arose from the interviews. As each interview followed roughly the same structure, sections of the transcripts overlapped with each other in particular areas and showed distinct uncertainties and differing viewpoints. These were pulled together and assigned to emergent themes. The analysis was an iterative process however, with codes refined and revisited as the analysis proceeded.

Coding Framework for Expert Interviews

Causes of OA	Example
Increase of atmospheric CO_2	…mainly fossil fuel CO_2 that's rising in the atmosphere, so that's increased… (Interviewee 1)
Burning of fossil fuels	It seems to me that the cheap option is obviously not to burn it in the first place, rather than to try and then deal with the consequences of the CO_2, which would be very expensive. (Interviewee 7)
Anthropogenic CO_2	the oceans have taken up somewhere between 25 and 30% of anthropogenic emissions (Interviewee 1)
Effects of OA	
pH decline	This is the sort of thing I can model, in that very rapid releases of CO_2 means that the pH goes down and the carbonate ion concentration goes down… (Interviewee 3)
Proton concentration decline	…when you plot it as proton gradient then you really see what's going on… (Interviewee 4)
Change in carbonate ions	If you have too little calcium ions and/or carbonate ions, the calcium carbonate tends to dissolve. If you have plenty of calcium and/or carbonate you'll tend to be able to precipitate. (Interviewee 3)
Increase of dissolved CO_2	So it's not just that the pH changes but also that the carbonate ion concentration changes and the amount of dissolved CO_2 gas goes up… (Interviewee 1)
Impacts	
Socio/economic impacts:	
Commercial species affected (mussels, oysters, fish)	…there's indications that actually some of these commercial species might be affected. (Interviewee 5)
Environmental:	
Ecosystems alter – phenology, community structure	So even if global warming wasn't happening, the acidification could be severe in some parts of the ecosystem. (Interviewee 7)
Migration of species	Now organisms may be able to migrate, so plankton may be affected differently from sessile[3] organisms, who basically are stuck where they are. (Interviewee 7)
Calcification altered (dissolution)	So it might be that you see a reduction in metabolic rate [or 0:13:13.9] a reduction in calcification rates. (Interviewee 5)
Shallow organisms better off (used to variability)	…shallow marine organisms on the whole, in for example shallow seas and shelf seas, on the whole may be less impacted. (Interviewee 7)

[3] These organisms are permanently attached to a place and cannot move about freely.

Deep ocean organisms (may be severe)	…we need to be careful of the deep ocean plankton because they live in such a stable general environment and not much is known about what their response would be. (Interviewee 7)
Ability to regulate energy tested	So if you actually have to spend a huge amount of your energy budget running around chasing things and catching them to eat then for you to then, say, get more energy requires you to put more investment in. So it's harder. (Interviewee 5)
Primary production (phytoplankton blooms)	…as you go more acidic some species may be able to bloom better than others at the commencement of the bloom. But during the bloom then the pH gradually increases. (Interviewee 4)
Regional differences (variability):	
Spatial/temporal variability	…it's not so much the mean amount of impact on a system but the spatial temporal variability in that impact. (Interviewee 2)
UK seas large variability	…on a temperate ocean shelf such as the UK we see fairly substantial - it's a temperate ocean shelf, it's already substantially affected by human activity… (Interviewee 6)
Arctic/North sea	…it's going to be the polar oceans that become under saturated in the surface waters before anywhere else. (Interviewee 1)
Annual/inter-annual cycle may be altered	…there's probably a pretty substantial inter-annual variability too… (Interviewee 6)
Saturation state lowered/altered (Southern seas – corals affected – structure weak)	…seawater is becoming not just lower saturation state but it's going to cross the theoretical boundary between super saturated and under saturated, so that calcium carbonate should, in theory, start dissolving. (Interviewee 1)
Coastal areas	…it's not just biotic, it's abiotic coastal structures which are impacted as well. (Interviewee 4)
Larval stages vulnerable	…the larval stages of some echinoderms[4] and other coastal and bottom dwelling organisms, that these may be affected badly or negatively by pH decrease. (Interviewee 6)
Biological pump affected (buffering capacity reduces as acidity increases)	Because of the change in the buffering capacity of the water, as you make it more acidic the buffering capacity becomes less… (Interviewee 4)

[4] An invertebrate marine animal such as the starfish.

Responses	
Geoengineering – CDR	…there's lots of scope for looking at geo-engineering and whether one might directly manipulate carbonate chemistry in reverse by adding lime to the ocean surface. (Interviewee 3)
Ocean fertilisation (calcium carbonate/lime dumped in ocean)	There is a proposal that you can [lime 0:41:34.5] the oceans and you can grind up calcium carbonate rocks and you can put them into parts of the ocean where they will tend to dissolve, and that that will change the carbonate chemistry. (Interviewee 1)
Reduce CO_2 emissions	Basically there's got to be less CO_2 being emitted. Or I suppose the other thing is that you've got to somehow take that CO_2 out of the natural system. (Interviewee 2)
CCS (BUT leak would be detrimental)	So leaks of a tonne or of 10 tonnes, or even that kind of rate, a tonne a day or 10 tonnes a day, you're looking at very local. (Interviewee 2)
Ocean circulation (natural time course)	So this is then where the circulation of the ocean starts playing a role and the timescale of that transporting to the ocean interior is 100 years to 1000 years. (Interviewee 3)
Observe changes (carbonate buffer)	…observing the carbonate system is one part of the observations that we really do need to be making if we want to understand how the natural world is changing under our influence. (Interviewee 6)
Acclimation/Adaptation (interspecies included, genetic mutation)	Of course the problem is if you do go through a period of rapid evolution such as - or rapid adaptation in [unclear 0:25:33.7], what you might do is lose an awful lot of genetic diversity. (Interviewee 5)
Shift in dominant species	…the marine ecosystem is a complex place with thousands of species in it. Some of them actually like it a bit more acid and some of them don't. So there's winners and losers. (Interviewee 6)
Interactions	
Ice melt (faster, negative impact)	For example the speed at which ice melts has a big impact on the alkalinity (Interviewee 2)
Temperature	…think there's a growing realisation that temperature is such a dominating driver that CO_2 sits on top of that as an additional stress. (Interviewee 5)
AGW/Climate change	I think it's a bit wrong to think about OA separate from climate change because they have to happen together. It's driven by the same thing. (Interviewee 2)
CO_2 emission rate	…a business as usual type scenario - then we're going to be seeing the worst acidification, or at least the lowest pH values in the surface ocean, by about the year 2300. (Interviewee 1)
River systems	…places like the North Sea, for example, you've got all these [riverine 0:14:05.3] systems around it. They have a huge impact on local conditions. (Interviewee 2)

Table 3. Coding Framework from Expert Interview

3.4 Developing the expert influence diagram

An influence diagram is a directed network or graph that shows the events and dependencies in a process. They are typically used in decision analysis (Atman et al., 1994). It allows for a visual representation to be created showing various pathways with how many different influences may impact an outcome. Morgan et al. (2002) state that it is no easy task to create an influence diagram of a particular risk and there are many ways to do this. In this instance, the assembly method described (Morgan et al., 2002, p. 44) is most appropriate for how this was constructed. As there were pre-determined wider themes (e.g. Causes, Impacts and Responses), these and others that had become clearer during coding and analysis allowed for the list of codes associated with these themes to be listed under the relevant themes. The interview data then allowed for the more specific codes to be linked together and sub-themes to be identified. The conceptual model was also checked to ensure that it was coherent at the wider level. This was an iterative process with revisions made over time. There were few differences emerging from the literature review and interviews. The interviews helped to determine particularly uncertain areas of the mental model. They also helped to expand the details on potential impacts and responses to OA. Following the inclusion of the interview data the final model could be interpreted using the in-depth descriptions given about particular processes and impacts on specific organisms, for example. These examples may not have been included in the literature because of the uncertainty around impacts of OA. Rather than a need to reconcile the final model based on the literature review and interviews the initial model was enriched and areas of certainty and uncertainty made clearer through incorporating both sources. As well as undertaking the literature review on OA and analysing the expert interview data, a subset of experts also validated the influence diagram which resulted in further changes and reorganisation of the influence diagram. Two experts, one with expertise in Paleoclimatology and the other in Earth System Modelling talked through each component of the influence diagram which resulted in changes being made until there was agreement on the final diagram. The process was similar to the approach taken in Cox et al. (2003) on chemical risks. The changes made after this process included a further cause of OA being incorporated describing climate change causing changes in upwelling, and also establishing that leaks from CCS would likely have a local effect on pH. They also highlighted areas of uncertainty in the model confirming the certainty and uncertainty of impacts established from the data. Finally, ‘upwelling’ was added as a possible interaction with the node ‘ocean circulation’ moved from an environmental

response to OA as an interaction. The advantage of combining concepts from the literature and interviews meant that a more comprehensive representation could be formed, which included certainties and uncertainties that may not always be present in the published literature.

Despite the highly detailed influence diagram that was constructed there are limitations to what will be presented. As already stated, the scientific literature is fast-moving, exponentially growing, and OA is a highly complex risk issue. The content of the model only takes account of the literature up until summer 2014 and interview data from seven experts working in the area completed in summer 2013. The model that will be presented provides a clear overview of literature reviewed alongside the expert interviews. Some aspects of consensus (e.g. chemistry) are established and not subject to change, while others are constantly evolving (e.g. impacts on organisms). These will be discussed further in the final part of this chapter. As well as possible change within the research area, the sample used was relatively small and although it encompassed many types of disciplines there are other relevant views which could have added to the influence diagram. Including scientists with a more active role who were involved in fieldwork may have provided unique perspectives from their regular interactions with a range of environments, organisms and societies. Though the focus of the thesis is UK-orientated researchers working in affected areas of the world (e.g. New Zealand, US West Coast) would have provided a more comprehensive global picture. Lastly, including marine practitioners and those in marine governance would have provided more detail around policy and other response options. The main focus of this model is on anthropogenic OA but there are natural causes as well which would have given further detail on the risk as a whole.

An influence diagram (see Morgan et al., 2002) was created by summarising this data from which five themes were identified; these are shown by each large box with sub-categories in these themes being separated into smaller boxes. Within the smaller boxes individual nodes are shown where an arrow between two nodes means the node at the tail has an influence on the node at the head of the arrow. Key factors are highlighted in each component of the model, boxes and nodes with a dotted border show where the uncertainties lie.

3.5 RESULTS

3.5.1 Expert knowledge of OA

The expert model consists of five main areas (a summary can be seen in Figure 3 below). The top-level concepts in this model are causes, processes, impacts, responses and interactions of OA. The full model is highly complex and has numerous areas of uncertainty. The cause and process of OA is the main area of consensus among the scientific community; an increase of anthropogenic CO_2 in the atmosphere results in an increase of CO_2 absorption by the ocean, with the chemical interaction leading to a decrease in pH. The next section of the model (showing possible impacts of OA) is one of the most uncertain areas. Though past impacts can be used to help work out what will happen today there are a whole host of interactions which makes this extremely difficult. For example, a type of calcifying organism (coccolithophores known as *Emiliania huxleyi*) was initially thought to be vulnerable to OA and was a focus of concern because it is crucial in the plankton ecosystem. However it was more recently found to be less affected than expected (Jones et al., 2013), as calcification is mostly intracellular and occurs under pH controlled conditions. Marine ecosystems are extraordinarily complex with an abundance of organisms which vary in only small ways, but which nevertheless, respond differently to OA. Temperature increases and climate change make it even harder to assess how marine organisms will respond to OA. The final part of this model illustrates the responses set out by the experts interviewed. Though there is agreement that reducing CO_2 emissions is the best response, other responses, such as geoengineering techniques, are still under discussion. The model that has been constructed is based on

expert knowledge at the time of the interviews, so is not a complete representation of how experts conceptualise OA.

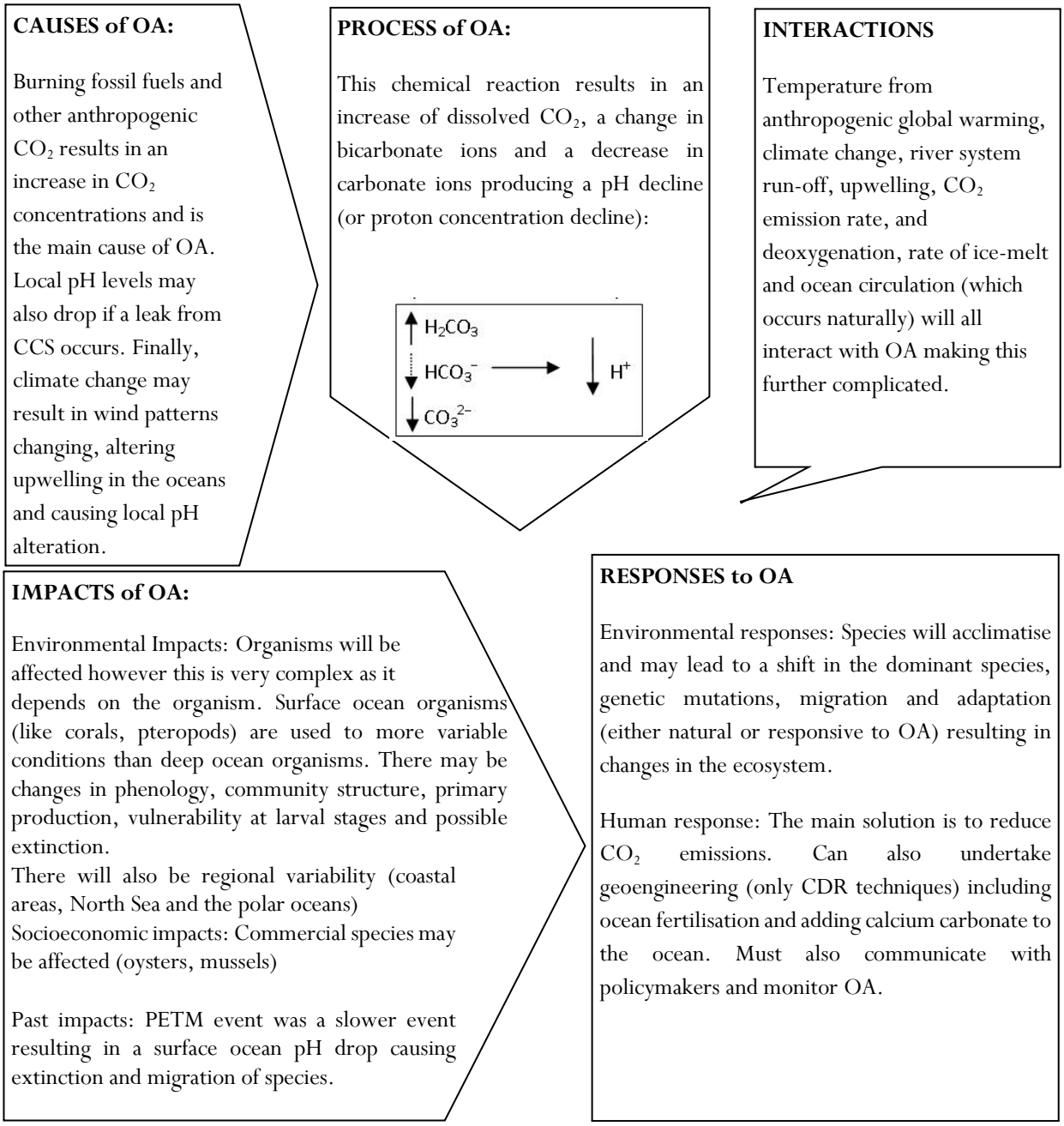


Figure 3. Overview of expert model summarising Ocean Acidification

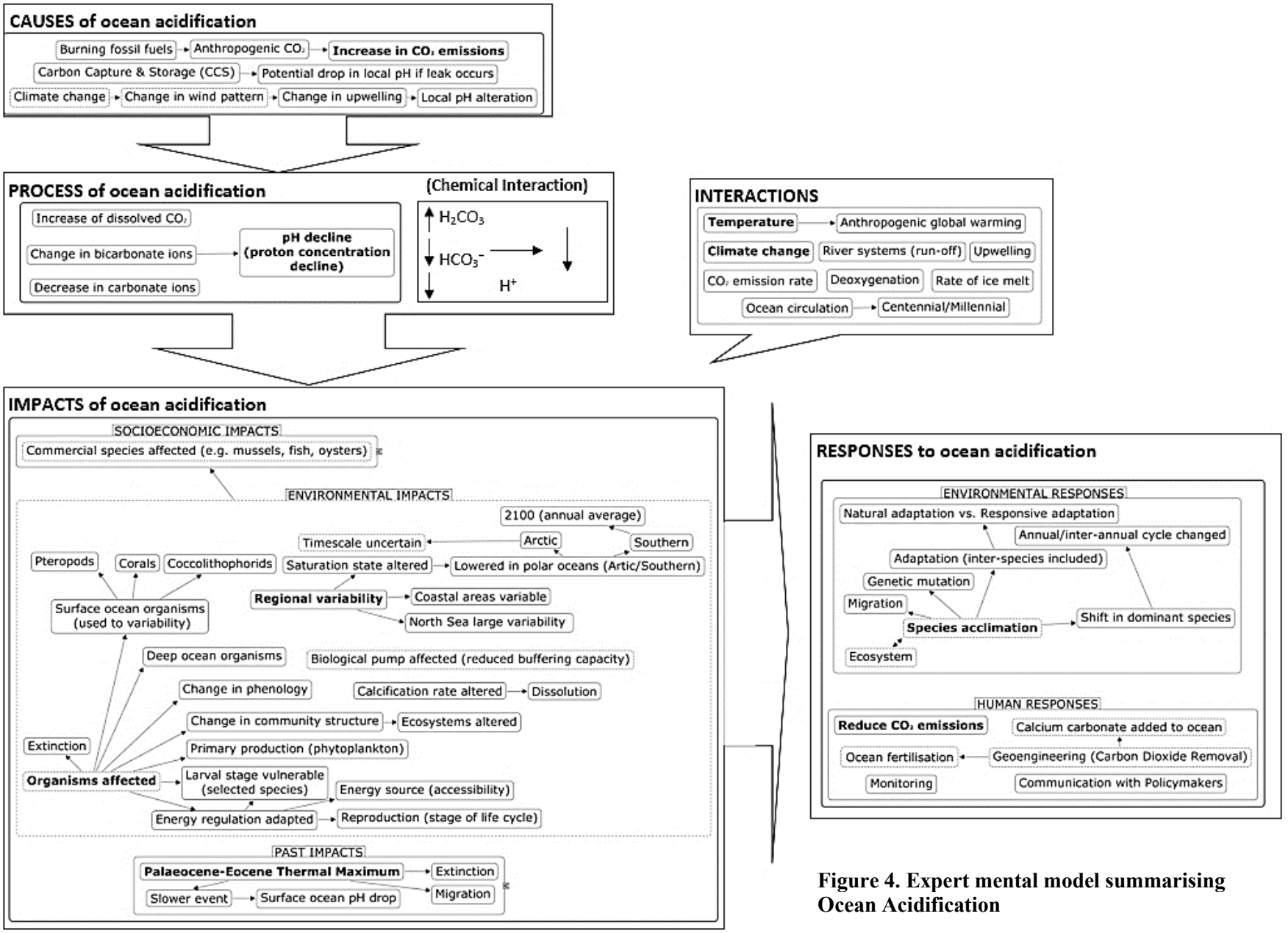


Figure 4. Expert mental model summarising Ocean Acidification

3.5.2 Understanding the Expert Model on Ocean Acidification

The model shown in Figure 4 is the full influence diagram of expert opinions on how they perceive OA and its challenges, certainties and uncertainties. The main focus of this model is on anthropogenic OA (except for 'past impacts'). Key factors are highlighted in bold in each component of the model; boxes with a dotted line show where the main uncertainties lie.

CAUSES

The first part contains an overview of what causes OA. Though there are natural sources of carbon dioxide which the ocean absorbs, the oceans have absorbed anthropogenic carbon dioxide created by the burning of fossil fuels which has resulted in an **increase in the uptake of carbon dioxide from these emissions** (Royal Society, 2005). Another potential cause of OA in the future could be from a leakage from offshore carbon capture and storage systems resulting in a locally negative pH. Finally, a change in upwelling events (where cold nutrient rich water is brought up from the depths of the ocean to the surface) also leads to local pH alteration; this is believed to be due to changing wind patterns which are being altered by climate change (Bakun, 1990).

PROCESS

The second part of this model explains how OA occurs from the absorption of atmospheric carbon dioxide and is an area of strong consensus. As the carbon dioxide enters the water it becomes a weak acid and results in an increase of dissolved carbon dioxide as well as a change in bicarbonate ions (HCO_3-) and a decrease in carbonate ions (CO_3^{2-}). These three components make up the dissolved inorganic carbon and a change in one component results in a change in the other two to maintain equilibrium (see Figure 5).

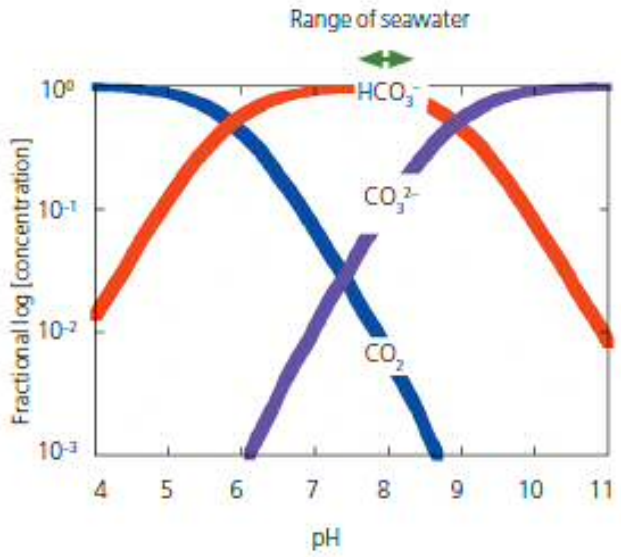


Figure 5. Relative proportions of the three inorganic forms of CO2 dissolved in seawater (taken from Royal Society, 2005, p. 43)

Over time there will be a decrease in carbonate ions as carbon dioxide continues to increase and bicarbonate ions decrease. This interaction results in a **decline in pH** (some prefer to refer to this as proton concentration as pH is the log scale) and thus an increase in hydrogen ions.

INTERACTIONS

The next part of the model illustrates the range of interactions that will influence the rate of OA, the main concern being the impact that multiple stressors will have alongside OA. **Temperature** is frequently mentioned as an important interaction; if atmospheric temperature continues to increase this will result in further global warming including warming of the oceans. Deoxygenation is also important to consider as there will be decreases in dissolved oxygen made worse by both OA and warming (Breitburg et al., 2015). Additionally, river system run-off also contributes to deoxygenation as nutrients (e.g. from fertilisers) are transported to the ocean (Gattuso & Hansson, 2011). OA is also dependent on CO_2 emission rates, if these remain high or continue to increase this will ensure OA continues at a rapid rate. The rate of polar ice melt will affect acidification especially in the Arctic Ocean where this influences the timescale. Sea ice melt results in faster acidification as the water is diluted causing a reduction in pH levels, more ocean is exposed by the ice melt as there is no longer ice cover. More generally **climate change** will impact on acidification as well as factors already mentioned, though clearly these will also interact with climate change. Upwelling waters also affect acidification as CO_2 rich water is brought up from the deep ocean, causing a local drop in pH, a phenomenon

which may become more common if climate change does affect wind patterns.

The final part of this section refers to ocean circulation. Though this may not strictly be a response to OA as it is something that occurs naturally it is still important to take into consideration. As there are so many variables which affect the uptake of atmospheric CO_2, how the ocean responds is important as the ability to absorb CO_2 will be reduced over time (due to increased temperature for instance) resulting in a range of impacts such as an increase in global warming. As mentioned in the impacts section, the current rate would result in the surface ocean experiencing a drop in pH as the ocean has not had enough time to effectively mix the surface water which had absorbed greater quantities of CO_2. Over time the oceans would gradually mix the CO_2 down into the deep ocean where acidification would get worse, while it would correspondingly ease in the surface ocean. This would occur over centuries for a fully mixed ocean to be achieved. Once in the deep ocean it would take millennia to get rid of the CO_2, and carbonate sediments would play a part as these would then be dissolved into the ocean causing a reduction in acidification (Ridgwell & Schmidt, 2010). However, projections of the latter are hard to be certain about as it is a complex set of processes.

IMPACTS

The fourth component of this diagram refers to the various impacts that may occur from OA. This is a significant area where the science is still shifting and is the least certain as there are numerous factors to consider. There are three sub-categories within this theme: environmental, socioeconomic and past impacts. Firstly, the model explores the environmental impacts of OA some of which were seen in Aze et al. (2014). There will **be regional variability** of OA with particular areas seen as more likely to be affected. Coastal areas will see a difference in the degree to which they are affected as there are a range of potential interactions such as surrounding river systems, saturation state and temperature etc. Some areas may not necessarily see a reduction in pH but acidification is still happening. For example, nutrient input from runoff may cause an increase in pH outweighing the effect of acidification (Gattuso & Hansson, 2011). Large variability is also assumed in the North Sea partly as a result of eutrophication. There is also a debate about the biological pump and the extent to which its buffering capacity will be affected. The biological pump refers to the transportation process of carbon dioxide from the atmosphere into the deep ocean by sinking organic matter, and without this process atmospheric CO_2 would be much higher (Honjo et al., 2014). A main area of general agreement is that the calcification rate will be altered causing dissolution in some

organisms because of changes in the saturation state (Tyrrell, 2011). The saturation state will also change with this being lowered in the polar oceans. The Southern Ocean is robustly thought to see undersaturation as an annual average by the end of the century (2100); mean surface conditions in the Southern Ocean are likely to show aragonite undersaturation. The Arctic will also become undersaturated however the timescale is less certain, primarily due to the interaction of the melting sea ice, which may have a major influence on this.

Organisms are also likely to be affected though expectations for what exactly may happen are very complex and uncertain. In general, a change in community structure and also phenology may be expected to cope with the impact of OA which would potentially impact on the ecosystem overall (Aze et al., 2014). One aspect which is important for organism's response is how they regulate their energy. How accessible their energy source is will rely on different levels of effort to obtain food. If more energy is required to access food there will be less energy available for other things such as reproduction however certain organisms in their larval stages are also quite vulnerable. Potentially some organisms may face extinction or migration may occur but very little is known as to what organisms this would apply to. The organisms that will be affected will be both in the surface ocean and also the deep ocean. Though initially the surface ocean organisms (the ones picked out are those most commonly mentioned – corals, coccolithophorids and pteropods) will be more likely to suffer the most, as acidification begins to affect the deep ocean, organisms native to the deep ocean are likely to be more affected overall. The surface ocean organisms (especially those that live in shallow seas and near the continental margins) are used to natural variations in pH and saturation state, for example through upwelling and downwelling unlike some deep ocean organisms and open ocean plankton. Though there are vulnerable species, there are others that may thrive such as seagrasses and others that live by CO_2 vents in the deep ocean (IGB, IOC, SCOR, 2013). Primary production which is crucial to the overall foodweb (in particular phytoplankton) will also be affected and though blooms of phytoplankton may be seen in some areas there may be migration of some marine organisms. Overall changes in the marine ecosystem would be expected, though there is substantial uncertainty on potential socioeconomic impacts, beyond the environmental impacts. Commercials species (generally calcifiers such as mussels and oysters) may be negatively affected by OA as they already have been in parts of the world (Feely et al., 2008). If there was a loss of marine goods and services it would impact on livelihoods and society on a much wider

scale (Turley et al., 2009).

A final area in the impacts of OA looks at **the Paleocene-Eocene Thermal Maximum** (PETM) event. This past event saw clear migration and extinction of species so allows scientists to consider possible impacts that may occur from OA (Zeebe, 2012). Though the PETM was a rapid and major event, the rate of OA is faster today and a larger drop in surface ocean pH is expected. Trying to predict future impacts by including time projections and past occurrences is very difficult because of the wide range of factors and interactions which influence what may happen.

RESPONSES

Two types of responses became apparent when considering how OA could be approached and minimised: human responses and environmental responses. Human responses are arguably the most important as actions taken will impact the scale of this risk. The most logical and effective human response would be to **reduce carbon emissions** (Turley et al., 2010). As well as reducing the impact of OA, this will also help to mitigate climate change and reduce the numerous other associated impacts. Other responses include continuing to monitor the carbonate buffer (main buffer for pH change in natural waters) which will allow the severity of OA and its impacts to be tracked in the oceans. Communication with policymakers is also important as acidification responses require effective policies to be created and followed through; illustrating the risks of OA and what is required to help mitigate these risks is crucial (Billé et al., 2013). Another consideration has been geoengineering (specifically, CDR techniques) though this is a controversial and uncertain solution. Only CDR can be considered suitable for mitigating OA as the cause is the atmospheric CO_2. Two main techniques that could be employed are ocean fertilisation and adding calcium carbonate to the ocean (or enhanced ocean alkalinity) though there is debate about how effective these would be (Williamson & Turley, 2012). Adding alkaline materials such as calcium carbonate would potentially increase the ocean's capability of storing CO_2 and buffer the ocean to acidification through the alteration of pH levels.

The potential cost and scale required for an effective response is a large part of the debate regarding these techniques. Some feel the economic cost of collecting calcium carbonate and transporting it to where it was needed would be far more than the cost of reducing carbon emissions. Aside from this, it is thought that this technique may only work

effectively for small areas, and that the consequences are also unknown for the environment. The technology required to implement a suitable response is still in its infancy, so currently this option is not viable but is being considered by some scientists as global carbon emissions continue to rise. Ocean fertilisation is another possible option where nutrients - such as iron in certain areas – are added to the ocean in a bid to stimulate primary production increasing the ability of the ocean to absorb CO_2. This is also seen as a costly solution with many potential unknown consequences.

The second type of response (environmental) is driven by the prevailing environmental conditions. This differs from environmental impacts as the focus is on the long-term effect and how OA is ultimately responded to by organisms rather than short term impacts. The main focus is on **species acclimation**. Though this is an uncertain area and it is difficult to predict the changes that might occur in organisms coping with acidification, there are possibilities that there could be similarities in changes during the current event to those that occurred during the PETM (Zeebe, 2012).

Responses from organisms may mean that species migrate to other parts of the ocean or if they cannot do this they may become extinct. There may also be genetic mutations in species as they cannot cope with the changed chemistry of the oceans. Adaptation is also important as it could occur within the same species, though it may be difficult to determine if the changes are driven naturally or as a response specifically to OA. All these changes would potentially result in a shift in dominant species, possibly through an annual cycle or inter-annual cycle. The ecosystem may also alter as a response to acidification but again this may change because of other factors such as species acclimation or this acclimation would result in a changed ecosystem.

3.6 Limitations of the expert model

As mentioned earlier this model of expert risk perceptions of OA was created in 2014 and is only a snapshot of expert views from that time. As the second phase of the process was to conduct mental model interviews with members of the public, the findings at the time were used to inform the design of the interview protocol. The visualisation of OA according to the experts is incomplete, as research has continued since then to explore additional areas of uncertainty, particularly those with a range of possible variability. Those interviewed were only given a set amount of time to provide their knowledge at one point in time and may have omitted to mention something important, or altered their views according to new findings since the interview. Additionally, as each interviewee

had a distinct background, with each from different disciplines, there is a risk that only a very select view was obtained and may not reflect the general consensus within their field. However, as instructed in Morgan et al. (2002) the creation of the expert model must contain all these views to provide a comprehensive picture, especially as there is a range of possibilities that may occur in the future.

The model is further limited as it does not contain everything related to the risk of OA. Firstly, this model only shows anthropogenic OA and does not account for natural causes so there are other possible factors that may explain a particular incidence of OA in an area or a time period. Zeebe and Ridgwell (2011) outlined a couple of past events like the Aptian Oceanic Anoxic event (OAE1a, 120 Myr) and the PETM (55 Myr) – see section 2.1 – in which natural inputs of CO_2 entered the ocean (for example, through volcanic activity). Secondly, if further detail had been included the model could have lost its coherence. Numerous impacts were mentioned in the model and could have been further explored or elaborated upon. Though the model mentions that organisms will be affected, little detail is given on which organisms will be affected and which changes they may undergo. This is deliberately a generalisation of possibilities that could affect marine organisms.

Though this model provides an insight into the scientific knowledge of OA at the time stated, it is important to remember that the expert model is not one of absolute truth. Despite knowing more than others about a specific risk, experts do not always know everything and they can be fallible in their judgements (e.g. Fischhoff, Slovic & Lichtenstein, 1982). If pushed to make a judgement on something where there is no data on the topic, they must use their best guess or intuition. It is important that they recognise their limitations, which most in fact do and state to be the case. For example, in the expert interviews when asked about areas of consensus and uncertainty all of those interviewed acknowledged the uncertainty around impacts and the complexity of trying to model them:

> *"The reason it's difficult … is that we're still at relatively early days of getting the biological impacts and the models. That's because all the impacts we see are measured in a variety of experiments with different species and different*

circumstances, each with a slightly different result, or even a very different result. *(*Interviewee 2)

Some risks such as OA are complex and a wide range of experts in a broad selection of disciplines are needed to build a more complete picture of the risks. This becomes increasingly important when it is clear that those linked to specific disciplines have particular beliefs or interpretations of impacts in the oceans (Hauser, Tobin, Feifel, Shah & Pietri, 2016) or climatic changes more generally (Nordhaus, 1994).

3.6.1 Certainties and Uncertainties

It is clear that there is a scientific consensus on the main cause of OA; anthropogenic CO_2 emissions, and that the process of OA is a straightforward and demonstrable chemical reaction. These two parts of the expert model are the only certain components. For the impacts of OA there is agreement among all the experts and the literature that there will be some consequences for ecosystems/organisms but it is unclear how severe these will be. Though the interactions outlined are certain to interact with OA, how influential these will be is uncertain. How temperature and climate change for example, combine with the impacts of OA, an already substantially uncertain part of the expert model, is the main focus of current research. Lastly, responses to OA are clear with regards to how humans should respond (by reducing CO_2 emissions) though these responses depend on technology. Environmental responses are uncertain as the initial impacts and the possible interactions make this difficult to predict.

In ordinary circumstances, it is straightforward enough to conduct research to determine whether predicted hypotheses are true or not. For OA, a large proportion of research programmes may focus on only one aspect (e.g. deoxygenation) and only on one very specific organism in a specific location. Indeed, predictions made by researchers may be proven and support their claims about how a certain organism will respond to reduced oxygen levels alongside OA. Unfortunately, there are numerous other factors which would further influence results found and other research may contradict a finding even if only one parameter was marginally altered. Two thirds of papers focusing on OA have investigated biological responses with many only exploring the single driver of OA (Riebesell & Gattuso, 2015). The call for future research to expand has become evident in the past couple of years. Breitburg et al. (2015) suggest that it is crucial that future work combines multiple stressors that will interact with OA and to do this it is necessary to have a theoretical framework to predict what these ought to be (as there are almost

limitless possibilities). Riebesell and Gattuso (2015) also reiterate this point and add that key organisms should be researched including those which show resilience to OA as well as vulnerable ones. The importance of scaling up research is emphasised with an acknowledgement that multidisciplinary approaches are necessary. Caution is required as uncertainty will enter multidisciplinary research in various ways. For example, there may be a lack of clarity about confidence levels in results, leading to false impressions of certainty (Busch et al., 2015). Explanations for findings may be more conceptual or affected by a particular statistical procedure making multidisciplinary research more complicated. As long as findings are acknowledged from all areas, this should help to ensure that a full picture can be achieved without the literature becoming biased and concealing relevant results which show uncertainty.

The second category mentioned in the model under impacts was socioeconomic impacts which are also largely uncertain. At the time that the influence diagram was created there was no substantive literature detailing how society or ecosystems services may be affected by OA. The ocean also provides obvious benefits which if affected could have serious implications for society, such as its role in climate regulation and carbon storage (Turley & Gattuso, 2012). These could have been included in the model but were omitted for clarity. Although it is clear that OA will have economic consequences for commercial fisheries, with much focus on US implications (Cooley & Doney, 2009), there are numerous other ways that OA will affect society. Though it is difficult to value the oceans and put a price on marine ecosystem services, Costanza et al. (1997; cited in Turley & Boot, 2010, p. 251) put a figure of US $21 trillion per annum comprising 63% of the Earth's ecosystem services of US $33 trillion.

The importance of fisheries is not only economic but is also tied to global food security. Fish is the primary protein source for ~3 billion people globally, with less fish being caught at a time when the global population is projected to increase (Turley & Boot, 2011). With fisheries under pressure from various stressors there has been a growth in the aquaculture sector but it is also threatened by the same stressors (including OA). These industries are both affected directly through the organisms and indirectly through food webs and their habitats (Turley and Boot, 2010).

As outlined in the expert model impacts will be regional, with the Mediterranean region one place that is threatened by OA as it is heavily reliant on the tourism sector (Rodrigues, van den Bergh & Ghermandi, 2013). The Mediterranean Sea is also home to indigenous Red Coral (*Corallium rubrum*) which provides highly diverse habitats (Cerrano et al.,

2013) attracts divers and is used to make jewellery. Already suffering from over-exploitation and increasing temperatures, OA is a further stressor on red coral. There is concern that as OA continues over time, habitats such as this will suffer, resulting in possible extinction of resident species.

Small Island Developing States (SIDS) are another area where reefs are crucial for societies that live in these regions. Reefs are crucial structurally as they provide coastal protection for the coastlines. If habitats were impacted by OA, dissolution may result in coastal land areas being destroyed with the inhabitants left homeless (Schmutter, Nash and Dovey, 2016). There are many coral reef organisms that can naturally regulate pH and as SIDS are in areas with high pH due to high ocean temperatures they may cope better. The marine environment is an important tourist attraction for SIDS and if it is affected by OA could negatively impact on the tourism industry and those reliant on the associated revenue. For instance, coral reefs are important ecosystems for goods and services, both directly and indirectly (Brander, Van Beukering & Cesar, 2007); direct use values (such as diving, snorkelling and sightseeing) and indirect use values (coastal protection and fisheries).

These examples of how OA could have socio-economic impacts and what these might be may appear 'regional' but have the potential to be far-reaching. Again, the complexity of OA and reefs, coral calcification rates, organism responses and other interactions makes it very hard to determine what is likely to happen. Though research will develop in future and answer questions we have about OA, an element of uncertainty will remain because there are so many possible outcomes. This undoubtedly will result in further questions with further variables and interactions included to assess how these may change original results. Despite this complex picture there are those trying to establish how the impacts of this risk can be minimised.

The last part of the model outlined possible responses showing a selection of options that we could take, though it is clear that reducing CO_2 is the most effective strategy. The uncertainty surrounding human responses occurs mainly because of the technological aspect and how technology will develop over time.

Before turning to human responses, it is worth acknowledging the environmental responses that are predicted. These are far from certain to happen and are based on

evidence of how numerous organisms responded during past events such as the PETM (for an overview, see Hönisch et al., 2012). The current event is thought by most researchers to be much faster and driven by other factors, primarily anthropogenic CO_2 emissions, but also affected by other things. It is important that appropriate responses are adopted to reduce emissions and ensure that the marine ecosystems, food webs and organisms are not severely impacted by a lack of action or inappropriate action.

Though the solution is obvious and certain to be most effective, the way this is approached is very uncertain and will be very difficult to implement. The successful signing of the Paris Agreement (UNFCCC, 2015) is a starting point as it requires governments globally to take action and meet the targets set out. The scope of policies required must be recognised in order to achieve the target of well below 2˚C of global warming. The reduction of carbon emissions will take time and OA is already having an impact in parts of the world. For instance, the Great Barrier Reef, is already shown to be under stress from OA (Albright et al., 2016), and if it is to survive needs to be protected through policies being enhanced or introduced to take action on climate change and other stressors such as OA to limit their impacts. The Australian and Queensland governments released the Reef 2050 Long-term Sustainability Plan (Commonwealth of Australia, 2015) which highlighted the multiple uses of the area but had no meaningful actions to the significant threats to the region; climate change and OA (Hughes et al., 2015; Australian Academy of Science, 2014).

The West Coast of the US is also severely affected by OA and numerous states have moved to take action. In the past five years, reports presenting the evidence that OA was a problem have convinced relevant organisations, governments and businesses to contribute towards local and regional management mitigation and adaptation strategies (Strong, Kroeker, Teneva, Mease & Kelly, 2014). Examples of local factors that if addressed would curb impacts include dealing with local discharge of carbon and nutrients, supporting organisms under stress so they can cope better (i.e. selective breeding) as well as continuing research to ensure the best decisions are taken in the future (Chan et al., 2016). Though action has been brought in some places like Washington State (Carr, 2016) the ultimate solution will require a global response. There are already ways in which state government agencies can mitigate OA or (address certain aspects of climate change) as air and water pollution reduction is already a priority such as through The Clean Water Act of 1972, and OA should only enhance the case for action. However, it

may well be that the global ecosystem and other benefits of taking action immediately will not be enough to incentivise various governments to take radical action until the issue becomes serious enough to impact significantly on the economy (Kelly and Caldwell, 2013).

Though policymakers are aware of OA, it takes time for proposals made by various scientific bodies to be put into practice in the relevant parts of the world. As for the UK, in 2009 there was no UK legislation that directly addressed OA (POST, 2009) though it has been acknowledged, alongside climate change, as something that must be considered and researched (as seen by the UKOA programme). Though the policy outlook is now more uncertain than it has been for some time in both Europe and North America there is already a clear list of recommendations from research which can be adopted in time.

The final part of the model, which is highly uncertain, concerns geoengineering. Research on geoengineering has been justified because of the possibility of a 'climate emergency'; however, defining what an emergency is will not be straightforward, as there will be interactions between the natural environment, political interests and social norms (Sillman et al., 2015). In the expert model only CDR techniques have been mentioned, however SRM is also under consideration. Because SRM does not affect carbon dioxide concentrations in the atmosphere or ocean, OA would persist but temperature increases would not be an issue if SRM succeeded. Accordingly, there could be second-order interactions between SRM, the global carbon budget and ocean chemistry, changing the rate of OA and further also influenced by terrestrial carbon sinks (Matthews, Cao & Caldeira, 2009). CDR techniques are presented as a more plausible way to reducing CO_2, and thus help to ameliorate both climate change and OA. The effectiveness of CDR with regards to OA are technique specific with some theoretically removing carbon and others relocating it to the mid- or deep ocean (Williamson & Turley, 2012). The particular techniques mentioned in the expert model (ocean fertilisation and enhanced ocean alkalinity) are uncertain in terms of cost and viability, similar to most geoengineering techniques proposed. However, there are further uncertainties, some of which are explored below.

Cao and Caldeira (2010) ran simulations to show an upper bound of the extreme case for ocean iron fertilisation in ideal conditions. They found that it could only slightly mitigate OA and there would be accelerated acidification in the deep ocean, organisms at this level

would suffer as they are sensitive to changes in pH. Lastly when exploring carbon-offset schemes whereby fossil fuels emissions continue, OA would persist in the surface ocean and result in further acidification of the deep ocean. Based on these simulations, iron fertilisation does not appear to be a useful technique as it simply moves the problem elsewhere and does not solve it. However, the deep ocean is a larger buffer than the surface ocean, and is less important socioeconomically, so it could be better to transfer the carbon to the deep ocean.

Enhanced weathering by open ocean dissolution of the mineral olivine has been shown to reduce atmospheric CO_2 in another modelling study (Köhler, Abrams, Völker, Hauck & Wolf-Gladrow, 2013). However, based on recent emissions it would be necessary to adopt numerous approaches as this would not be enough by itself. Köhler et al. (2013) also highlight possible issues such as marine organisms being affected by the dissolution of olivine (e.g. input of trace metals iron and nickel). The mineral must also be ground to a particular size to be effective and it must be spread by a fleet of ships, reducing the efficiency of this method.

CDR interventions have been explored on a large scale to assess their effectiveness and whether they can be done appropriately. Mathesius, Hoffman, Caldeira & Schellnhuber (2015) concluded that CO_2 emissions (RCP 8.5) followed by CDR would recover the surface ocean but the deep ocean would take centuries to recover to pre-industrial or low emissions scenario (RCP 2.6) conditions. Though it is important that geoengineering is explored, the evidence so far suggests that many amongst the public (including scientists) would rather see CO_2 emissions reduced immediately as it would be the most effective approach (Pidgeon, Parkhill, Corner & Vaughan, 2013). The uncertainties surrounding geoengineering are complicated with many possible interactions and further issues caused whereas reducing CO_2 emissions is straightforward and would not cause further damage.

Though there appear to be a large number of uncertainties within the model there are also areas that can be clarified or researched further, the model presented here is only one conceptualisation of how experts perceive OA. One obvious component that does not feature is the public and how they fit in. Though there is some mention of how there may be socioeconomic impacts which would affect certain communities, there is no other mention of their role. Since this model was constructed this has changed and the need for the public to become involved has been recognised, with researchers outlining various

education and outreach programmes (e.g. BIOACID, 2012; Kelley et al., 2015). Additionally, if particular mitigation and adaptation strategies are adopted by policymakers the success of these will require society to accept them. We are already aware of how geoengineering is perceived by the public (Corner & Pidgeon, 2014) for instance, and it is now crucial that people's perception of OA is explored in detail to determine how they understand this risk and what they know about it.

3.6.2 Reflexivity

DATA ANALYSIS AND DEVELOPING THE EXPERT MODEL

It is essential that my position and background in the research is acknowledged as it will have influenced this piece of work. My background as a psychologist, interest in environmental topics and previous work during my undergraduate and postgraduate degrees (in which both research projects were interested in public perceptions of climate change), will have contributed to my data collection, analysis and conclusions. The topic of ocean acidification was novel to me prior to embarking on this PhD and seemed very complex, encompassing different disciplines including chemistry, biology and palaeontology all of which I was unfamiliar with.

Data analysis was challenging due to the novelty of the topic and was certainly built from the ground up. Of course, this may have influenced how I interpreted the interviews and literature as I was establishing my own idea of what OA was and what it meant from my perspective. The themes that resulted do explore OA from a very scientific viewpoint as my unfamiliarity with the topic meant I constructed my own mental model based on the interview data and the scientific literature. The expert mental model of OA will not have been heavily influenced by knowledge of the topic (outside my reading of the literature and interviews) but will have been by my position as a social scientist.

When considering the difficult task of researchers trying to explore the impacts and interactions etc. of OA (natural scientists), from my perspective as a psychologist (or a social scientist), the attempt to build up a comprehensive picture of the risk of OA was challenging. Though both perspectives can focus on very particular questions, both can be influenced by numerous variables and made more complex. A natural scientists main aim may be to determine what the risk is and how serious it could be whereas a social scientist may be more interested in establishing the best way to communicate the risk effectively to society and to policymakers. Similar issues arise as with climate change, as OA is a complex risk issue with a range of impacts which may affect different groups of

people in different ways. As a social scientist, it is crucial to establish a clear understanding of the risk you are trying to communicate and this can be quite difficult at times.

Chapter 4: Public Interview Methodology and Analysis

Chapter Overview

This chapter explains the methodology and data analysis used for phase two of this project, in which 20 mental model interviews were conducted with members of the public who lived in and around Cardiff. The first part of the chapter will discuss the mental models process including the interview design, ethical considerations and recruitment strategies. It will then explore the data analysis undertaken which utilised content and thematic analysis resulting in a public model of ocean acidification. The second part of this chapter will provide a detailed explanation of the public model and the outcomes of the interview analysis. This second empirical phase aims to determine what public perceptions of ocean acidification are, how they relate to expert perceptions and finally to inform the design of the survey conducted in phase three of this project.

4.1 RATIONALE

OA is a novel risk issue and one which is not familiar to members of the general public. Using a mental models approach was most appropriate for the purpose of this research, as semi-structured interviews allowed people the opportunity to create their representation of this risk. Mental models interviews enable anchoring to take place and social representations to form allowing prior associations to interact with the topic being asked about in the interview. If people had simply been given a questionnaire this would have been based on an expert model which in this case was technical and very specific. For example, it would have been difficult to establish how certain terminology may have been interpreted and responded to including the term 'ocean acidification' itself. In order to design effective risk communications on OA, an in-depth understanding of public beliefs on this risk issue is crucial. The use of focus groups was not a viable option for a number of reasons, in particular the possibility that some attendees may not have established their views about the topic at all or in the same way they may have done if asked individually (Flick, 2014). They are more appropriate for exploring questions on acceptability or values associated with a risk rather than examining knowledge. As knowledge about OA amongst the general public has been shown to be low in other work (Chilvers et al., 2014), there may have been less willingness to propose ideas which individuals thought silly or unimportant. One problem with focus groups is the difficulty in accurately establishing an individual's beliefs and opinions separately because of others' influence and as a result was deemed not suitable for this kind of research.

4.2 MENTAL MODELS INTERVIEW

The open-ended interview allows for a broad opening question to be asked, establishing the 'core dump' (Morgan et al., 2002) of a topic before moving onto more specific questions as the interview progresses. The use of semi-structured interviews allows a one-on-one interaction giving a respondent the freedom to express themselves openly. In these mental model interviews the purpose was to establish a detailed mental model of OA for each respondent in a way that they conceptualised and understood this risk. The direction of the interview was led by the respondent with questions in the interview protocol

brought in as necessary to keep the discussion moving forward and to ensure all areas were covered.

ETHICS

The ethical guidelines set out by The British Psychological Society's Code of Human Research Ethics (BPS, 2010) were followed, and ethical approval was obtained from the School of Psychology Ethics Committee at Cardiff University to conduct interviews with members of the public. The main ethical issues for this research were anonymity and informed consent. The data collection process was strictly confidential, but was not anonymous. Data was confidential during the research process and transcription, with actual names only available to me. Participants were asked if they consented to be included in a database which allowed their data to be retained (both audio recording and transcript) until analysis had been completed and used in publications. Whether participants gave consent for this database did not affect their participation in any other way, however, all those who took part were happy to provide consent for this. This allowed participants to be contacted to review, validate and clarify the transcripts content.

Permission to record the interview using audio equipment was also obtained with participants informed about the confidentiality procedures for storage and use of data, which was managed in line with the ethical procedures of the British Psychological Society (BPS, 2010) and the Data Protection Act 1998. After the audio recordings were transcribed they were made anonymous, with pseudonyms applied to all participants. These anonymised data will be retained indefinitely for the purpose of analysis, publications and potentially for further analysis by other researchers. In all related publications, participants' quotes are made anonymous. In that context, only non-identifying generic terms (e.g. gender, age) and the pseudonyms were used to describe participants.

To ensure informed consent was obtained from participants, emails were sent to a selection of people that had signed up to the School of Psychology Participant Panel containing a request to complete an interview along with clear details of the study and what would happen in the interview. Participants were told the interview was about the health of the ocean; OA was explicitly not mentioned during recruitment to prevent participants researching the topic before the interview though there may still be some biasing effect in recruitment. The research aims were outlined verbally directly prior to

the interview beginning ensuring that any consent given can be considered informed. A consent form was given to all participants which outlined the research aims, the interview process, information on confidentiality and anonymity as well as data collection and how the data would be used (see Appendix B). Participants were also informed of the right to withdraw from the study at any point during the procedure. Opportunities were made available for participants to ask any questions they had in case they felt they required any further information.

Participants were provided with a debrief form (see Appendix B) at the end of the interviews. Participants were thanked for taking part in the study and informed that they have the right to access the information they give up until the point it has been anonymised. They were also made aware that they have the right to ask for the information they give to be destroyed/deleted up until the point that the data is anonymised.

4.3 DATA COLLECTION

4.3.1 Recruitment and sampling

A sample of 15 – 20 interviews should be satisfactory to achieve 'saturation' of topics (Morgan et al., 2002; Henwood & Pidgeon, 1992), where no new themes arise as the number of interviews increases. Though I judged that in the event saturation had been achieved after 15 interviews with few new themes being mentioned for the first time, I wanted to ensure that the sample was diverse enough so continued collecting data to achieve this. 20 semi-structured interviews were conducted with members of the public who lived in and around Cardiff with a demographically diverse sample selected to reflect differences in gender, age, education and occupation. Lists of participants were provided from the administrator of the School of Psychology Participant Panel and members were e-mailed until interviews had been completed with a diverse sample. Age ranged from 18 – 69 with an equal gender split. Respondents included some who were retired, students, unemployed and others. The sample had a good age range with half of the respondents aged less than 35, 30% aged 35 – 64 and the remaining 20 % over 65 years of age. There was a diverse range of level of education among respondents with over half having no

qualifications, school qualifications or college education. The remaining 40% had a degree or a postgraduate qualification.

See Table 4 for full demographics. Participants were recruited using the School of Psychology Participant Panel and awarded payment of £10 for completing the interview. Interviews were between 35 – 75 minutes in length with the majority lasting an hour. Interviews were conducted between June 2014 and December 2014. The interview protocol was designed after development of the influence diagram constructed to illustrate the expert mental model of OA.

Pseudo	Date of Interview	Age	Gender	Education	Occupation
Stan	23/6/14	34	M	GCSE	Unemployed Refuse Collector
Fiona	26/06/14	39	F	BA, PGCE, MSc	Teacher
Edward	07/07/14	49	M	No formal education	Sound Engineer
Karen	14/7/14	61	F	BA, PG Diploma	Retired Librarian
Emma	22/7/14	19	F	A Levels	Student
Annie	23/7/14	23	F	BSc	Registered Dietician
Abi	27/7/14	23	F	BA	Student
Charlotte	30/7/14	49	F	PGCE	Training Co-ordinator
George	4/8/14	58	M	HNC	Self-Employed Charity Worker
Philip	4/8/14	55	M	BSc, MSc	Development Worker
Helen	8/8/14	23	F	BA	Learning Support Assistant
Joe	8/8/14	24	M	Cert He	Unemployed
Sophie	11/8/14	28	F	BSc	Clinical Studies Officer
Adam	12/08/14	19	M	A Levels	Catering Worker
Tricia	2/10/14	66	F	Vocational	Retired Homeopath
Darrel	9/10/14	66	M	A Levels	Door Supervisor
Steve	14/11/14	69	M	Dip Spanish	Retired Steel Worker
Margaret	30/11/14	67	F	N/A	Retired Civil Servant
Stuart	12/12/14	26	M	BTEC National	Store Manager
Allan	13/12/14	32	M	BSc	Software Engineer

Table 4. Overview of Public Participant Demographics

4.3.2 Interview Protocol

Respondents were interviewed in the School of Psychology on a one-to-one basis. They were told that the interview was being carried out to find out more about what they thought about the health of the ocean and possible risks to the ocean, and that in the last

section there would be a short narrative for them to read with a few final questions. They were not told that the interview was about OA specifically though this would have become obvious as the interview progressed and questions mainly focused on the topic. After reading the consent form respondents were informed that the interview would be more like a conversation and that there may be some things that would be followed up on, but the direction of the session was mainly determined by their discussion. They were also assured not to worry about what was right or wrong and just to share their views and thoughts on the topics – however basic they may seem, as this is what I was interested in. They were also told not to expect much feedback as I wanted to know their personal thoughts and reiterated that I was no expert.

For the full interview protocol please see Appendix C. As suggested by Morgan et al. (2002, p. 68) this worksheet was designed to fit onto one page with a space to mark whether a topic had been raised. It was arranged in a similar style to the structure of the influence diagram with the interview consisting of four sections. To ease respondents into the interview a couple of general opener questions were asked about the health of the ocean. OA is an unfamiliar topic and it was felt that it would not be appropriate to open with this because people were not expected to have a clear mental model of this risk issue. This has been illustrated in other mental models work; studies on emerging technologies such as CCS are unfamiliar and many people lack a mental model (Fleishman-Meyer & Bruine de Bruin, 2013) resulting in respondents being unable to provide an answer when asked about the topic directly.

After the starter questions respondents were asked about their understanding and personal opinion of OA, for example, “What do you understand by ‘ocean acidification’?” as well as being asked to mention the first thought or images that came to mind for this risk. Prompts were also given to those who struggled to provide an answer by rephrasing the question; “Have you ever heard of ocean acidification? Can you remember anything at all about it?”. If respondents still struggled they were given a little bit more information on the topic with a definition provided for those who could not give a meaningful answer from other prompts.

After establishing the initial understanding of OA the interview then had a detailed focus on OA including questions asking about causes, impacts, solutions and risk assessment, “Can you tell me about the causes of ocean acidification?”. Each of these areas was further probed with more direct questions such as “Can you tell me about how ocean

acidification could affect you?". As well as exploring the main areas that were apparent in the expert model, questions were asked about the future changes in the ocean over a selection of time periods and about personal risk of OA. To further probe each of the areas in the interview, respondents were asked questions such as, "Can you tell me more?", "Anything else?" in order to try and build a more complete picture of how they perceived this risk.

The third part of the interview included questions about climate change, "Do you think it is happening?", "What do you think are the main risks of climate change to society?", to enable me to explore responses to this well-known risk in comparison to the novel risk of OA. Respondents were also asked about whether they saw a link between OA and climate change as this has consequences for how OA should be communicated. It is also important when considering how people make links across related concepts and other beliefs and values. There is a risk that framing OA as a part of climate change may fail to engage some people (Capstick et al., 2016) which will be discussed in more detail in the discussion chapter.

The final part of the interview required respondents to read a short piece of information about the causes, impacts and solutions of OA and also to look at a diagram showing the process of OA (see Appendix C). The final questions asked respondents about their thoughts on OA after reading the information as well as ratings of how they felt about the risk. This allowed the respondent an opportunity to further elaborate on anything they had said previously or express other ideas based on the information, given that this risk is relatively unheard of amongst members of the public (Chilvers et al., 2014). This piece of information would have possibly influenced responses given by respondents due to the low level of knowledge expected in the sample.

The design of the interview was something which required a lot of care as it was clear that this topic (see section 3.6.1) was regarded by scientists as complex and full of uncertainties. As this was a mental models approach and as we already know there is low knowledge about OA, it was necessary to construct a piece of narrative to inform participants about OA. This was shown after the initial round of questions to allow participants the opportunity to share their first thoughts on OA and construct their mental model. Looking into materials for this there were basic pieces of scientific information, documentaries, short video clips, posters and other materials on OA. There were some examples from earlier projects where respondents were presented with a carefully

constructed piece of information on OA prior to being asked questions about the topic. One example comes from deliberative workshops which looked at more general perceptions on marine climate change impacts (Chilvers et al., 2014), in which posters were presented showing various marine impacts including OA. However this study also had experts deliver a presentation afterwards on marine climate change impacts. O'Neill and Hulme (2009) used a similar approach but framed it as an 'expert-led icon'; the information represented typical framings of climate change from an 'expert' viewpoint.

The examples that have been used previously have been very scientific and responses illustrate low awareness, low concern and also incorrect information about what has caused OA (many of those in Chilvers et al., (2014) attributed it to sewage). The approach taken in the current study was to frame the information for someone completely unfamiliar with OA drawing on the information used in the resources and earlier work referred to above.

4.3.3 Pilots

The pilot interviews were crucial for determining whether the content from interviewees was meaningful and to test the interview protocol worked. Five pilot interviews were conducted with friends and family resulting in some modifications of the protocol with the piece of information on OA also having to be simplified. However, interviews lasted between 20 – 65 minutes and interviewees could give detailed responses, despite initial uncertainties. One interesting finding from the pilot interviews was the focus on local effects; most of the interviewees are from the North East of Scotland where the oil industry dominates everyday life. This was mentioned frequently across a number of the main themes.

4.4 DATA ANALYSIS

4.4.1 Transcription

Data transcription can be naturalistic where every utterance and non-verbal detail is transcribed, or it can be de-naturalistic where only the contents of the interview itself are transcribed (Oliver, Serovich & Mason, 2005) with less focus on the structure of the conversation. Additional features of the interview (such as non-verbal gestures) are removed from the transcript and the conversation is also corrected to create a standardised text. In these interviews, the latter transcription style was adopted because the main

interest is the content of the interview. As seen in Table 5 the approach adopted was a mixture of both of these, with more emphasis on the de-naturalistic transcription style. Some naturalistic features such as gaps in conversation and obvious tones or gestures were transcribed as they appeared contextually relevant; these would have been missed if transcription was purely de-naturalistic.

All of the interviews were audio recorded and transcribed, with around 147, 000 words transcribed. The interviews were transcribed verbatim with an adapted system developed from the literature (Poland, 2002; McLellan, MacQueen & Neidig, 2003):

Protocol	
Short pause (up to 3 seconds)	…
Long pause	[pause]
Interruptions	- at point of interruption
Overlapping speech	[overlapping]
Inaudible speech	[unclear and timestamp]
Unclear speech	[insert suspected words and timestamp] or [unclear and timestamp]
Sensitive information	XXX
Slang, mispronunciations, grammatical errors	Transcribed as heard
Filler words e.g. hmmm; err	Transcribed as heard
Non-verbal communication (gestures)	Not transcribed unless meaningful
Laughter or other similar features	[laughs]
Off topic or irrelevant conversation	Not transcribed, description given e.g. [talking about the weather]

Table 5. Transcription Protocol used for public interviews

This process took considerable time and effort to ensure that transcripts were as accurate and complete as possible. There were advantages to transcribing the interview data myself, mainly that familiarisation with the data helped me to initially consider the methodology and theory relevant for my interpretations and further analysis. Interviews were conducted by myself meaning the chance of transcription error was minimised. I could contextualise everything in the transcripts having been present throughout the interview process. Where there were clear errors in interviews (i.e. respondents said the wrong word) or it may have been possible to guess what was said I did not change

transcriptions to reflect this, though where quotes are presented in the thesis some aspects were tidied e.g. minimising or excluding filler words (King & Horrocks, 2010).

4.4.2 Analysis of interview data

After all the interviews had been transcribed they were entered into nVivo (V10), a computer-assisted qualitative analysis program to aid coding, storage and organisation of the data.

To determine how prevalent knowledge factors from the expert model were in those interviewed, a content analysis was conducted to assess how frequently relevant codes appeared. This was coded as set out in Table 6 below:

Topic mentioned unprompted	A
Topic mentioned prompted	B
Topic not mentioned	#
Mentioned after information	C
Mentioned but not explicitly linked to OA	*

Table 6. Coding Framework of Public Responses

An Excel spreadsheet was then created and the full list of expert nodes in the expert model was entered. Each transcript was read through and respondents assigned a code reflecting whether they mentioned a particular topic and if so, in what way. If a topic was mentioned without prompting, respondents were given an A – and this was judged most important since respondents had provided their own knowledge linking into the expert model. If a topic was mentioned but had to be prompted, i.e. a respondent was asked about something specifically, responses were coded with a B. This was still counted as an important topic illustrating suitable knowledge in line with the expert model. In this analysis, a large proportion of topics were not mentioned at all which was unsurprising and this was noted. As described above, respondents were given a piece of information towards the end of the interview about OA (see Appendix C), and if they brought up something new after reading this the topic was coded with a C. On occasion respondents also mentioned topics which were relevant to the expert model but without linking them specifically to OA. Instances where this occurred were also noted as this might indicate a fragmentary belief; i.e. the theme was mentioned but without context or in reference to OA. Lastly, knowledge that was clearly 'incorrect' in relation to the expert model was identified through the thematic analysis.

To establish how the mental model of the public mapped onto the expert model, after the initial themes found in the expert model were identified through a content analysis, a thematic analysis was conducted to take into account the non-knowledge aspects of OA (the process was the same as in the expert perceptions phase). As the mental models approach focuses on knowledge, and OA has a very low awareness among the public, there were a number of other aspects which contributed to conceptualisations of OA. These include the risk of OA, emotion and trust and are outlined in the coding framework (Table 7) showing how these feature in beliefs about OA amongst members of the public sample. These examples are key because they will be crucial in determining how best to design communications about the risk of OA in future and also help to explore theoretical and psychological implications of understanding perceptions which is done in the second public perceptions phase.

Within this thesis, thematic analysis was used as it works well with SRT in a deductive way and this was a very exploratory analysis. Rather than simply presenting descriptive themes, findings are presented through social representations which can be engaged with on a more meaningful level (as done by Jaspal and Nerlich (2014) who explored climate change in the media).

In the next section of the chapter the content and thematic analyses will be explored in more detail to try and obtain a complete picture of how the public conceptualise OA in comparison to the experts and scientific literature.

Public Interview Coding Framework

Codes and sub-codes	Example	Frequency
Emotion		
Negative	...I'm not going to lose sleep over it but I would think in a more negative way about it. (Margaret)	52
High concern	Yeah. Any pollution concerns me. Yeah anything that will affect life on the planet concerns me. (Tricia)	19
Low concern	Well only knowing about it in the most general terms at the moment it doesn't really cause me any alarm or panic or make me stop and think. (George)	3
Don't care	Probably doesn't interest them, doesn't occur to them unless they're somehow involved or work-related to it I should imagine the bulk of the country to quote phrase couldn't give a toss. (George)	17
Guilt	...the term ocean acidification sounds like we've done something, yeah. Like we should feel bad for doing something. (Stuart)	4
Anger	They [other people] would be angry at the government for not preventing it, but if no one knows about it then, I don't think they would care much. (Emma)	3
Frustration	...I wouldn't feel particularly happy about it. So yeah it would make me feel frustrated and annoyed. (Adam)	2
Hopelessness	...hopelessness really and it's quite frightening having a child and bringing them into that world. (Fiona)	1
Safety	...I would hope that ocean acidification was at the right balance so that there wasn't too much or too little of it so that it was at a safe degree for both for humankind and for the ocean to survive and creatures in it. (Philip)	1
Responsibility OA		
Government	The governments whoever they would be. I suppose cause the oceans are all around the world aren't they… (Charlotte)	9

Global	...it concerns everybody because nobody lives detached from the ocean so even directly or indirectly but so I think it would be a global responsibility… (Joe)	2
Industry	The producers of- if it's a result of pollution than the producers of the pollution have to be held accountable and they have to be part of the remedy. (Darrel)	2
Scientists	Generally though scientists and yeah, people who work in the ocean like marine scientists who are like monitoring the ocean anyway as part of their job so they have a better sense of it than anyone else cause they're like looking out for things that might be changing… (Helen)	1
Industry profit	...loath corporate nature of America, of quite a lot of Europe, of this country and the drive for profit overriding absolutely everything else. (Fiona)	6
Information source		
Internet	Have a quick look on Wikipedia and see if there's any more detail and usually they link then to other websites that are more specialist… (Allan)	29
Trust	I buy into them but I've never really looked deeply into whether I could find them really trustworthy. (Stuart)	24
NGO	…Greenpeace or that kind of I guess, yea. That is actually my main source when it comes to environmental issues really… (Adam)	11
Books	...books on that particular subject even if they're old books because they will give you an idea roughly what it's about… (Helen)	10
News	…it would be through websites and the news if there was a big news story about it. (Philip)	9
Information bias	…Sometimes if you're biased in one direction you automatically only read those articles. You don't read the opposite side of view which perhaps you should do. (Karen)	7
TV	...some of these you know ecological television programmes should bring it up as well. (Tricia)	5
Research	...I would expect to come across it in perhaps an academic environment… (Darrel)	4
Family	Like I say through my father, petrochemical industry. (Edward)	3
Work	Some of my knowledge comes from my background as an analytical chemist particularly working on analysis of water. (George)	1

Ignore information	...but it's quite easy to not listen properly to the news and kind of just scroll past things… (Emma)	5
Low media coverage	If it was something on the current agenda or has been for some time then you know not embarrassed, I'd feel a little bit like why have I not heard of that? (Edward)	15
Lack of scientific knowledge	I don't have any scientific knowledge to justify that but it is an instinctive reaction to the phrase… (Darrel)	28
Want to know more	...I'd like to know more about it, I think I should increase my knowledge of oceanic acidification. (Darrel)	26
Nature		
Oceans vast	Because it's so big isn't it the sea. (Fiona)	19
Messing with nature	I would say predominantly it's a bad thing because we're messing with a massive system that we don't really understand… (Fiona)	3
Ocean natural	...the ocean's been as the ocean is for millennia. I see the world as a whole place like the Gaia principle you know, that everything is balance… (Tricia)	2
Other environmental change	…it could have a huge impact on the whole of the global environment in terms of air, sunlight and that could have an impact on vegetation, fauna and health. (Darrel)	6
Risk		
High importance	I think ocean acidification is one of the biggest threats to the ocean. (Allan)	19
Low importance	Well at the moment I'd say it's not that important but it depends really- if there is a problem… (Karen)	9
High societal risk	I absolutely think it is a big risk because it has- when there's this kind of environmental damage and competition for resources it's got implications. (Fiona)	
Low societal risk	It would be- Friends of the Earth would be shouting about it and- so to the best of my knowledge nothing like that is going on at the moment so I should imagine we're at a low risk. (George)	23
Low personal risk	I think my own personal risk in my lifetime is probably quite low… (Joe)	12
High personal risk	Mine might be high because I live by the sea … (Helen)	6

Human nature	When it comes to the general populous it doesn't matter what it is, be it ocean acidification, be that the World Trade Centre's coming down, be that global warming or whatever, no just completely blinkered to it. (Edward)	12
Day-to-day life	…in the everyday people don't actually care… (Annie)	11
Only care if directly affected	I think until something actually affects an individual I'll say most people aren't really particularly bothered… (Charlotte)	8
Scepticism	…if there's anyone denying the acidification of the oceans in the way that there's a real powerful platform in America and to some extent in this country denying climate change. If there's that we have got a problem then. (Fiona)	1
Terminology 'ocean acidification'		
Negative term	By the very definition of ocean acidification it sounds like something a bit Star Trek and a bit scary say on a social society point… (Edward)	10
Word association	Only from like an English language point of view that it must be getting more acidic, the process of getting more acidic. (Joe)	12

Table 7. Public Interview Coding Framework

4.4.3 Reflexivity and limitations

DATA COLLECTION

Conducting interviews with members of the public highlighted some issues with my interviewing technique as this was the first time I had carried out interviews. The first few interviews were the most difficult as it took some time for me to become confident enough to build rapport with each person. This was essential to ensure respondents were comfortable in opening up to me (King & Horrocks, 2010). As the topic was completely unfamiliar to the vast majority of respondents there were some long silences in the initial stages as they struggled to formulate answers. The first couple of respondents did require a definition to establish a thought out response (see Appendix C for prompts and definition), however, interviews flowed smoothly afterwards. Once I had become accustomed to conducting interviews I found it much easier to build up to the difficult question of "What do you understand by ocean acidification?" and getting a meaningful response.

Interview content ranged widely from respondents unsure of themselves and how to answer questions posed, to those who talked constantly whilst trying to work out their responses. In those who were very unsure of their responses and did not elaborate on some questions, there were some blanks and pauses whilst respondents struggled to come up with answers. One participant claimed they found it difficult to discuss because of their economic background. Having a lack of scientific knowledge was a common thread among those interviewed:

> "*I'm constructing a very bad scenario as a result of it but it's not based on my scientific understanding of acidification which is nil*" – Darrel (66, Door Supervisor)
>
> "*My impression is there is something going on I don't know about. I probably ought to know about it and when I get home I will start researching it. That's how I feel right now."* – Tricia (66, Homeopath)

Quote Box 1. Lack of knowledge

Generally the themes covered by those who were more unsure of the topic were primarily those which were most common and had been mentioned previously.

PARTICIPANT INFLUENCE ON THE DATA

Each participant brought past life experiences or previous work which would have influenced the content of the interview. The final sample was diverse and included a respondent who had been a chemist at one stage in his life, analysing water samples

(George). As the interviewer, I anticipated that he would be very knowledgeable about OA, and on reflection thought he would have been the most knowledgeable in the sample. The influence of his knowledge of chemicals did seem to help him formulate his ideas and thought processes with a clear focus on the cause of OA being on sulphuric acid, and ultimately acid rain, rather than carbonic acid. He also took a rather measured view of scientists and consensus on occurrence of OA and also climate change (though he does believe climate change is happening and he was concerned about both). Some questions he said he could not answer without having some physical data collected over a period of time to make a judgement, for example when asked about comparisons of acidification to pollution or if OA was an important risk or if there were other risks more important to the ocean. With regards to wildlife, food chains and specific organisms he was quite accurate in his assessment of how these would be affected with an emphasis on shellfish because they are composed of calcium. At the conclusion of the interview George attributed his knowledge and responses to the wide range of documentaries that he had watched as opposed to his chemistry background though did say that contributed. George found it difficult to formulate a definition of OA that he was happy with but answered questions well. He covered many of the themes already mentioned by previous respondents and seemed to have a genuine concern about environmental issues.

INTERVIEWER INFLUENCE ON THE DATA

As well as personal influences such as George's past work, the interviewer also had an influence on the interview. One obvious example of this was when I asked a respondent where he would expect to come across OA in the information sources he reads:

> *"I can't- I would really struggle to think of where I've heard that term before to be honest so because I'm in a university with a researcher I assume it's a term that exists."* – Philip (55, Development Worker)

The interview content itself, as well as the context, were Philip's reason for determining that OA was a definitive risk at all. As this is an unfamiliar topic, the analysis should be regarded with caution as it only accounts for one perspective from data collected at that one point in time.

4.5 INTERVIEW ANALYSIS FINDINGS

This section will explore the outcomes of the public interview data analysis and how it maps onto the expert model of OA. This will be presented by displaying a mental model of an individual respondent showing their coded responses which link to specific expert nodes. An overall mental model will then be shown to highlight the frequency that nodes were mentioned in those interviewed to establish where beliefs are most prevalent. After outlining commonalities between the expert and public mental models, the differences and non-expert nodes will then be explored including any misconceptions. As conceptualisations between the experts and the public are very different a public model was designed and will be explained in detail.

4.5.1 Mental Model Completeness

As can be seen by the coding framework for the public interview data, the themes are quite different to those outlined in the expert model. This may simply be because of the technical and scientific language used by this group. To illustrate how salient the themes in the expert model are, the mental map of Allan was overlaid (see Figure 6). The themes mentioned are shaded and those not mentioned are left unshaded. The bold text in this Figure (and Figure 7) shows key factors from each component of the expert model. This respondent had the highest mental model completeness score of 20/69 (see Appendix D) which is still fairly low (only two people had heard of OA prior to the interview). The overall salience of themes which were produced in the expert model was calculated for public respondents to determine which themes were acknowledged and which themes were not mentioned**.** These were calculated by those scoring a 1 (mentioned a topic consistent with the expert model unprompted) being totalled and a percentage given. For those given a score of 2 (mentioned a topic consistent with the expert model, prompted) the percentages were halved and allocated to each respondent assigned a 2. If a respondent scored a 1 they received 5% and if they scored a 2 received 2.5%. These mental model completeness scores were created by totalling how often a topic was mentioned in line with the expert model either as an unprompted response (assigned code A) or a prompted response (assigned code B). The highest a respondent could score was 69 for a complete mental model of OA, scoring one point for each topic see Table 6.

As the majority of nodes are present in the 'Impacts' theme within the expert model this is not surprising especially when this is a particularly uncertain area with a wide range of possible outcomes.

Allan was the only respondent who knew what the main cause of OA was, attributing it to carbon dioxide (see Quote Box 2 for supporting quotes). Though he mentioned carbon dioxide going into oceans this was not explicitly tied to OA but brought up as a current problem. He did acknowledge that the changes had resulted in a pH decline but was not sure about the chemical process behind it. When discussing interactions with OA, changes in the water temperature were linked to possible migration of fish and also to climate change. However, the main interaction Allan talked about was river systems and the impact that industries had on them which in turn would affect the oceans.

Allan recognised a number of possible impacts that OA could have mainly with regards to environmental impacts. Organisms such as corals were clearly identified as being affected by OA with mention of possible extinctions occurring. Additionally, he recognised the issues that organisms may face when trying to source food. In this section, regional variability was also brought up. When considering socioeconomic impacts he reasoned that impacts on organisms would also affect those that some livelihoods may be dependent upon.

Finally, an equal number of nodes were brought up in the theme 'responses' (three nodes in each type of response) with a clear acknowledgement that CO_2 emissions had to be reduced. Further thinking from Allan also elicited ideas about how this could be done as he was aware of some geoengineering techniques already in use as well as considering more direct approaches for OA. As already mentioned, the possibility of organisms migrating was also brought up with a realisation that the ecosystem would have to respond to this kind of outcome. Lastly he also alluded to organisms being used as well and being adapted for the purpose.

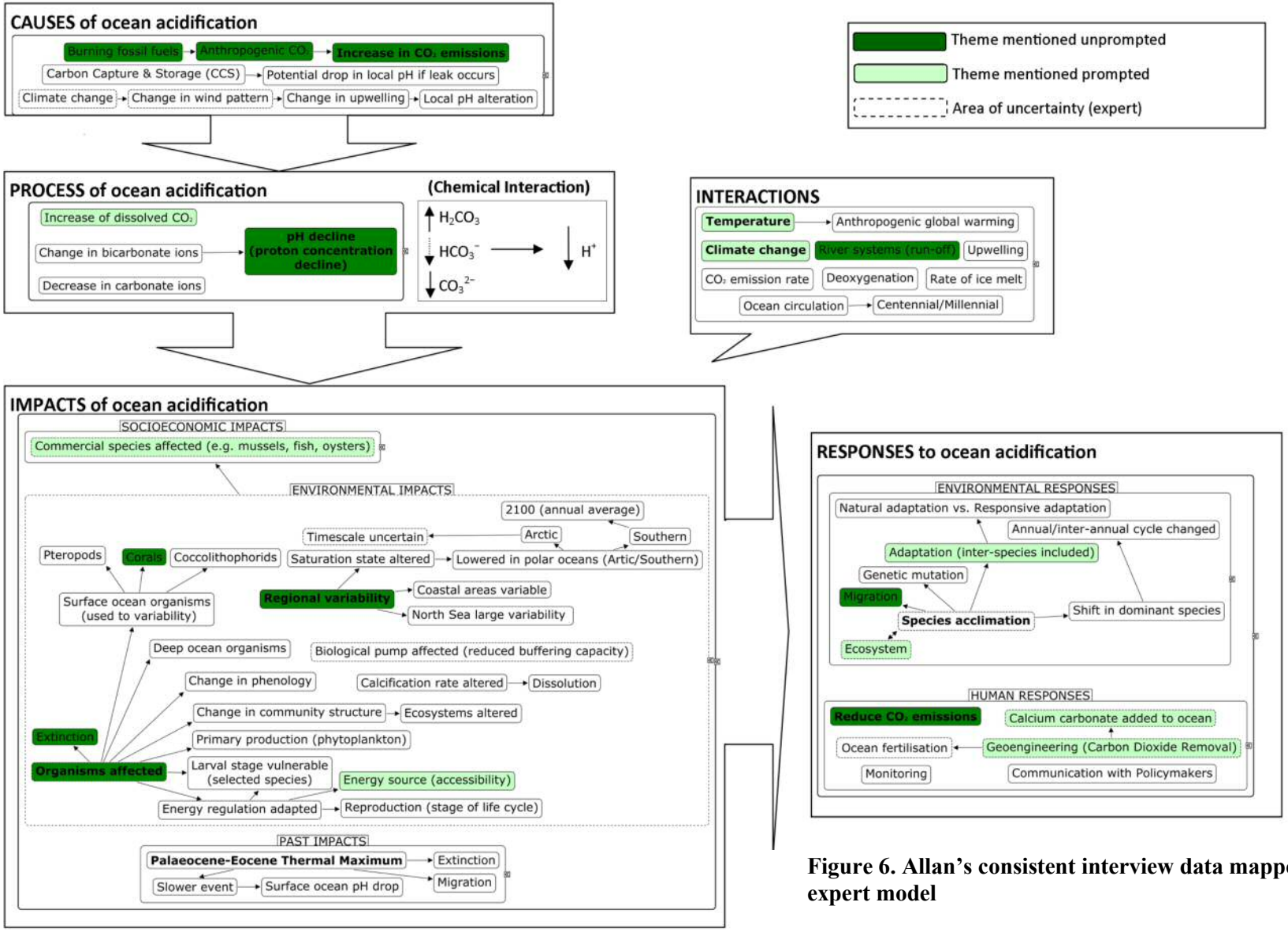


Figure 6. Allan's consistent interview data mapped onto expert model

Causes

"I'm not 100% sure but I think it's something to do with the amount of carbon and things we're putting into the air I think. But I'm not 100% sure because most of the things that seem to be going wrong seem to be to do with the carbon footprint."

Process

"Well based on the name I'm guessing it's to do with the ocean pH level, it's dropping or increasing, making it more acidic."

Interactions

"Climate change obviously, I think I remember reading somewhere or I saw somewhere that changing the water temperature in an area about one degree causes certain fish to not be able to live there and they migrate somewhere where it is slightly warmer or colder or whatever they prefer. Then it affects the other wildlife in the area so yeah I'd say they're very- there's a good degree of linkage between the two-"

"Trying to not to interfere with local water tables you know, trying to not pump things into rivers and streams and oceans and things like that."

Impacts

"I think I've read a little bit about it in the past, changes the pH level of the water which like makes it unliveable for certain species and it changes the ecosystems of certain areas and kills off reefs and things like that."

"So it doesn't just- it immediately affects like fish and corals, and things like that but then it's going to affect everything up the chain. Perhaps more slowly but things that rely on the fish will slowly move to somewhere else. The things that rely on hunting those will move and so on and so forth."

"Probably be sort of more focused in certain areas where there's dumping and a lot more industry but it's going to have an overall effect with it."

"-but it would probably affect the people who make their livings from the sea kind of thing a lot more and certain areas, poorer areas that can't afford to import food and things like that, that rely on the sea for food-"

Solutions

"I don't know anything about terms of remedies but stop doing whatever we're doing in it and stop dumping things in it, lower our carbon footprint and try to stop messing up our environment."

"I think I remember reading something about- they've got some, I can't remember what it is now- carbon scrubbing filters and things like that, they actually remove all the carbon and everything they pump out sort of thing so they're pumping out just water vapour and air."

"Yeah there's probably some chemical way, something they can put into the ocean to reduce the acidity but then obviously that will impact on other things."

Quote Box 2. Examples supporting Allan's mental model of OA

This respondent seems to be fairly well-informed about OA in comparison to others. The lowest mental model completeness score was Annie who only scored 5 (Appendix D). However, English was not her first language and the interview was affected somewhat by the language barrier. Tricia and Margaret had scores of 7 which are still very low. Margaret in particular, had plenty to talk about and was genuinely concerned about the issue but her conceptualisation of OA was very different to the experts.

Figure 7 shows how salient expert themes were in all 20 of the public respondents with the darker green areas showing the themes which were prominent in the model. There were many more themes which were mentioned by a few respondents as shown in the figure. See Appendix D for a full breakdown of how salient each theme was; a higher percentage means more respondents mentioned that particular theme. Determining the saliency of themes does not necessarily illustrate if respondents comprehended the themes which they brought up, but only illustrates that they mentioned them and that there were a number of consistent statements made by public respondents which tied into the expert model. What became obvious was the uncertainty of responses, particularly in the initial stages of the interview. The following statements were correct but there was an element of doubt in respondents' replies when describing possible causes of OA.

Cause

"I think perhaps it's something complicated to do with pollutants in the air somehow getting into the sea." – Joe (24, Unemployed)

"I think ocean acidification is one of the things that we're causing. You know, not being as green as we could be, using fossil fuels and things like that." – Allan (32, Software Engineer)

"I would regard it as some sort of pollution whether it was greenhouse gases, I'm using very generic terms here I appreciate that. Whether it's an overall reaction to the global climate and global pollution or whether it was a specific change of the ocean pollution I wouldn't know." – Darrel (66, Door Supervisor)

Quote Box 3. Cause of OA

Determining the public mental model of OA was complicated and it was not appropriate to map this onto the expert model of OA in its completeness. The mental model completeness scores show that there was a low level of knowledge about OA. Figure 7 does show that there were shared ideas about the risk of OA but there was also a minority of prominent themes. There were a wide range of other themes mentioned in the public interview sessions which resulted in the design of a public influence diagram depicting the full public mental model of

OA. The consistent themes mentioned by respondents which were in line with expert conceptualisations were incorporated into this model as well.

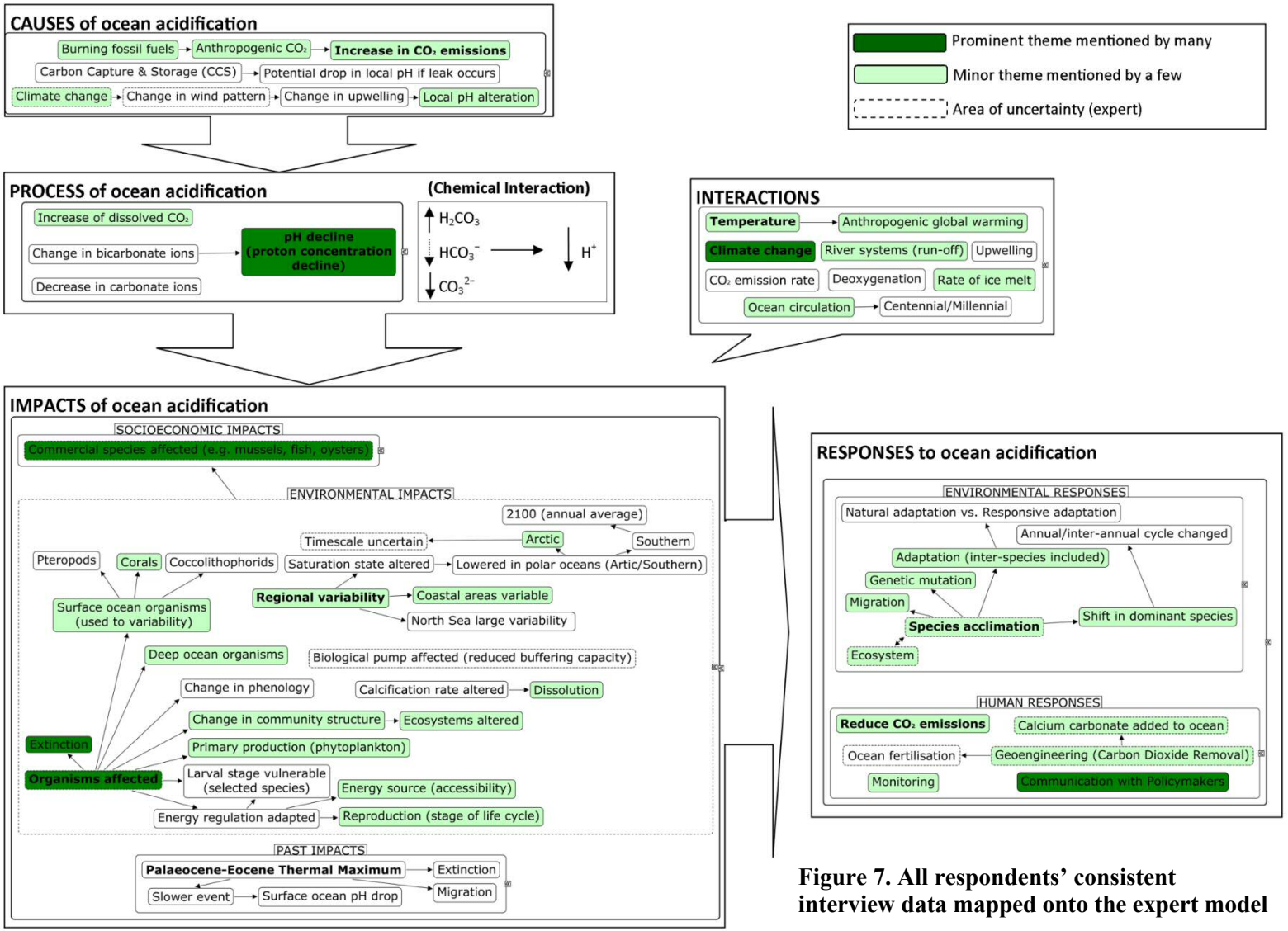


Figure 7. All respondents' consistent interview data mapped onto the expert model

4.5.2 Public Mental Model of OA

The influence diagram of expert conceptualisations of OA was summarised giving an overview of the themes raised within each top-level concept; causes, process, impacts, responses and interactions (see Figure 8). It also allows for comparisons between expert and public mental models of OA to be easily made, which is one of the main aims of this phase. The content analysis was crucial in determining how consistent beliefs and understandings of OA were in the public respondents but it only made up one part of the picture. The thematic analysis identified a list of other 'knowledge' aspects but also allowed other factors to be explored; these are outlined in Table 7.

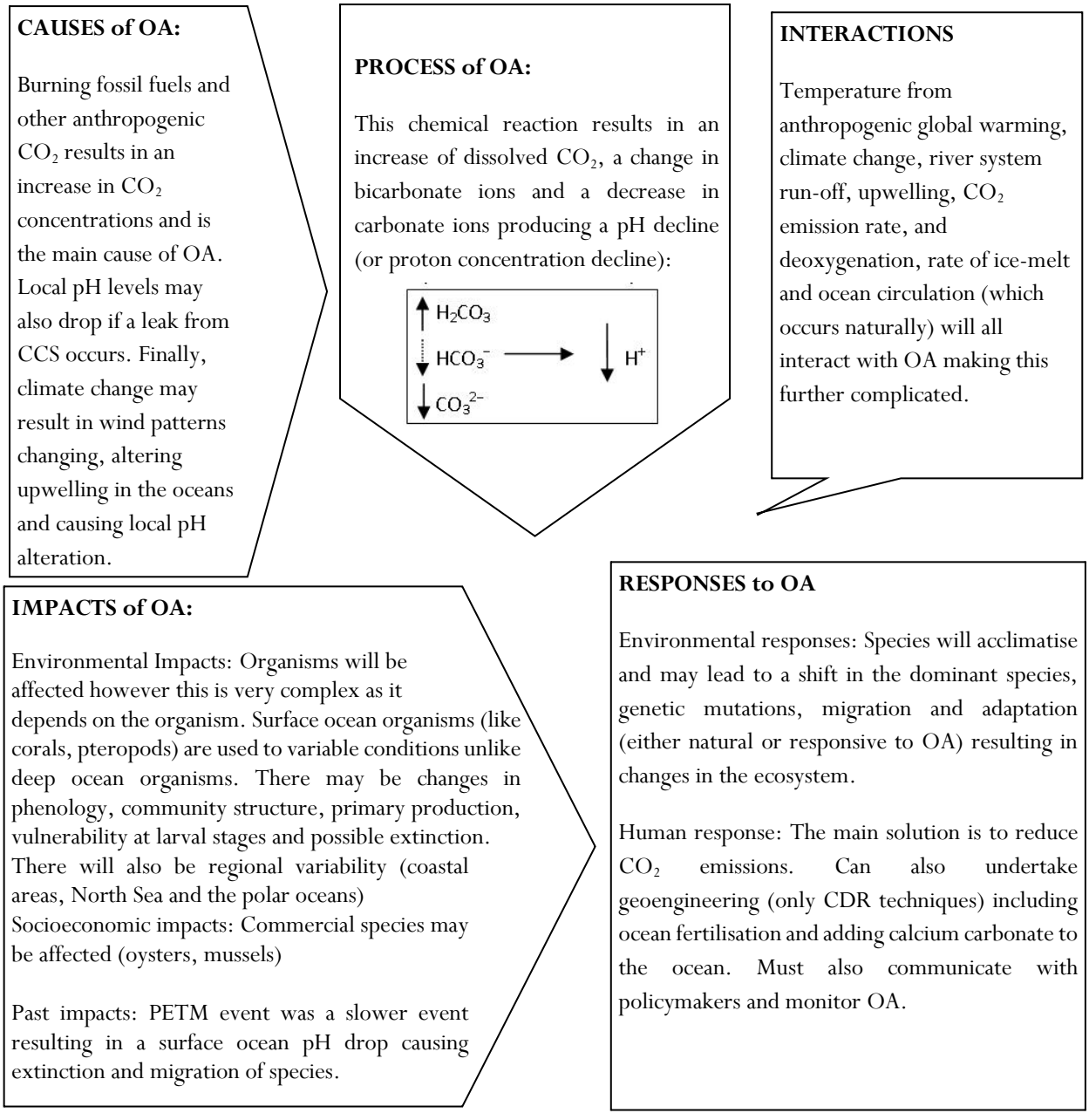


Figure 8. Overview of expert model summarising Ocean Acidification (same as Figure 3)

Figure 9 is the final public model of OA and portrays how this risk issue is understood and explained by those who took part in the public interviews. Though there is some scope to compare the two perceptions of OA between the experts and the public this must be done with caution. The methodologies behind the construction of these models were different with the expert interviews conducted by another researcher in a different format. The experts focused on their own knowledge and expertise about the risk of OA and did not share their personal concerns or feelings about the risk of OA.

In the interview protocol used for interviewing members of the public, these 'non-knowledge' aspects (i.e. personal concerns or feelings about the risk of OA) were important considerations as they will be useful for designing risk communications. The main purpose in comparing the two groups is to determine where 'knowledge' is similar or different. The main upper level concepts of the expert model formed the base of the public model establishing where similarities in beliefs lay between these groups (as shown in Figure 7). Other knowledge aspects relating to the main concepts were added in giving a much clearer insight into how people perceive the risk of OA. To determine how salient particular beliefs were, the percentage of respondents who mentioned each node was totalled. This includes all mentions of each node and does not distinguish what was prompted or unprompted however it was all prior to respondents receiving the main piece of information about OA.

4.5.3 Imagery and OA

At the start of the interview respondents were asked to share their first thoughts or images of OA, "what are the first thought or images to come to mind when you think of 'ocean acidification'?". Open-ended elicitation techniques have been used to obtain concepts of climate change (Smith & Joffe, 2013) and allow people to share their first responses to a topic. These free associations were important because it was a good way to encourage people to begin talking about an issue that many were unsure about (see Table 8).

Visualising OA		Frequency
Visibility	…we'll go down to the edge of the ocean and we'll still see it and we'll think yeah and we'll see the sun setting but underneath the surface of the ocean I think there could be a lot of serious, serious problems. (Darrel)	12
Acid	… when I think of acid I automatically think of damage I guess. (Steve)	9
Wildlife	Dead fish. Dead life in the sea. (Steve)	7
Pollution	Sewage and pollution coming out on the coast. (Karen)	4
Acid rain	It's going to be in our rains, there's going to be acid rain in certain areas of the world. (Sophie)	3
pH	I've never thought about the ocean in terms of that before so I wouldn't even know its natural state, what the- if you compare it to the garden what the pH balance is. (Margaret)	3
Erosion	...picture like a coastline that's being damaged. (Joe)	2
Human-caused damage	…sadly in some cases it's not able to cope with our mistreatment of it… (George)	2
Atmosphere affected	The plankton which floats on the top would be- is killed off which means a lack of oxygen coming in the atmosphere. (Steve)	1
Burning	…would burn if you put your hand into it [the ocean] (Joe)	1
NGO	...Greenpeace when you talk about any environmental damage. (Fiona)	1
Ocean appearance	...I don't know if that would lead to a much clearer ocean or whether or not it would make- or it would be foggier, it would be dense in the colour and transparency of water on the coasts. (Sophie)	1
Ocean living	...pain almost to the ocean in a way because it's like a living organism really… (Helen)	1

Table 8. Imagery associated with OA

Free association techniques are useful when unfamiliar topics are being discussed such as OA. Images mentioned were established through an inductive content analysis before the data was reduced into thematic categories in response to the question asking for initial thoughts or responses to OA. Most of these were linked to possible impacts and the causes of OA with 'Visibility' being the most discussed free association. The process of OA (as well as the impacts and causes) were perceived to be invisible and something which could not be seen. The mental imagery helped give greater meaning to both of these themes which is explored in greater detail in the next section.

4.5.4 Comparison of expert and public perceptions

CAUSES OF OA

Table 9 provides an insight into how often particular nodes came up during the interview when respondents were discussing the causes of OA. Within the public group, awareness of OA was very low with only a couple of respondents saying that they had heard of it and only one explicitly identifying carbon dioxide as the main cause which is in line with the findings of Capstick et al. (2016). Though most people in this sample had not heard of OA the majority believed that it is caused by pollution. A wide selection of possibilities was mentioned resulting in two types of pollution being identified:

(i) Direct input into water

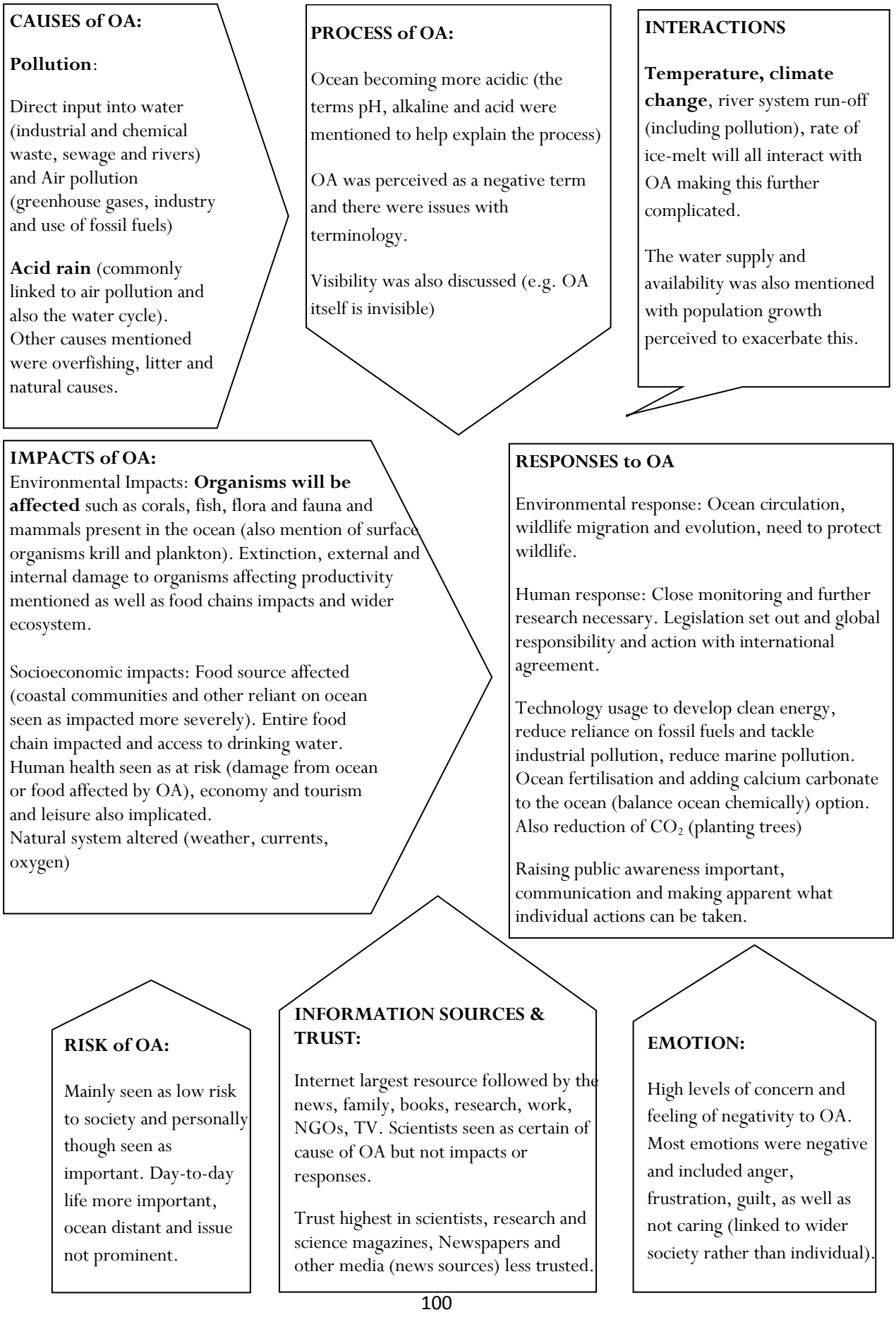
(ii) Air pollution

Causes	% respondents (N= 20)
Pollution	70%
Human cause	55%
Chemical Waste	55%
Acid rain	45%
Carbon dioxide	35%
Air pollution	25%
Dumping waste	25%
Litter	20%
Related to atmosphere	15%
Gas absorption	15%
Natural	15%
Ozone layer	15%
Ships	15%
Water cycle	10%
Damage to ecosystem	10%
Overfishing	10%
Sewage	5%
Loss of wildlife	5%
Overseas industry	5%
Rivers	5%

Table 9. Percentage of respondents who mentioned each node (Causes of OA)

PUBLIC MODEL: Public perceptions of OA

Figure 9. Overview of public model summarising Ocean Acidification



The first type of pollution - direct input into water – refers to pollution where pollutants are directly put into water. Industrial and chemical waste were thought to be main contributors with two respondents mentioning by-products of certain industries such as oil and gas. One person included overseas industry as well. Three respondents felt that ships also added oil or general waste spillages into the ocean. Some respondents said that dumping waste was also a possible cause as individuals and industry used the ocean to dump their waste. Sewage waste was also thought to be a possibility with one respondent referring to the acidity of urine. Many respondents referred to chemicals produced by industry being expelled into rivers (The one mention in Table 9 related more to rivers themselves as part of the water cycle picking up pollutants):

> *"Pollutants I suppose could acidify if they come out down through the rivers. And some companies put pollutants into the rivers without thinking carefully about what they're doing*." – Tricia (66, Retired Homeopath)

The second type of pollution - air pollution – refers to pollution produced by industry and factories, fossil fuels and transport. A few respondents talked about the atmosphere and how it may be connected due to the changing composition of the atmosphere (e.g. increase in greenhouse gases). Three respondents also brought up the ozone layer as possibly playing a part but could not explain how this would work.

Another common response was acid rain which respondents linked to air pollution. Some described the water cycle to explain how this would happen:

> "*…we don't understand the full impacts of a lot of what we do with those pollutants going into the atmosphere and then falling again as rain or-. I suppose that might be one of the causes of acidification."* – Philip (55, Development Worker)

This connection to acid rain seemed to be based on word association, which will be discussed shortly. Other causes mentioned included damage to the ecosystem (perhaps through overfishing or loss of wildlife), litter and a natural cause. Litter was usually mentioned as a last possible cause or loosely linked in. Only a few believed that OA may be a completely natural process that would happen without human activity. Technically one could argue that OA is a natural process as the cause is atmospheric CO_2 concentration (which do indeed vary naturally) and associated chemical reactions, however, the current event is an accelerated one from human activity (Zeebe, 2012).

Many respondents directly implied that OA is human-caused mainly from pollution or human-made waste as illustrated by the numerous causes mentioned. As those interviewed were largely unaware of OA, CO_2 was rarely mentioned as the main cause. Most respondents thought about pollution in the oceans in more general terms and other marine issues they were more familiar with.

PROCESS OF OA

In the expert model the process of OA is clear; it is a chemical reaction resulting in a decline of pH levels resulting in OA (Gattuso & Hansson, 2011). Some of the nodes that were created through the thematic analysis (Table 7 and Table 8) were important in trying to understand respondents' comprehension of OA.

Process	% respondents (N= 20)
Word association	55%
Visibility	40%
Negative term	40%
Acid	35%
pH	10%
Acid rain	10%

Table 10. Percentage of respondents who mentioned each node (Process)

A summary of the relevant nodes can be seen in Table 10. Public respondents' understanding of OA was simply that the ocean is becoming more acidic. Some used the terms pH, alkaline and acid states to help describe the process:

> *"That's the change in the pH of the ocean towards being more acid than alkaline or neutral."* – George (58, Self-employed Charity Worker)

The terminology was an issue for many as they found it too scientific and predominantly felt that the term was negative (it links to acid which is seen as destructive):

> "*Well just on that term as I know nothing about it what I would imagine is that there wouldn't be any positives, just think about how I feel about yeah acid isn't it and acidification so I suppose everything would be about negative aspects*." – Charlotte (49, Training Co-ordinator)

As well as asking respondents about their understanding of OA they were also asked about images that came to mind (see Table 8). Imagery mentioned included acid (with regards to impacts and damage) and acid rain (used to describe the process). Imagery also included pollution (used to describe causes of OA with an emphasis on human-

made pollution) and impacts on wildlife so again was similar to those found in Capstick et al. (2016).

IMPACTS OF OA

In the public model two types of impacts were found: environmental and socioeconomic impacts (see Table 11 for specific nodes mentioned). The third area in the expert model was about a past event of OA known as the PETM which occurred 55 million years ago (Zachos et al., 2005) and unsurprisingly does not appear here.

Impacts OA	% respondents (N= 20)
Wildlife (e)	100%
Evolution (e)	60%
External damage to organisms (e)	20%
Internal damage to organisms (e)	20%
Migration (e)	15%
Burning (e)	15%
Surface organisms (e)	5%
Affect humans (s)	90%
Food chain (e/s)	75%
Fishing (s)	50%
Health (s)	50%
Severity determined by location (e/s)	50%
Ecosystem (e)	40%
Erosion (e)	30%
Salt (e)	30%
Water (s)	25%
Tourism (s)	15%
Weather (e)	15%
Currents (e)	10%
Ships (s)	10%
Water Extraction (s)	10%
Industry (s)	10%
Atmosphere (e)	5%
Research impacted (s)	5%
Temperature (e)	5%

Table 11. Percentage of respondents who mentioned each node (Impacts of OA).

s =socioeconomic and e = environmental impacts. Italicised nodes are sub-nodes of 'Wildlife'.

For environmental impacts, respondents focused on wildlife being impacted (coral reefs, fish, flora, fauna and mammals were all mentioned, with a respondent mentioning specific surface organisms). Two respondents referred to the CO_2 vents where plant life has been able to adapt despite the conditions there showing hope for

wildlife. Karen felt that there might be hope for coral reefs despite them being severely impacted by OA:

> *"I forgot about the coral reefs as well because they're losing a lot of coral reefs because of acidification I've just remembered now. So let's hope that, because I know coral is something that can regenerate itself because if it's left on its own it can regrow again."* – Karen (61, Retired Librarian)

As seen in the expert model calcifying organisms such as coral were believed to be at risk from OA. There was disagreement between respondents on whether larger or smaller organisms would be more affected by OA. Those who felt that smaller organisms would be more affected thought they would be more fragile so be more affected by the acidity whereas those who felt that larger organisms would be more affected thought that the depleted food source would impact them more. Some people felt that wildlife was more at risk than humans as humans can adapt to the changes.

The public sample recognised that there would be direct impacts on marine organisms, the food chain and ecosystem similar to the expert model. Many public respondents focused on populations reliant on fish (e.g. Bangladesh) and considered socio-economic impacts instead of local environmental impacts. Though most people thought that the effects would be worse locally, OA was perceived as a global issue and one that would become a problem everywhere. The impact of OA on particular regions was seen as dependent on the level of pollution in the local area by some respondents with one feeling that pollution was more problematic than OA. All public respondents agreed OA would have a negative impact and cause damage to organisms potentially resulting in extinction of some species because of the changes in the environment. Though some respondents thought that organisms would be able to evolve quickly there were those who thought it was unlikely:

> *"You know it's taken millions and millions of years for things to evolve … and then we're fiddling with one part of it..."* – Fiona (39, Teacher)

A few people said organisms would have to migrate to other parts of the ocean in order to survive but this would have a knock-on effect to the food chain and interfere with reproduction and breeding. Some people felt that the acidity would have a direct physical impact on organisms and may cause external damage. A couple of

respondents mentioned organisms with shells would be affected in a unique way with the shell becoming dissolved or trapping water in with the organism:

> *"Well the shell wouldn't protect them from acid. It might rot the shell for example but they live under the shell and they stick their- they stick parts of their body out of the shell to feed and they take in the water and the water would surround them and it would eat into their flesh. Depending on how severe it was."* – Tricia (66, Retired Homeopath)

However, there was a belief that the shell would provide a defence against the corrosiveness of the water (two respondents had said that organisms more generally may be burned by the acidified water). Internal damage such as organ damage or deformities impacting on reproduction were also mentioned by a few people. As well as impacts on wildlife, the environmental impacts discussed by respondents also included the environment more generally.

A number of respondents felt that OA would result in damage to the marine ecosystem including natural structures and coral reefs. Many expressed that small changes in the ecosystem would have significant negative implications. Two people acknowledged that surface organisms like krill and plankton were especially vulnerable with Steve outlining how this would potentially affect the atmosphere:

> *"…I think it's plankton that's on the top…tiny little plants what give off oxygen and get rid of carbon. As I say if they are damaged like that and the damage is so great then they'll be big, big trouble as far as oxygen in the atmosphere is concerned."* – Steve (69, Retired Steel Worker)

People also mentioned natural systems predicting changes in the atmosphere, ocean currents and weather from OA. Some thought that weather patterns may alter (such as changes in precipitation patterns). The currents were also thought to influence the water cycle (e.g. evaporation) and OA may affect this. One person explained that changes in natural systems would have a global impact:

> *"And do you think it might be something that occurs locally?"* - Interviewer
>
> *"No. When it comes to stuff like this and even though I don't know a great deal of it you say locally, if- depends on intensity but the intensity of a problem will obviously affect the local area as a whole however because of atmosphere, because of ocean currents etc etc things happen globally…"* – Edward (49, Sound Engineer)

Though the effects on natural systems are also found in the theme of interactions, especially for experts, this was mentioned specifically when asked about impacts of OA rather than how the systems interacted with OA. A couple of other thoughts which

were less prevalent were temperature (one person thought that this may change from OA), salt and erosion. Salt was thought to be important for the balance of the water so changes would have an impact on the ocean. Lastly a few respondents thought that there may be an increased rate of erosion of rocks and coastlines.

The second type of impact also found in both the expert and public models was the socioeconomic impacts. The emphasis of many responses was on this type of impact for the members of the public. The expert sample did not mention these in much detail as it is far more uncertain what will occur; they simply acknowledge that there could be an impact. A large proportion of the public sample cited food source and availability as being the main impact on humans with the impact on organisms ultimately linked to the effect on humans. Many referred to those who rely on the ocean for food such as fishing communities or coastal populations:

> *"…but I think in terms of humans it would affect people who are most directly reliant on the sea or you know fishing stocks and stuff like that to survive especially if they were isolated communities that couldn't find any other way of getting in food or were very poor and that was their alternative communities that sort of rely on the sea for their economy."* – Joe (24, Unemployed)

This reflects back to the severity of OA varying in different locations (i.e. coasts and islands in this case) and varies from how the expert group talked about local impacts of OA. They focused on environmental changes like saturation states, river systems and eutrophication.

The majority of the public respondents mentioned fishing being impacted by OA with overfishing already an issue affecting fishing quotas and fish stocks. Some also thought that fish may be poisoned or contaminated and this could feed up through the food chain to humans. As well as impacting food there were some respondents who thought water may be affected and clean water may become hard to find. These issues were also thought to be made worse by overpopulation as food availability and drinking water supplies for some parts of the world are already an issue.

Numerous people also said that OA could affect livelihoods and industries reliant on the sea causing local economies to suffer (such as fisheries). Jobs including research

were mentioned as possibly being affected. Ships were thought by some respondents to be susceptible to OA possibly being corroded by OA:

> *"…ships and things will be affected and they won't be able to transport things."* – Abi (23, Student)

Tourism and leisure was also considered to be vulnerable to OA. Many respondents talked about the attraction of coral reefs which already suffer damage from holidaymakers. One person speculated that the ocean and beaches would become unusable so would impact on the economy as there would no longer be a draw to an area for travel and tourism and this may be a crucial source of income.

Interestingly, while some of these human impacts are mentioned in the literature as possible they are extremely uncertain (Hoegh-Guldberg et al., 2007). The experts focused on environmental impacts instead, as these can be measured at this point in time (though are potentially unlimited). It is likely that they focused less on impacts on humans because there is more uncertainty in the future depending on what action is taken. Impacts on humans are very difficult to predict as these may be dependent not only on the severity of environmental impacts but other societal issues (demographics, population location, dietary changes etc.).

Health was also mentioned as a possible impact by respondents with a belief that the risk of disease would be increased including skin being affected. Some people thought that swimmers, fishermen and those in direct contact with the ocean would be affected by OA in this way. As already noted fish were thought to potentially become contaminated and might cause illness if ingested. This is not something that came up in the expert model and may simply continue from the link people made to acid, acid rain and the damage it could cause to organisms. Alternatively, it could be an association between ideas of 'poor ocean health' impacting on those of personal health. The link between climate change impacts and how this could affect human health has been widely discussed (Woodward et al., 2014) and also how the marine environment could be affected and the implications of this for health. Fleming et al. (2006) describe some of the human health risks from the marine environment which could occur if ocean health continues to decline, mainly focusing on food availability and safety.

INTERACTIONS

The interactions mentioned by the public mapped well with those of the experts, though there are differences (see Table 12). Many respondents could envisage OA interacting with other parts of the environment or other risk issues. There were a few who said that they assumed there would be some sort of interaction although they did not know enough to imagine what this could be.

Interactions	% respondents (N= 20)
Climate change	90%
Pollution	80%
Acid rain	40%
Natural cycle	20%
Temperature	20%
Sea level rise	20%
Erosion	15%
Ozone layer	15%
Ice-melt	15%
Atmosphere	10%
Climate	10%
Global	10%

Table 12. Percentage of respondents who mentioned each node (Interaction with OA)

Public respondents were specifically asked if they could imagine an interaction between OA and climate change towards the end of the interview. Prior to this, few respondents had mentioned that this was a possibility. Two respondents said that the climate may interact; for example, if it was hotter there may be less water. While the majority of people thought that climate change and OA would interact, two respondents were unsure climate change was an issue at all with one being fairly certain that it did not exist (consistent with other work on general 'climate scepticism' (Poortinga, Spence, Whitmarsh, Capstick and Pidgeon 2011). A number of those who agreed that there was an interaction said that it was obvious that the atmosphere and oceans were connected and there would be changes in the environment:

> *"Well I'm going to say yes just because there's that cycle isn't there of…water, our seas, evaporation into the sky and down and everything that we do I suppose whether it's flushing our toilet."* – Charlotte (49, Training Co-ordinator)

The other interactions in the model were brought up by respondents earlier in the interview. Pollution was a prominent node considered by the public sample to interact with OA. Some people thought that marine pollution may affect marine life in the same way that air pollution affected land-based life. This was also linked to acid rain with numerous respondents who thought this would become worse as further pollution

entered the water cycle. Some people talked about the natural cycle and how the ocean and air interacted (including the water cycle) with one person who was hopeful that this would be self-cleansing of both components. The ozone layer was also brought up as two respondents considered the possibility that it may affect the water cycle or it was all just a natural phase.

Sea-level rise was also thought to possibly interact with OA however this was not explained by those who mentioned it. One person thought it may result in soil acidity altering if there was more flooding. Additionally, erosion was mentioned by a few respondents as possibly combining with OA or simply worsening erosion.

Lastly, two nodes were mentioned here that are also found in the expert node; temperature and ice-melt. Temperature was understood to interact with OA in a few different ways by the public sample. One person thought that rising atmospheric temperature could cause ocean temperatures to also rise whilst a couple of respondents thought OA itself may increase the temperature of the water. Temperature was also linked to ice-melt with respondents who believed rising temperature from OA would mean more ice-melt. There was a key misconception by some respondents as shown here:

> *"I guess the ocean would probably- cause if the ocean is heating up which is another thing that it sounds like it, then it's probably more likely to dilute the polar ice into it which would probably balance it out because that's all sort of almost clean frozen water and if it gets enough of that back into it it would maybe balance itself so I could see it doing that."* – Stuart (26, Store Manager)

The way that Stuart believes ice-melt will affect the ocean is not in line with the experts. The increase in ice-melt will not cause OA to be balanced out as the oceans are diluted, since in the polar regions the melting ice will result in further uptake of CO_2 by the cold waters resulting in further acidification for this vulnerable region (Yamamoto-Kawai, McLaughlin, Carmack, Nishino, & Shimada, 2009).

RESPONSES

Responses	% of respondents (N= 20)
Regulations	65%
Individual action	60%
Technology	60%
Monitoring	35%
Catalytic converter	10%
Algae	5%
Chemical process	5%
Capitalism	5%
Nature	55%
Raise awareness	50%
Global action	45%
Factories	45%
Industry finance	25%
Alter chemistry	40%
Monitoring	35%
Waste reduction	35%
Research	35%
School Education	25%
Transport	25%
Change consumerist society	25%
Protect or help wildlife	20%
Communication	15%
Recycling	15%
Investigate cause	10%
Values	10%
Sustainable fish	10%
Trees	5%
Aid affected communities	5%
Cover the ocean physically	5%
Europe more environmental	5%
UK more environmental	5%
OA already being tackled	5%
Reduce oil	5%

Table 13. Percentage of respondents who mentioned each node (Responses). Italicised nodes represent sub-nodes of the main node 'Technology'.

As shown in Table 13, responses to OA in the public model were wide ranging with many solutions being proposed by the respondents. A large number of respondents thought legislation was important to ensure industrial emissions were limited or stopped but that legislation should be enforced appropriately. Some people felt that marine pollution or waste should be reduced including stopping ships discarding their waste and reducing drilling for oil, thus preventing possible oil leaks with any wildlife affected or at risk protected in some way. Recycling was also mentioned to avoid waste reaching landfill and potentially ending up in the ocean. Respondents also mentioned a potential impact on the economy with a belief that the government would not enforce legislation in order to protect industry. The majority acknowledged that global action

with international agreement was needed and everyone should take some responsibility but ultimately thought that the government should deal with it:

> *"Well I would guess it's the same thing that they're trying to do with the emission of polluted gases generally in industry that really governments should step in. I mean I know that there is a requirement … I think they talk a lot about doing these things and they don't do as much as they could because everything in society revolves around money these days."* – Margaret (67, Retired Civil Servant)

Many respondents felt that factories needed to stop polluting the environment and some talked about how waste should be treated to reduce emissions further. As well as being regulated, people thought that new energy sources should be developed such as renewable energy; e.g. tidal and wind power. If industry switched to these alternative energy sources they could reduce their pollutants. This included altering public transport systems or switching to electric cars or car-pooling. One person also said that transport usage on the ocean should be reduced by industry and countries should become more self-sufficient. However, a few respondents did not think that industries would change and that they would continue to use the ocean to make a profit despite the risk issues:

> *"… loath corporate nature of America, quite a lot of Europe, of this country and the drive for profit overriding absolutely everything else"* – Fiona (39, Teacher)

The majority of people believed that technology would have an important role to play. A few discussed how industrial pollution could be captured or cleaned through scrubber systems or something akin to catalytic convertors with one person who mentioned algae being used to remove carbon from water (Allan, who identified CO_2 as the main cause of OA).

As well as using technology to reduce pollution, public respondents thought it would be important to help monitor OA. Monitoring OA was seen as key so action could be taken if OA became an issue. Using technology for this purpose was thought to allow accurate and regular readings to be taken with one person saying that technology could be attached to fish to help monitor pH changes in the water.

Many people also mentioned counteracting OA (balancing the system chemically) but were wary of 'messing with nature' (Corner et al., 2013) and did not want to cause further damage:

> *"Well people could put some sort of counteractive chemical in the water but then, it's kind of messing with the natural system also. Oceans are pretty big so you would need a lot of whatever it was to put in there."* – Emma (19, Student)

Geoengineering was also included in the expert model and those interviewed shared the same concerns about the impacts of it. The potential impacts on ecosystems are unknown but may produce a negative response. Countering OA by adding alkaline such as calcium carbonate could be effective on a local scale as the ocean could store more CO_2 and buffer it, however, factors like transportation of material would make this a costly option. This approach needs further research but potentially could be one seriously considered and utilised in the future (Logan, 2010).

The majority felt that raising awareness of OA was crucial and that the topic needed to be accessible with the issue communicated more openly. Some said that environmental campaigns or advertisements could be used to raise its profile or documentaries broadcasted that were fronted by popular personalities. A number of respondents also thought that education in schools should include information on these types of risk issues. Some said that they were annoyed that there was no information readily available and they did not understand why they had not heard of it before:

> *"And so is there anything else that you want to say about it or anything perhaps we've not covered that you think's important that you'd want to say?"* - Interviewer

> *"No I don't think so. Only I suppose that the media needs to- why aren't the media making kind of more of a big deal of this really? Because you do hear the climate change kind of mentioned here and there but it's either in a Daily Mail, you're going to have to canoe to the newsagent to buy your copy of your paper. It's either in this kind of quite extreme headline grabbing attention-attention grabbing way or it's you know, kind of not there at all so why aren't we raising people's awareness of this more effectively?"*- Fiona (39, Teacher)

Many said that they would take individual action if they knew what they could do and that actions which would make a difference should be made more apparent. Two participants did say that these actions may be hard to carry out in relation to an individual lifestyle, and that perhaps the government should be pushed to take action instead. Four respondents felt that consumerism was a real issue and needed to be

tackled to try and encourage sustainability. Equally, two people thought that industries would be resistant to this suggestion as consumerism related back to the capitalist society and making a profit, which was in their best interests. Additionally, people's values were thought to be highly influential for their actions. Respondents said that trying to encourage values to change so that people had a greater appreciation of the environment and rethought consumerist lifestyles was necessary. It is unclear how 'values' were interpreted by respondents and how this change could be undertaken.

The need to communicate with the public was absent in the expert model at the time of its construction but has recently been discussed within the scientific community who are engaged in OA research. Since the original acknowledgement that informing the public about OA was necessary, the need for social scientists to help explore public perceptions has now been noted (see Busch et al., 2015).

In the interviews, public respondents expressed a wish to know more about OA with some who thought that the cause needed to be clarified (whether it is natural or human-made). Of course, whether this was genuine interest or social desirability (wanting the interviewer to approve of the interest expressed in OA) is hard to tell. Others thought further research into impacts was needed before action could be taken. Though this is a valid point, modelling for the future is very difficult and if action is not taken now but in 50 years' time the consequences of waiting may be severe (Duarte, 2014). One person hoped that action was already being taken to reduce the impacts of OA while another respondent felt that affected communities should be helped and given some sort of relief aid if it was a serious problem for the community.

So far, the solutions covered by respondents are human responses and how technology may play a part in reducing the impacts of OA. Like the expert model, there was an environmental responses theme which explored how the environment and natural changes may ameliorate OA. The oceans were seen as able to balance themselves out if left alone. In general, the oceans were perceived as vast with pollution being spread from a local scale to a global scale. Some saw this pollution as becoming diluted or eventually dispersed by the currents so it would no longer be an issue. Respondents also mentioned the migration and evolution of organisms with some citing organisms that currently survive well in areas of high acidity so believed that it may be possible for other kinds of organisms. There were a few people, however, who thought that OA would happen too fast for organisms to evolve in time. These responses were also

mentioned in the expert model though ocean circulation was seen as more of an interaction with OA. The idea that the ocean can naturally disperse OA was common because of the vastness of the ocean. The circulatory patterns of the oceans are complex and are cited by respondents as another aspect which makes the impacts of OA more difficult to predict.

Though responses do not specifically refer to CO_2 reduction as the main way of responding to OA, many saw reducing pollution and agreeing on targets internationally as one of the main ways of dealing with this risk. Only a few people mentioned carbon dioxide reductions directly with one person who believed that more trees should be planted to try and rebalance the system. Within the public sample, many people linked OA to something caused by marine pollution resulting in responses geared towards solutions to this issue rather than OA. The respondents were given information about the risk of OA but this was towards the end of the interview session. Once they had read the information many felt that they had answered consistently with the information on OA that was provided (Appendix C and that their responses were based on this.

The concepts described so far only explore knowledge aspects of OA including many nodes that are inconsistent with the expert model. The remaining non-knowledge aspects of the public model (Figure 9) will now be described. As already stated, these themes are important when considering how future risk communications should be designed.

4.5.5 Non-knowledge aspects of OA

RISK OF OA

It is important to note that the percentages shown in this section only reflect how many people discussed a particular node and that nodes with higher percentages were not necessarily more important in a particular theme than those with lower percentages. All nodes should be considered important. Though it could be argued that more popular nodes show evidence of more salient beliefs, this is only a small sample so all figures here must be taken with caution.

Risk of OA	% respondents (N= 20)
High importance	50%
Low importance	30%
High personal risk	20%
Low personal risk	60%
High societal risk	45%
Low societal risk	40%
Human nature	40%
Day-to-day life	40%
Only care if directly affected	30%
Scepticism	5%

Table 14. Percentage of respondents who mentioned each node (Risk)

Table 14 shows that many public respondents thought that OA sounded like an important environmental risk issue; however, OA was not a priority risk for respondents though some felt that people should be aware of it. Many did not yet see it as a risk or felt that it was a low risk (partially because they had not seen it in the media so they were unaware of it). Daily life was more important to people (for example finances and personal relationships are the focus of day-to-day life) with some who said that people may only care if there was a direct effect on them such as when the person lived in an affected place. The term 'human nature' was used in a negative way and was seen to play a role in responses and engagement to OA as society was seen as not caring about OA, with people just carrying on with daily lives. The personal risk of OA was low for the majority of respondents as they had no link to the sea or it was distant from them. They also discussed the visibility of the ocean and OA, and said that ocean visibility was important and that OA cannot be seen on the surface like rubbish can:

> *"I don't think people have an interest in it to be honest so they don't think about positively, it doesn't hit their radar… I don't think people know much about it or even if they hear snippets of anything to do with the oceans it's just removed from day-to-day life. For most people."* – Philip (55, Development Worker)

EMOTION

The majority of people were concerned about OA as seen in Table 15. All associated emotions were negative (e.g. anger, guilt, hopelessness, frustration) similar to Capstick et al. (2016) who found a main theme of negative associations when

respondents were asked to give spontaneous image associations with the term OA (see Table 8 for images).

Emotion	% Respondents (N= 20)
Negative	100%
Don't care	70%
High concern	65%
Low concern	15%
Anger	15%
Guilt	15%
Frustration	10%
Safety	5%
Hopelessness	5%

Table 15. Percentage of respondents who mentioned each node (Emotion)

Respondents were also asked to rate positivity or negativity towards OA with all but one rating OA negatively and there being a need for action.

KNOWLEDGE AND INFORMATION SOURCES

Most respondents felt that they did not have enough scientific knowledge to answer questions confidently during the interview. Responses included feeling ignorant or that OA sounded complicated. Many said that their answers were not based on scientific knowledge but were 'off the top of their head'. The majority were interested in the issue and wanted to know more about it though a few said it was easy to ignore information:

> *"I think perhaps it's something complicated to do with pollutants in the air somehow getting into the sea. I don't know. But I don't- because I don't really have like a very good scientific knowledge sort of. It does strike me as a negative thing."* – Joe (24, Unemployed)

Many said they would ask experts for more information especially about the impacts, rate of occurrence and solutions including what the best solution would be and what they could personally do to help mitigate OA. The greatest source of information for people was the internet with many also looking at news websites and some looking at TV news (see Table 16); many said that newspapers had to be considered carefully (due to bias).

Information source/Trust	% respondents (N= 20)
Internet	70%
News	45%
Books	40%
NGO	30%
Information bias	25%
Low media coverage	25%
TV	20%
Research	15%
Family	15%
Work	5%

Table 16. Percentage of respondents who mentioned each node (Information sources/Trust)

Respondents were more likely to trust science magazines and research. The majority felt that scientists were sure OA is happening but that they do not know the effects or a suitable solution which seemed to be counter to the results of Capstick et al. (2016) who found that people felt scientists were unsure about what was causing OA but knew about the impacts and solutions to a greater extent. This may be because public respondents felt that they themselves were aware of a wide range of impacts and could respond to these questions much more readily, but they found it difficult to answer questions about the possible causes of OA. It is also possible that they thought the varied impacts may make it hard for scientists to establish the main issues. Respondents may also have thought that there could be a wide range of factors which may be causing OA. In the survey, participants had a multiple choice response rather than having to create something out of their own head. Again, the range of possible causes may explain why in the survey respondents thought scientists may not be sure what the main cause of OA could be.

4.5.6 Social Representations Theory

Social representations theory provides a suitable way of considering OA and how people have conceptualised this risk (Smith & Joffe, 2013). How people engaged with OA and tried to understand it can be explored by focusing on the first thoughts and images elicited from respondents'. Social representations theory states that a range of symbols and images found in people's social-cultural sphere help them to make sense of an unfamiliar risk such as OA. As many respondents used the term itself to produce mental imagery and think about the impacts of OA this helps to explain how they formed their mental model. OA appears to have been anchored primarily through the emotional response to the term, as it was perceived as a negative risk by all of those interviewed. A range of emotions were mentioned including feelings of concern, anger

and guilt with regards to the risk of OA. The association of OA to other environmental risk events such as acid rain and pollution helped people to objectify OA by drawing on a familiar mental representation allowing them to concretise the risk. These misconceptions mainly on the cause and process of OA have also been seen in other work (Capstick et al., 2016; Danielson & Tanner, 2015) so are important to understand when seeking to improve understandings of OA in the future.

4.6 Summary

The findings in this chapter will be discussed in more detail and in relation to the literature in the final chapter. Following on from the construction of the expert model, the public interviews that were conducted allowed for a thorough analysis of how OA is perceived by members of the public. The content analysis showed that those members of the public that were interviewed only shared some beliefs and knowledge about OA with the experts. A thematic analysis clearly identified a range of other beliefs and ideas that helped public respondents form their mental model of OA. There are clear differences and similarities between the expert and public mental models. Those interviewed in the public sample were trying to make sense of an unknown risk based on any knowledge they deemed to be relevant but also through word associations, affect and links to other risks with only two respondents who stated that they had heard of OA. Most of the participants interviewed were trying to make sense of an unfamiliar risk by familiarising it through anchoring and objectification (Moscovici, 1984).

A key factor found in the public model was the feeling of strong negative emotion associated with OA. This was not knowledge-based and indeed respondents made it clear they were constructing their thoughts off the top of their heads and not using 'correct scientific knowledge'. This strong link to negativity came from word association as well as images that respondents produced. It would appear that the affect heuristic played an important part here (Slovic et al., 2007) as images produced of acid rain, the destructiveness of acid and corrosiveness, resulted in a strong negative response to OA. Though there was a general sense of negative affect when people were talking about OA, for many this was linked to the terminology. "Ocean acidification" did not produce any positive feeling or associations.

The public sample recognised that human activity is causing OA with a few people attributing it to natural causes and changes in the environment. The majority of the sample thought that pollution was the main cause of OA with few linking it to carbon dioxide. Acid rain was also mentioned as a possible cause of OA. When respondents were trying to explain the process of OA, word association and imagery was crucial with many who determined that there must be a change in pH in the ocean. Within the expert model it is clear that carbon dioxide is the main cause of the current OA event and it is a result of a simple chemical reaction.

With regards to the impacts of OA the public and the expert groups did highlight a selection of similar impacts. For example, both said that fisheries and possibly the economy would suffer as a result of OA, however, there were some inconsistent points such as the effect on human health. The main difference was the emphasis of environmental impacts in the expert model but the emphasis in the public model was of socioeconomic impacts. The interactions of OA were the most similar part of the model between the two groups. Climate change in particular, was seen as most likely to interact with OA. Though some beliefs were shared between the expert and public group, the way in which these would interact were confused (e.g. ice-melt).

The last part of the expert model, responses, had some shared beliefs. In the public model many focused on reducing pollution though there were some who thought that carbon dioxide should be reduced. However, the latter was not cited as the main response. The public mainly focused on raising awareness which was not in the original expert model but has become more prominent in recent discussions.

Finally, the other components of the public model of OA (emotion, risk of OA, and information sources and trust) need to be taken into account. In order to effectively engage the public with OA, the construction of these mental models of OA will allow concepts to be explored on a wider scale within the population.

Chapter 5: Public Survey Methodology and Results

Chapter Overview

In this chapter, the third and final research phase is covered, in which a survey was administered to a wider UK population to determine how widespread beliefs identified in phase two were in this sample. The first section of this chapter will outline the survey design and how this was developed in line with the mental models approach as well as sampling, ethics and data collection. The second part of the chapter will describe the data analysis that took place including the descriptive data and also exploration of particular relationships. For example, the acceptability of ocean acidification is assessed and whether this is influenced by perceived risks and benefits or risk perceptions more generally. This third empirical phase aims to show how prevalent public perceptions of ocean acidification are, how they compare to public perceptions that were identified in the previous stage of this research as well as how these link to expert perceptions. Through the analyses carried out it should be possible to identify how people make sense of risk and in particular, the emerging risks such as ocean acidification.

5.1 Rationale

Following the mental models process outlined by Morgan et al. (2002), the survey phase is a critical stage in assessing public perceptions of OA. Measuring the prevalence of beliefs in the wider population will allow for effective risk communications to be created in future work. Through conducting this survey two main questions are explored:

Q1) How prevalent are the interview respondents' conceptualisations of OA in the survey participants?

Hypotheses:

- There will be low knowledge and awareness of the issue with the main cause or the most suitable response to reduce OA not identified
- OA is expected to be perceived as a negative risk issue and to produce a strong negative affect in participants

Q2) How do the beliefs, understandings and knowledge of the wider population compare to the scientific consensus and expert conceptualisations of this risk?

Hypotheses:

- We expect to see clear knowledge gaps in those surveyed with the cause and key solution to OA around carbon emissions not chosen as the main response
- It is expected that participants will identify the same impacts and interactions mentioned by the experts

As well as answering these broad research questions there are numerous more specific hypotheses that will be examined and are included in the survey overview.

5.2 Survey Methodology

Quantitative surveys are very common when measuring beliefs about environmental issues (see review by Capstick et al., 2015) as they are best for establishing broad constructs and assessing trends over time. However, framing of questions will affect responses and surveys cannot always explain why certain views are held. If using surveys to track trends over time, it is imperative that samples and questions are identical to allow for accuracy when determining what has changed and why (Pidgeon, 2012). Using mixed methods allows for a more complete picture; the survey data

allows for a general trend to be identified but the in-depth interview data provides an insight into why such a view is held. Triangulation, in which qualitative and quantitative methods are combined to study the same thing (Balnaves & Caputi, 2001) is exceptionally useful for exploring highly unfamiliar topics such as OA. It allows for each set of research findings to be corroborated and to establish how unfamiliar risks are understood from each perspective.

Survey research requires a thorough designing and testing process to ensure that the final product is clear and measures what it is supposed to measure. In this survey, jargon and technical terms were an issue with terms having to be simplified. Carrying out the survey online was seen as the best way to both target a nationally representative sample and collect data quickly. A web-based survey is a cost-effective method as it allows large sample sizes and reliable data to be obtained quickly though using a survey panel company can be costly (Hewson, Vogel & Laurent, 2016). The main issues with conducting a survey online are that participants are self-selecting once they receive an invitation to complete it and certain groups are less accessible such as those living rurally, the less educated and older people (Neuman, 2011). Overall, this was the best approach for this piece of work and the sampling strategy ensured a varied demographic which will be discussed later on.

5.2.1 Survey Design and Structure

It was important to incorporate the concepts identified in both the expert model and the public interview sample whilst designing the survey. As this piece of work was exploratory it was important to ensure that the full public mental model was visited in the survey with questions on each main aspect such as the causes, impacts and responses to OA. As well as measuring knowledge levels, other important constructs such as affect, concern and general perceptions on climate change were also included. The survey was developed with reference to the interview data as well as the UKOA survey items (Capstick et al., 2016). Items were also taken from other sources and will be mentioned as appropriate in the survey outline. Questions were clearly written and checked with experts to ensure that they were accurate, particularly for the definition and description of OA. As this is an unfamiliar risk issue a ‘no opinion’ option was not included as a possible response for the knowledge items, to avoid reducing the number of participants providing a meaningful opinion (Schaeffer & Presser, 2003). The knowledge items were asked prior to participants receiving information about OA

and were asked at the start of the survey. These questions were critical as they were asked to highlight how prevalent the interview findings were with the survey responses. It was important to ensure responses were as meaningful as possible despite the fact that participants had not been given any information so a 'no opinion' response was not included. Satisficing theory suggests that if the 'no opinion' option is presented and is selected it may not be an accurate opinion of the participant. Selecting the 'no opinion' response option may simply be a way to reduce the cognitive work required to formulate a meaningful response. Krosnick et al. (2002) found that those with the lowest level of education were also most attracted to the 'no option' response. Inclusion of this option may not necessarily help data quality, but will possibly reduce the effective sample size.

Appendix E contains the full survey questionnaire. It was 42 questions long and took participants 20 - 30 minutes to complete and consists of the following parts:

Introduction and Consent

The welcome page contained details of the study, how the data would be handled and stored, as well as contact details of the researcher, supervisor and ethics committee. This was followed by consent information and a box to tick if participants were willing to participate.

Demographic questions (Items 1 – 9)

Participants were asked to give their age, gender as well as their highest level of scientific qualification and political affiliation. They were also asked to specify if they were a member of any environmental groups, how far they lived from the coast and their media usage. These questions were to ensure a wide range of people were surveyed which enabled comparisons across groups and thus could aid the development of communication guidelines.

Section 1 (Items 10 – 18)

Q10: Ocean Risk Issues – This multiple-choice question assessed the main issues that people associated with the ocean with OA expected to be a low risk issue to the majority of people. Participants were given nine options including

‘Other’ and could select as many as they wished or just the final option ‘There are no issues’.

Q11 - Q12: Awareness of OA – The first two items were asked to establish self-reported knowledge with the first item asking whether participants had heard of OA and the second item asking how much participants thought they knew about OA (choice of four responses from ‘I had not heard of OA before taking part in this survey’ to ‘I know a fair amount about OA’. Low awareness and self-reported knowledge were expected in the sample.

Q13 – Q18: Knowledge of OA – This set of items was to assess what knowledge the participants had of OA including the causes, impacts, responses and interactions. OA knowledge is expected to be poor, however participants may determine the correct responses as shown in the findings of Capstick et al. (2016). These items are asked to compare with expert knowledge and determine which themes are understood and which are not, in order to help understand what information people really need to know. A scale of ‘Strongly Agree’ to ‘Strongly Disagree’ was used for most of these items. The first had 11 possible causes of OA for participants to select whether they agreed or not if something was a cause of OA. The next item allowed participants to select one of the 11 possibilities as the one they thought most likely to be the cause of OA. The third item had 15 possible consequences of OA and used the Strongly Agree/Disagree scale. The fourth item asked participants what they thought was the main consequence of OA and to select one of the choices. The fifth item asked participants to select what they felt would be the most effective at reducing OA out of 12 possible choices. The final item in this part was about interactions and contained seven possibilities which participants were asked to rate on a Strongly Agree/Disagree scale. A ‘Don’t Know’ response was also permitted in this particular item.

Section 2 (Item 19)

Q19: Concern – This item was asked to determine the level of concern about OA to compare with the level of concern in climate change. Participants had six possible options ‘Not at all concerned’, ‘Not very concerned’, ‘A little

concerned', Fairly concerned', 'Very concerned' and also a 'No opinion' option.

OA Information (Items 20 – 22)

Participants were given a brief piece of textual information about OA in order that participants have enough information to answer the following questions.

Q20: Policy – This item assessed levels of support in various policies to deal with greenhouse gases. 18 possible policies were given with participants asked to decide if they would support them ('Definitely Yes', 'Probably Yes', 'Unsure', 'Probably No' or 'Definitely No').

Q21: Values – This scale assessed cultural worldview and environmental identities to see how these would influence risk perceptions of OA. Participants were asked to rate each item on a five point scale (Strongly Agree/Disagree). Three items were included to assess egalitarianism and three items to measure individualism. These items were taken from Capstick and Pidgeon (2014a). Four items asked about participants environmental identities taken from Whitmarsh and O'Neill (2010).

Section 3 (Items 22 - 24)

Q22 – 24: Information Sources and Trust - This section examined where people got their information from and how trustworthy numerous sources were thought to be. It was expected that most people would refer to social media, TV and press media for their information. Trust in scientists, family and friends would be high with trust in the media and industry lowest. The first item asked participants to select one response out of 11 options as to their most trusted source of information for OA. The second item asked which source participants would most likely use out of the previous options. The third item allowed participants to rank the 11 sources of information from most trusted to least trusted, using drag-and-drop.

Section 4 (Items 25 – 35)

Q25 – 27: Affect - Level of affect and emotions elicited by OA were explored with a strong negative response to OA predicted. The first item assessed how positive or negative participants felt about OA on a 1 (extremely negative) -

10 (extremely positive) scale. The second item measured how strongly a range of emotions (15 in total) were felt on a 1 (not felt it at all -10 (felt it extremely) scale. The third item asked participants how OA made them feel with five options ('Very bad', 'Bad', 'Neutral', 'Good', and 'Very good'). These items were taken from Böhm (2003).

Q28 – 29: Psychological distancing –The first item focused on spatial and social distance and had four statements with a Strongly Agree/Disagree scale. The next item measured temporal distance with nine options ranging from 'We are already feeling the effects' to 'Never' and also included 'Don't know' and 'No opinion'. This item was taken from Spence et al. (2012).

Q30 – 34: Risk – These items assessed how much of a risk OA is perceived to be and what the benefits are perceived to be, as well as how acceptable OA is. OA is predicted to be seen as a low risk to society with those who are concerned about OA perceiving a greater risk from OA. These items were adapted from Pidgeon et al. (2005).

Q35: Place attachment – This item measured how attached people feel to the ocean by asking them to rate on a five-point scale how strongly they agreed or disagreed with eight statements such as 'No other place can compare to the ocean'. It is expected that those who feel more attached to the ocean will be more concerned about OA and will perceive OA as a local risk issue. Items were adapted from Williams and Vaske (2003).

Section 5 (Items 36 – 42)

Q36 – 42: Climate Change – These items explored what climate change beliefs were, including levels of concern, information sources and trust as well as general risk perceptions of climate change. This measure will allow for comparisons to OA in various aspects. Items were taken from Spence,

Venables, Pidgeon, Poortinga and Demski (2010), and Corner, Capstick and Pidgeon (2014).

Final page

A debrief page at the end of the survey thanked participants for their time, reiterated the purpose of the study, provided further details of the aims and hypotheses, and included contact information should participants want to get in touch.

5.2.2 Data collection

SAMPLING AND RECRUITMENT

The questionnaire was piloted with colleagues, friends and family in February 2016 to check for unclear terms or instructions and to get feedback on survey length, ease of use etc. Approximately 20 individuals piloted the survey, with all pilot data remaining entirely anonymous. Based on the feedback some of the terms were simplified or clarified with the values scale response options shortened to exclude 'don't know' and 'no opinion' response options as these would have provided no useful information and everyone should be able to give a meaningful response to these items. The information sources response option 'media' was also changed to more specific forms such as 'the internet'.

Upon completion of the pilot phase, the survey was administered to a sample of participants recruited using Maximiles, a recruitment agency that specialises in online panels. Data was collected in March 2016. All participants were over 18 and resident in the UK. Recruitment involved participants already held on a confidential database by the market research company, as is standard practice, and in accordance with the Market Research Society Code of Conduct. Participants themselves can then decide whether or not to take part and are remunerated via an arrangement with the market research company. This is usually either as a small cash payment for participation in several studies, or rewards such as vouchers for stores. Participants are only able to take part in a select number of surveys a month to ensure that they are motivated to complete them appropriately, and to ensure that they receive payment.

Qualtrics software was used to design the survey as it had a good selection of question formats that enabled the survey flow to be adjusted as needed, allowed for timed pages to be incorporated and could also be linked up to the recruitment agency. Within Qualtrics, quotas were set on certain demographics (gender, age, political party

affiliation) to ensure that the demographic profile was as varied and as representative of the UK as possible. For a full breakdown of the demographics and comparison to national statistics see Appendix F. In the survey data collected, men were overrepresented in the sample (54% compared to 46% of women). For level of education those with a degree or above were underrepresented as 32.5% of the sample had at least a degree (22.7% first degree and 8.2% PG) with 67.5% educated to below degree level (11% no formal qualifications, 29.4% GCSE/O-Level/Standard Grades, 17% A-Level/Higher/BTEC and vocational/NVQ at 10.1%). With regards to age, those aged 55 + were slightly overrepresented (38.7%, 61.3% under 55) in comparison to the national profile. The breakdown of age groups was as follows: 18 – 24 (6.3%), 25 – 34 (18.2%), 35 – 44 (17.8%), 45 – 54 (19%), 55 – 64 (15.9%), 65- 74 (8.8%) and 75+ (14%).

As mentioned earlier there are possible issues with using an online survey, the main one being the representativeness of the sample as well as lower researcher control (Hewson et al., 2016). However, there are great advantages as well, such as being a time and cost-effective method of obtaining large sample sizes and reliable data.

5.2.3 Ethical considerations

No ethical issues were foreseen with this well-used methodology. Using a consent button has become more accepted for this methodology though it is impossible to verify that participants have read and understood the information for both the consent statements and the debrief (Hewson et al., 2016). However, online panels are regularly used by research companies and participants' details are held confidentially on their databases. Participants are made aware of their right to withdraw at any time and can decide not to take part in the questionnaire at their own discretion, which is reiterated in the consent form.

It was not anticipated that any of the material within the questionnaire was likely to cause distress or offence to any participants. Any of the questions could be omitted should the participant not wish to answer them. The questions that asked for participants' demographic details could be left blank if the participant did not wish to fill in this information.

All data is held anonymously and cannot be linked back to any individual person. At no point will the researcher know the names or addresses of participants.

5.3 Data Analysis

Unusable participants were screened out prior to data analysis. First, data were screened for responses that were completed abnormally fast. The median average time for the survey was 30 minutes and when completing the survey myself, whilst barely skimming, it took 8 minutes. Removing those who took less than 9 minutes (30% of the average time taken) meant 81 participants were removed from the analysis. This brought the sample down to 956 participants. Two additional participants were removed as one had not answered any of the theoretically relevant questions, with the other one answering all items the same. The final sample was 954 participants.

Data were screened for any abnormalities, outliers and violations of normality allowing for suitable tests to be chosen. Analyses conducted included correlations and multiple regressions as well as factor analyses for scale development.

5.3.1 Descriptive Statistics

For the complete set of percentages of the data see Appendix G. In this section, the survey findings will be shown and compared to both the expert model as well as the public model.

AWARENESS AND KNOWLEDGE OF OA

As seen in the public interview data and previous surveys (Capstick et al., 2016), awareness of OA was predicted to be low. The current survey shows an increase of self-reported awareness over the survey conducted in 2014 by Corner and colleagues with 29.4% saying that they had heard of OA, an increase of almost 10% (see Table 17).

	%	%
Have you heard of ocean acidification before today?	**2014**	**2016**
Yes	20.5	29.4
No	79.5	70.6

Table 17. Change in self-reported awareness of OA from 2014 to 2016

There was an increase in media coverage when the Summary for Policymakers on ocean acidification was released by the IGB programme and others (IGBP, IOC,

SCOR, 2013) with the BBC news running the headline 'Emission of CO_2 driving rapid oceans 'acid trip'' (BBC News, 2013). Corner et al. (2014) released their report shortly before the CBD synthesis report on the impacts of OA (Aze et al., 2014) with a story appearing on the BBC News titled 'Science chief warns on acid oceans' (BBC News, 2014). The Guardian also wrote a piece when Capstick et al. (2016) released the completed study about the low awareness in Britons about OA (The Guardian, 2016). As well as the examples given above, social media is also worth mentioning as Twitter and Facebook also drove the conversation about OA (for an overview see the report by Upwell, 2015).

Before they completed the knowledge section of the survey participants were asked to report their perceived level of knowledge. A Spearman's Rho correlation ($r_s = .174$) showed a significant positive correlation with those reporting high levels of knowledge also scoring higher in the knowledge section (though this was a very low correlation).

To explore knowledge of OA, participants were asked questions about the causes, impacts, interactions and solutions to the risk of OA. In this section, each part of the expert model with the public interview data overlaid will be compared to the survey findings enabling us to see how prevalent certain beliefs are and how these compare to the scientific consensus. Before presenting these findings it is important to set out which knowledge items (Q13 – Q18) came from the public and expert interview data and which came from the survey conducted by Capstick et al. (2016). Some items from the earlier survey were reworded however the items in Table 18 below came directly from the interview data. Items on interactions and responses were entirely from the interview data. Items based on the expert interview data will be preceded with (E) and public data with a (P):

CAUSES
(P) Acid rain entering the ocean
(P) Pollution from chemical and industrial waste
(E) Climate change altering wind patterns and ocean circulation
(E) Carbon dioxide leaks from carbon capture and storage systems
(P) Litter (such as plastics) in the ocean
IMPACTS
(E) Damage to the marine food chain
(P) Skin damage from contact with ocean (e.g. swimmers)
(P) Impact on food availability for people
(P) Tourism and leisure will be affected negatively by ocean acidification
(P) Availability of drinking water impacted
(E) Extinction of some marine organisms
(E) Natural systems affected (such as weather patterns and currents)

Table 18. Items developed from public and expert interview data. **Items marked with (E) are from expert interview data and items marked with (P) from public interview data.**

CAUSES OF OA

The cause of OA is clear with a scientific consensus that the main cause of OA is the increase in CO_2 emissions (and concentrations) with other contributors mentioned as seen in Figure 10. During the public interview a range of causes were mentioned resulting in a list of possibilities being asked in the survey. Participants were asked how strongly they agreed or disagreed with a number of causes of OA.

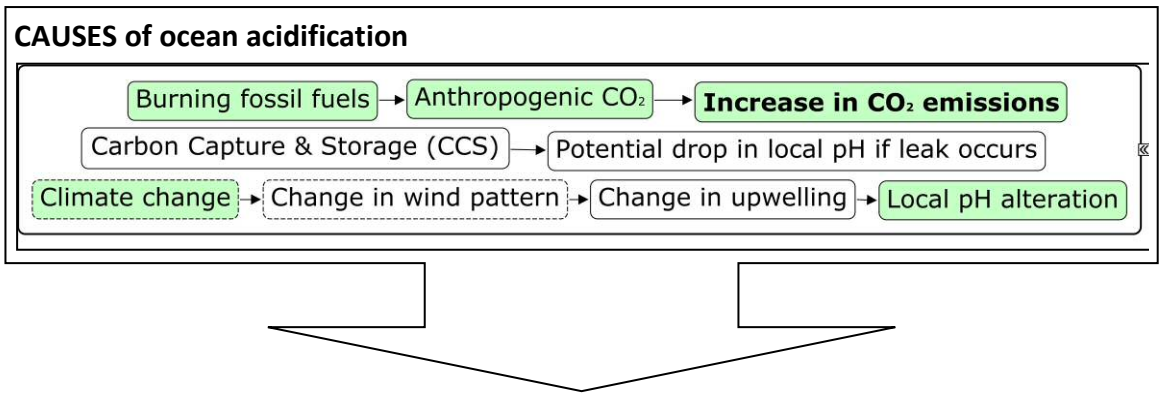


Figure 10. Overlay of public interviews on expert model of OA (Causes)

Figure 11 and Figure 12 show the possible options given to participants and how they responded. In Figure 11 the causes that are in line with the expert views are shown and in Figure 12 causes that are seen as incorrect are shown. Out of the 11 options only three were acknowledged as causes of OA with the other eight not appearing in the expert model as seen in Figure 10.

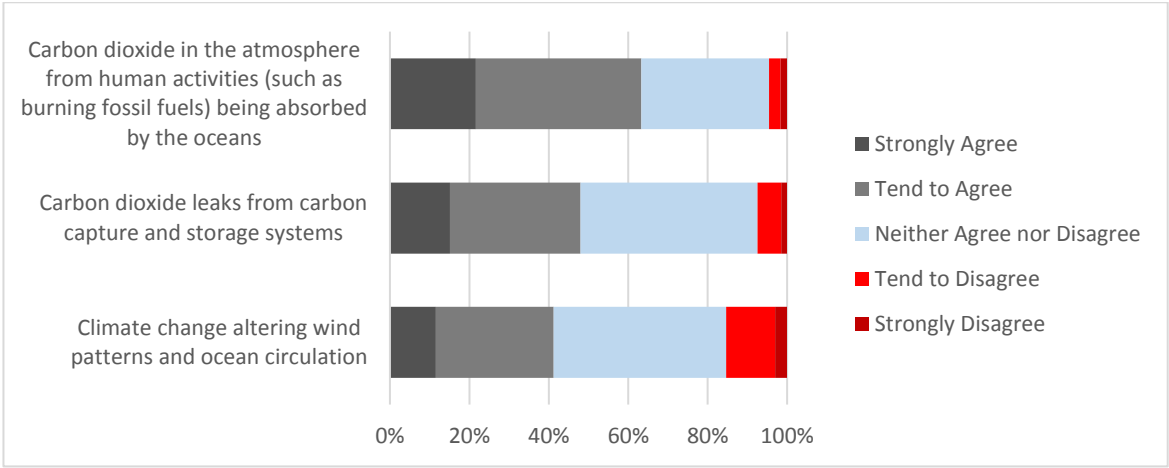


Figure 11. Response options to scientifically accurate statements about the causes of OA from survey data

It is clear that a large proportion of participants could correctly identify CO_2 as a cause of OA (63.3%) however this is smaller than those who agreed that pollution from chemical and industrial waste, pollution from ships and litter were more likely to be

causes of this risk issue (all 65% and over in agreement with these as causes of OA). In fact, all of the incorrect statements (aside from natural cycles of change in ocean chemistry) were thought to be more likely causes than CO_2 leaks from CCS and climate change altering wind patterns and ocean circulation.

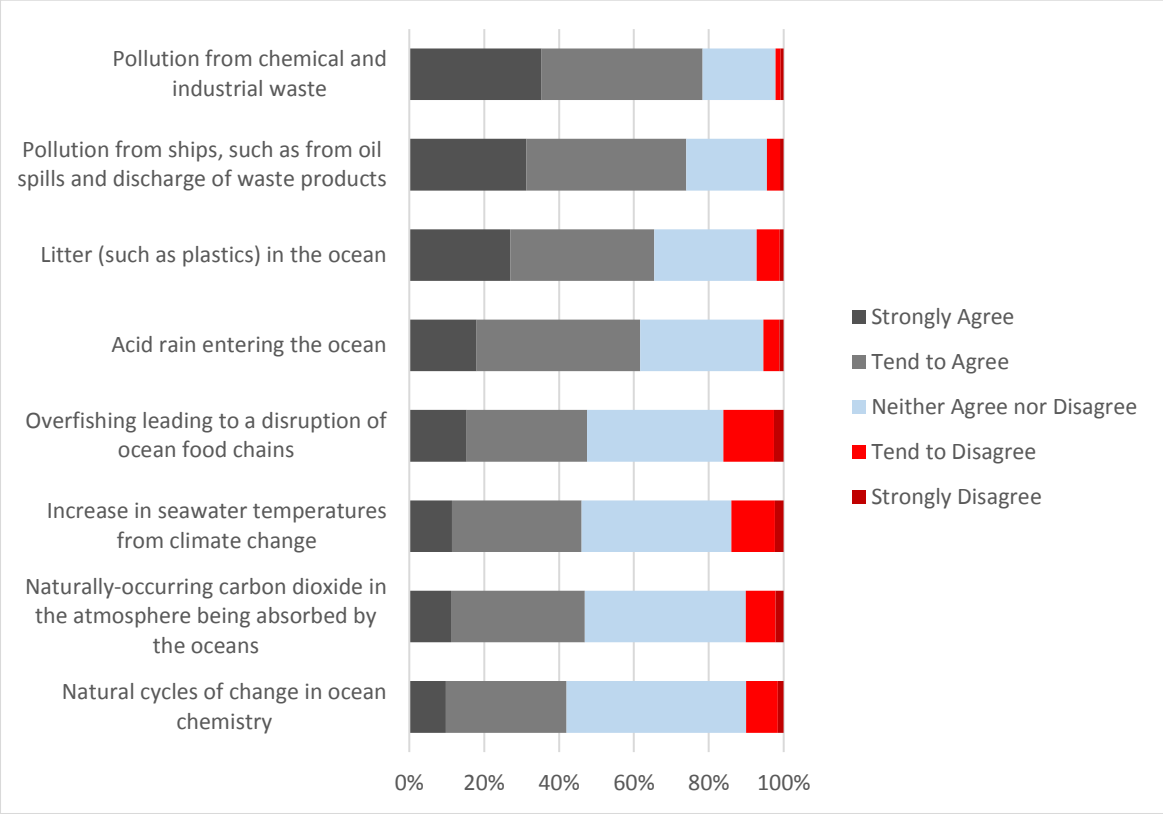


Figure 12. Response options to incorrect statements about the causes of OA from survey data

To understand the prevalence of agreement with the possible options given between the expert model and the public model each option will be briefly summarised:

CO_2 in the atmosphere from human activities (such as burning fossil fuels) being absorbed by the ocean – This is seen as the main cause of OA. 63.3% of survey participants agreed this was a cause of OA with only 4.5% disagreeing with this.

CO_2 leaks from CCS – Another accepted cause of OA amongst the experts though only a local effect expected. Amongst the survey participants 47.9% agreed this would cause OA, 7.5% disagreed with this.

Climate change altering wind patterns and ocean circulation – The final recognised cause seen in the expert model. 41.2% agreed this could be a cause of OA with 15.4% who did not agree climate change would cause OA in this way.

The remaining statements are not perceived to be contributors to the current OA event:

Pollution from chemical and industrial waste – 78.3% survey participants agreed that this type of pollution was the cause of OA with only 2.2% disagreeing with this statement.

Pollution from ships, such as from oil spills and discharge of waste products – 74% of people thought this was a cause of OA. 4.5% disagreed that this was a cause of OA.

Litter (such as plastics) in the ocean – 65.4% of survey participants agreed that litter was a cause of OA and 7.2% of the sample disagreed.

Acid rain entering the ocean – 61.7% agreed that acid rain was likely to be a cause of OA with only 5.5% disagreeing that it was a cause.

Overfishing leading to a disruption of ocean food chains – 47.5% of participants agreed that overfishing was likely to be a cause of OA, 16.1% disagreed.

Increase in seawater temperatures from climate change – 46% agreed that seawater temperature was a cause of OA with 14% who disagreed this was a cause of OA.

Naturally occurring CO_2 in the atmosphere being absorbed by the oceans – 46.8% of survey participants agreed that this was a cause of OA with 10.1% disagreeing that natural CO_2 was a cause of OA.

Natural cycles of change in ocean chemistry – 42% of people thought that this was a cause of OA with 10% disagreeing.

From the low level of awareness of OA found in the survey sample, it is not surprising that there were misconceptions around the causes of OA. As well as asking participants about each of these possible causes individually, they were also asked about what they thought was the main cause of OA out of the possibilities they had just rated. The results found that CO_2 was seen as the second main cause of OA (18.5%) after pollution from chemical and industrial waste which accounted for 24.9% of the sample. The third most cited cause of OA was pollution from ships according to 13.1% of those who completed the survey. For a complete overview see Appendix G (Q12 – 17 for the section assessing knowledge).

IMPACTS OF OA

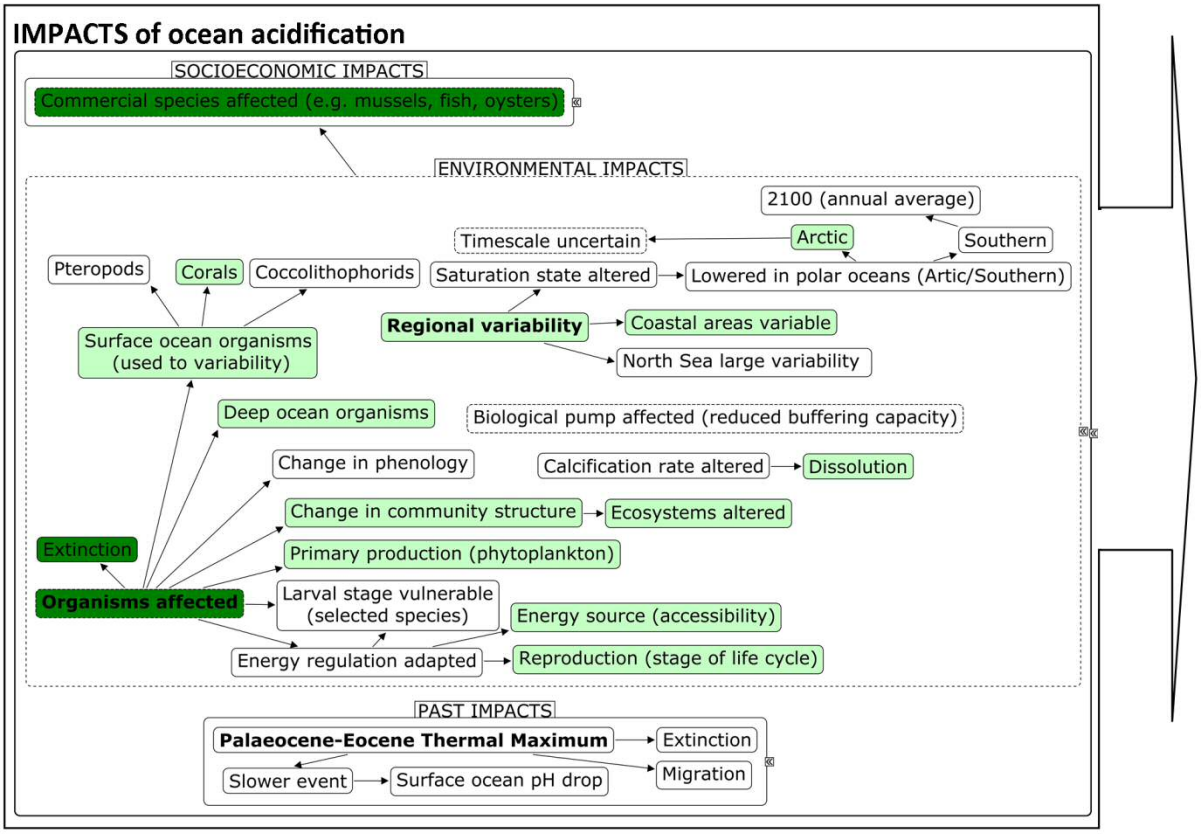


Figure 13. Overlay of public interviews on expert model of OA (Impacts)

The largest and most uncertain part of the expert model is the impacts that may occur from OA. There are a wide range of possible impacts with some more certain than others. In the public interview phase it was clear that many of the respondents felt that organisms would be affected by OA in a myriad of ways (as seen in Figure 13). The experts expected these impacts to knock-on to society as well, which was also mentioned by the public respondents in the interviews. In the public survey it was only possible to provide a limited number of response options which were more general, and also took into account new themes brought up in the public interviews. The possible response options were a mixture of both consistent and inconsistent ones: findings are shown in Figure 14, Figure 15 and Figure 16 before being summarised.

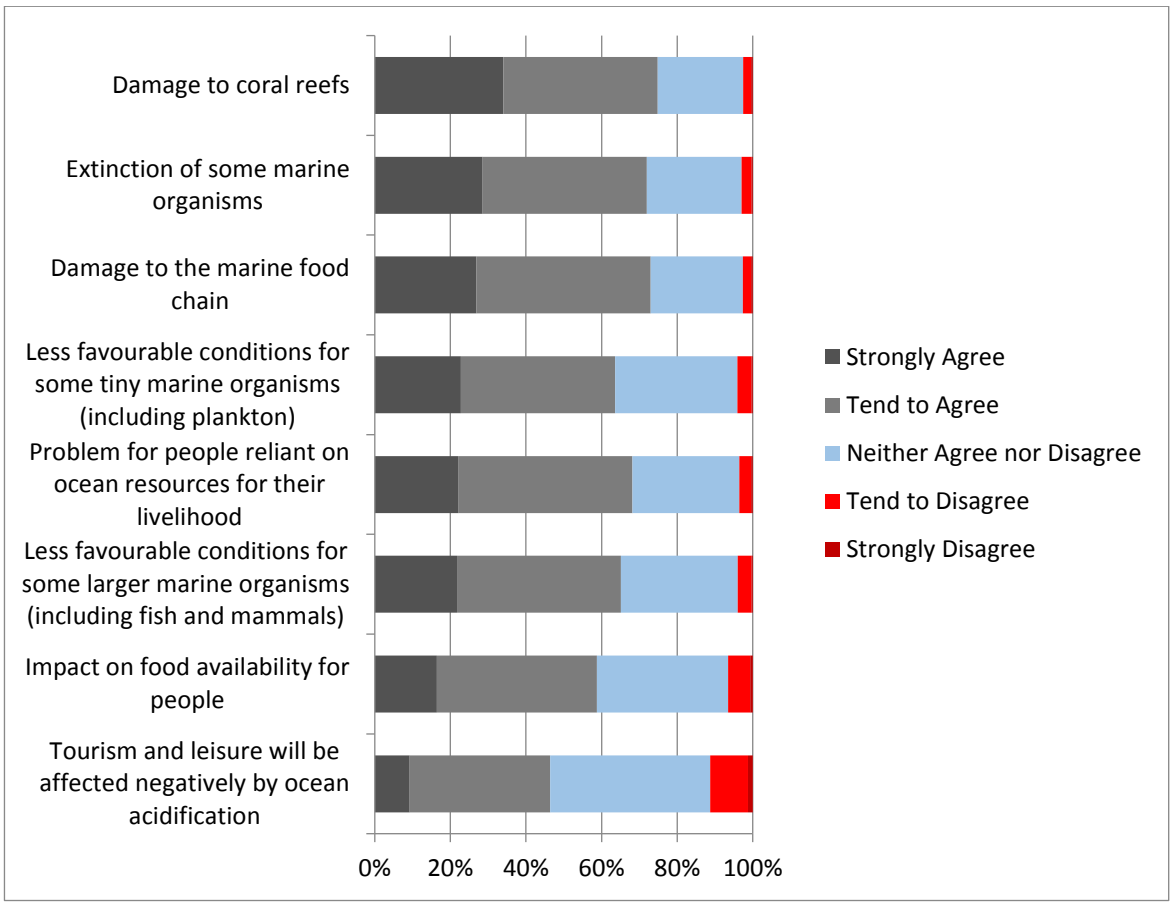


Figure 14. Response options to correct statements about the impacts of OA from survey data

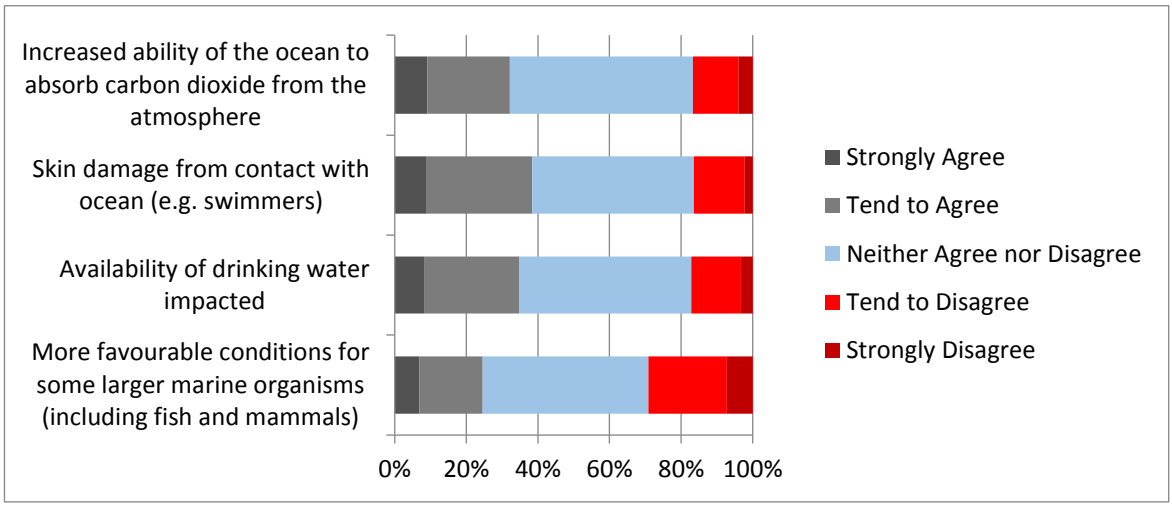


Figure 15. Response options to incorrect statements about the impacts of OA from survey data

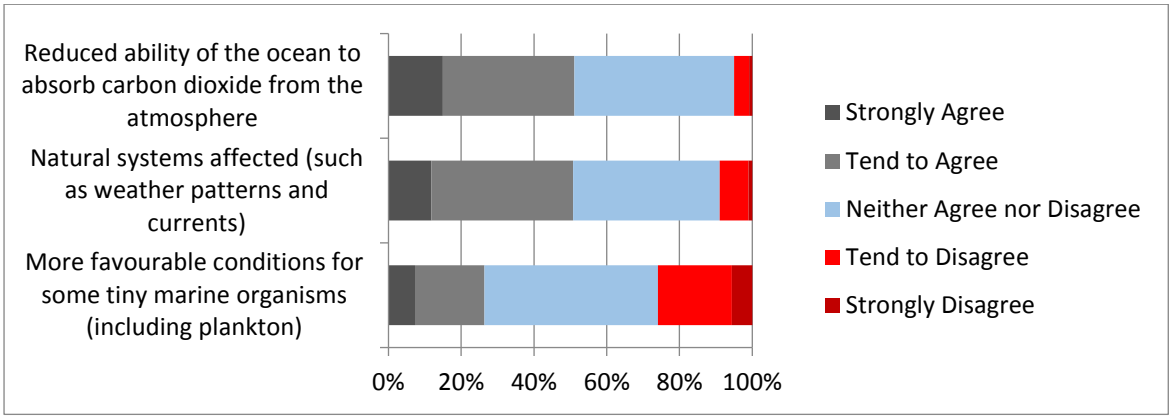


Figure 16. Response options to uncertain statements about the causes of OA from survey data

The first set of options shown in Figure 14 are those that are consistent with the scientific consensus and those in Figure 15 are incorrect beliefs about the impacts of OA. The last three options shown in Figure 16 were more complicated and could be considered correct if certain circumstances were met. The response options contain impacts on society which were not clearly laid out in the expert model but are seen as a possibility in the future.

SUMMARY OF IMPACTS

For the first three statements in Figure 14 (Damage to coral reefs, Extinction of some marine organisms, and Damage to the marine food chain) almost three-quarters of the sample agreed that these would be impacts of OA which reflects the data from the public interview sample. The impact on organisms was the most mentioned theme during the interviews and the proportion of participants agreeing with this in the survey data suggests that the environmental impacts are perhaps easier to infer rather than be recognised. The socioeconomic impacts outlined in the public interview data (Problem for people reliant on ocean resources for their livelihood, Impact on food availability for people, Tourism and leisure will be affected negatively by ocean acidification) which are recognised in the scientific literature were also agreed upon by the survey sample though 42.4% neither agreed nor disagreed whether tourism and leisure would be impacted by OA or not.

The response options in Figure 15 do not appear in the expert model but are incorrect examples of how OA would have an impact taken from the earlier survey and interview data (as shown in Table 18). With regards to environmental impacts and the response that there would be more favourable conditions for some larger marine organisms only a quarter of participants agreed, with more disagreeing that this would

be an impact. A third of survey participants agreed that the ocean would have an increased ability to absorb carbon dioxide from the atmosphere. The socioeconomic impacts options (Skin damage from contact with the ocean (e.g. swimmers) and availability of drinking water impacted) were both themes that were introduced in the public interview phase. The survey participants in both cases neither agreed nor disagreed with these options.

Lastly there were three options which are seen as uncertain by scientists and survey participants also seemed to be uncertain, with only half of the sample agreeing that there would be a reduced ability of the ocean to absorb carbon dioxide from the atmosphere and that natural systems would be affected (such as weather/currents). In order for these natural impacts to occur, there are possible interactions which may have an influence, such as the temperature and seawater chemistry more generally. It is important to remember that this is a highly uncertain area and that many of the possible impacts are predictions based on past events and evidence collected with a whole range of parameters that make this very complex.

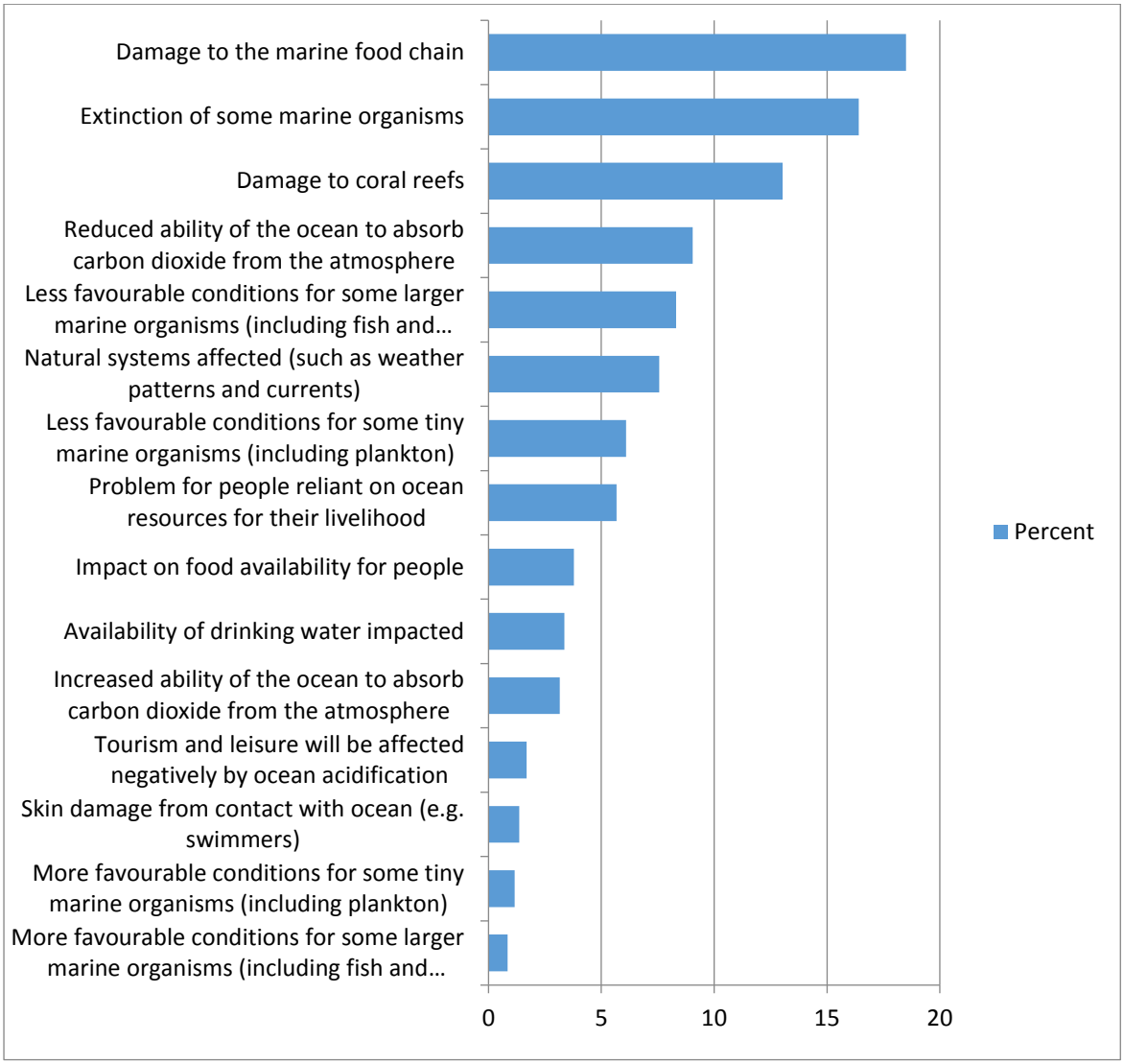


Figure 17. Main impact of OA

When participants were asked to select what they thought would be the main impact of OA, 18.5% thought that the marine food chain would be at risk with 16.4% predicting that there could be extinctions of some marine organisms (as shown in Figure 17). When asked, participants saw environmental impacts as the most likely; the top responses were consistent with the expert model.

INTERACTIONS WITH OA

The interactions outlined in the expert model appeared in the public interviews (see Figure 18), and though some new themes were brought up such as acid rain and pollution, only those found in the expert model were included in the survey. Interactions between OA and other parts of the environment are difficult to predict and the themes introduced may well be possible interactions. This part of the model was deemed less important to test fully because of this. The opportunity was taken to assess

whether providing a 'Don't know' option would result in fewer participants giving a meaningful response given that this is an unfamiliar topic.

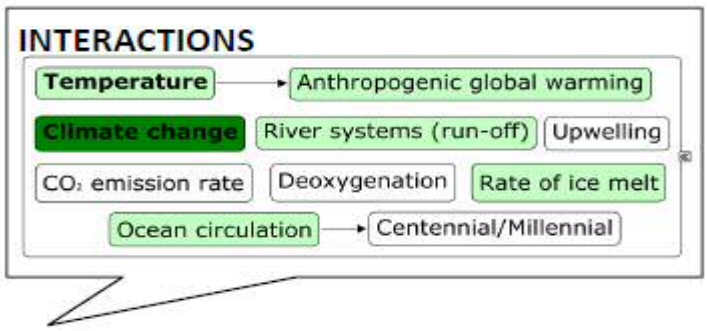


Figure 18. Overlay of public interviews on expert model of OA (Interactions)

A total of seven statements were given to determine how prevalent aspects of the expert model were within the survey sample. The results can be seen in Figure 19. As well as including temperature increases from human-made global warming, natural temperature changes were also included though the latter is not seen as an interaction with OA. A large proportion (72.5%) of survey participants agreed that river system run-off was a key interaction with OA however this is seen as more of a local issue by the experts. Increasing CO_2 emissions was closely followed by climate change with more participants agreeing that these would interact with OA and make it worse. The last statements saw more participants unable to give a meaningful response either way. Interestingly the 'Don't know' response option was not selected as often as expected due to the low level of awareness about this risk issue.

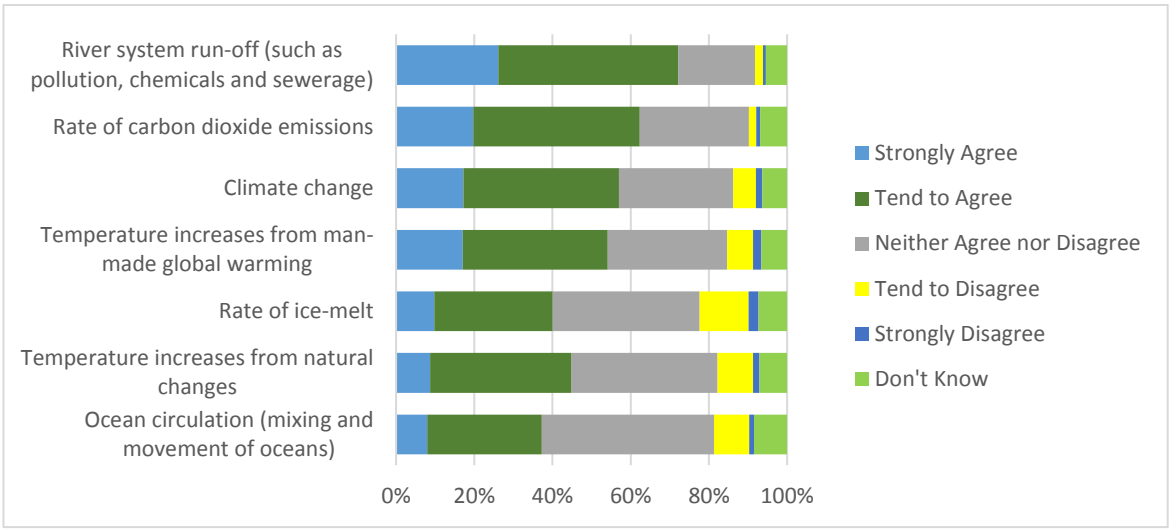


Figure 19. Response options to statements about the interactions with OA from survey data

RESPONSES TO OA

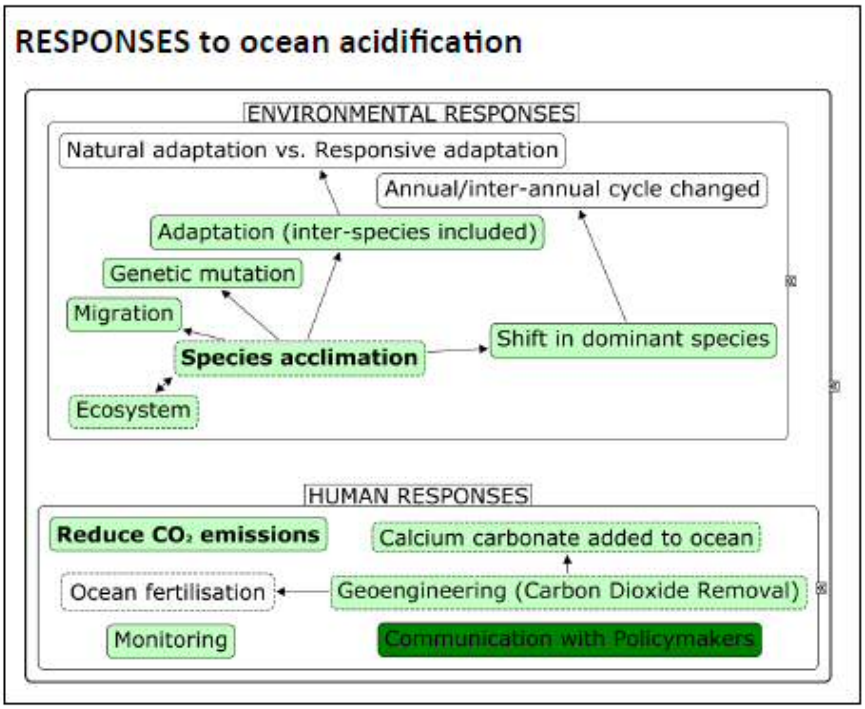


Figure 20. Overlay of public interviews on expert model of OA (Responses)

As shown in Figure 20 interview respondents mentioned the majority of possible responses present in the expert model. In his final part of the expert model and the knowledge aspect of the survey participants were simply asked to select the measure they felt would be best to reduce OA. Unsurprisingly over a quarter of the sample thought that the reduction of chemical and industrial waste would be the most effective solution with only 12.7% correctly identifying the reduction of carbon emissions as being the best option (see Figure 21). Interestingly 13.7% selected the second option, that public awareness should be increased, which was not a prominent theme in the expert model. When exploring this alongside the public model and the interview data, 50% of interview respondents said that awareness about OA should be raised. Though not directly mentioned by many, reducing CO_2 was referenced indirectly through reducing pollution and reducing fossil fuel reliance or setting international targets and legislating to respond to this risk.

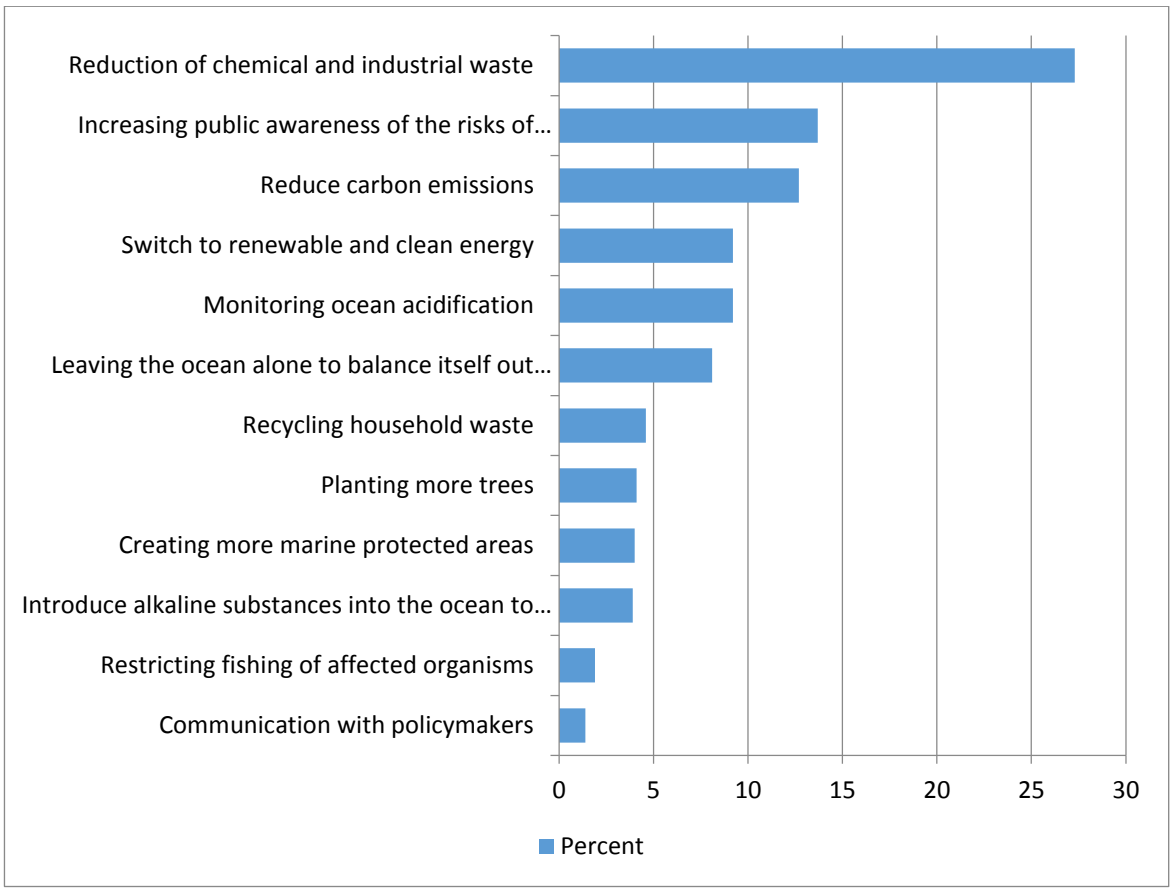


Figure 21. Response options to statements about the responses to OA from survey data

The expert model of OA was mainly tested through knowledge of OA but as we have already seen, knowledge was only a small part of how the public perceived OA. The public had low levels of awareness and knowledge of this risk issue. The public model contained a range of other themes which explained how people built their mental model of OA including through their emotions, their risk perceptions and information sources used. The next part of this chapter will explore how the public interview data and the public model for these components corresponds to the survey data.

EMOTION AND CONCERN

During the interview phase of this project it was clear that OA was perceived as a highly negative topic with a range of emotions such as guilt and anger cited as feelings people associated with OA. In the survey, participants were asked about how positive or negative OA made them feel and though a large proportion rated OA as 5 (mid-

point on the scale) almost as many rated OA as something that made them feel negative (36.3%). See Figure 22 for a breakdown of how survey participants rated OA.

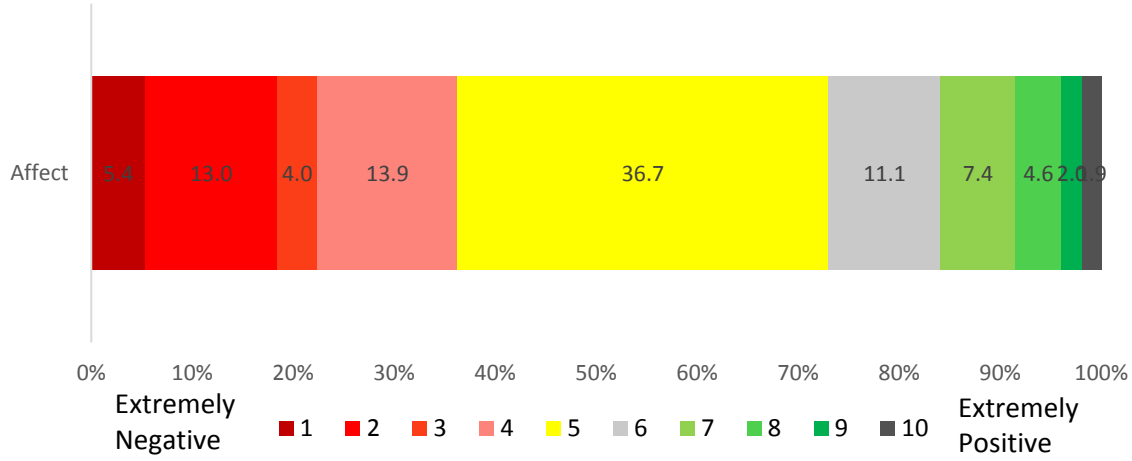


Figure 22. Responses to 'On a scale from 1 to 10 how positive or negative do you feel about OA' from survey data

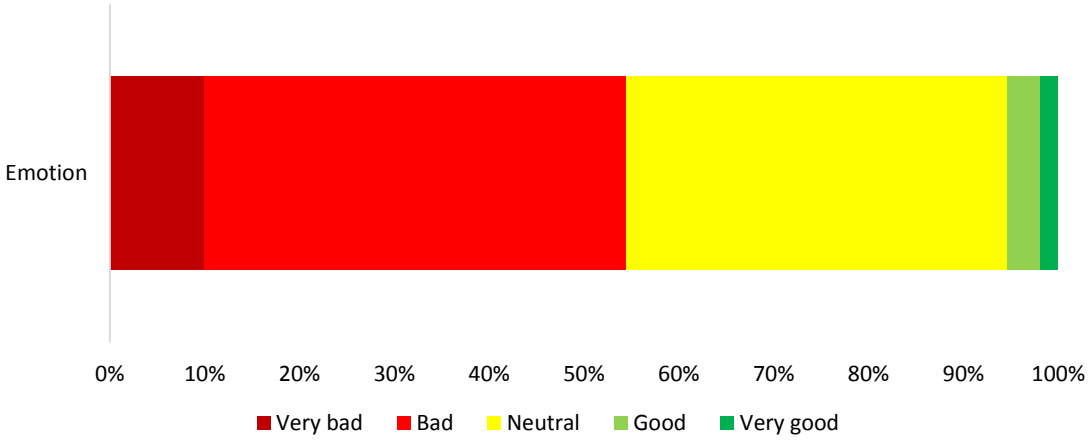


Figure 23. Responses to 'As a whole, does OA make you feel… [see legend options]' from survey data

As well as determining how affective OA was to the survey sample they were also asked how OA made them feel on a whole. Results in Figure 23 show that a large part of the sample (54.5%) elicited a bad feeling towards OA with much of the remaining sample (40.2%) feeling neutral about it.

The survey findings support the interview data in that OA is perceived as a negative topic. All interview respondents said that they felt negative towards OA with 75% of them saying that it concerned them. In the survey, participants were also asked how concerned they were about OA (see Figure 24).

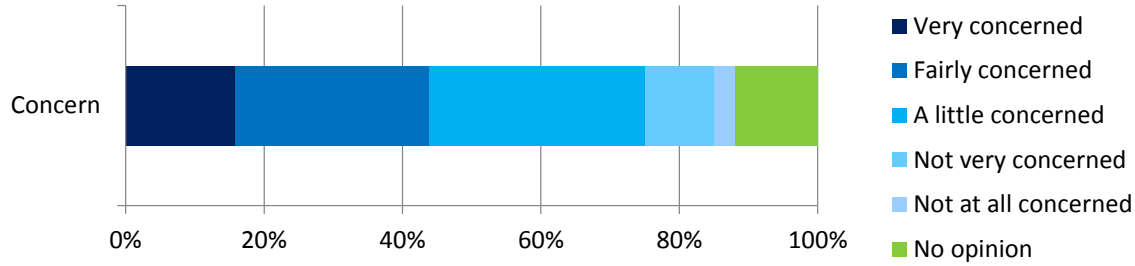


Figure 24. Responses to 'To what extent are you concerned about OA' from survey data

43.9% of participants were either very concerned or fairly concerned about OA with a further 31.1% answering that they were a little concerned; showing that concern about OA is high in the wider population as expected.

INFORMATION SOURCES AND TRUST

In order to develop effective risk communications, it is important to ascertain where people are most likely to access information about a particular risk as well as how trustworthy they find these sources. In the interviews, respondents were asked about their media usage with the majority referencing the internet (including news websites) and television news as their main source of information. Despite the internet and the news being most used, science magazines and research were most trusted in this sample. In the survey, participants were asked about their trustworthiness of numerous information sources as well as from which one they would get their information about OA. As expected, scientists were most trusted by participants with 41.6% selecting this option. Television documentaries came second but only received 12.3% overall showing a big difference in how trustworthy scientists are regarded in comparison to a range of other sources (see Figure 25).

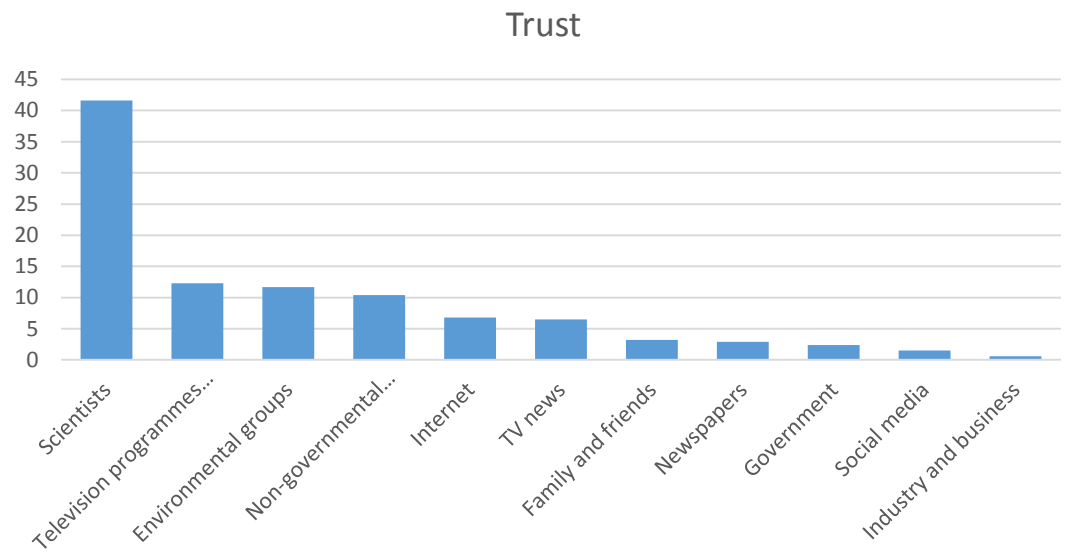


Figure 25. Source of information most trusted to give correct information about OA

Trust in particular information sources is a key factor to consider when deciding what outlet best suits the message to be communicated to a particular group but it is only one of many. The sources accessed by members of the public do not seem to reflect those that they trust, as in this sample the internet was heavily used with a similar proportion who said that they would use it to learn about OA as those who said that they would get their information from scientists, as seen in Figure 26.

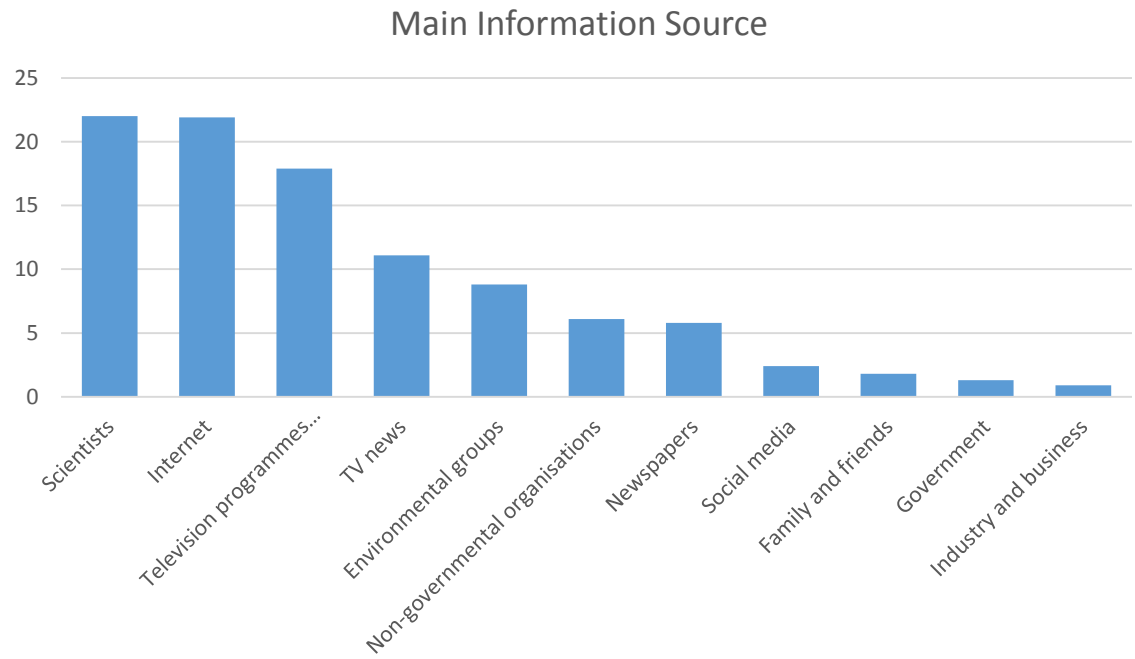


Figure 26. Source most likely to get information about OA

Only 6.8% of the sample rated the internet as the most trusted to give correct information about OA with six times more participants trusting scientists the most.

RISK PERCEPTION

The final part of the public model that was identified in the public interviews was how respondents perceived the risk of OA to themselves and others, as well as those living in other parts of the world. They also talked about how important this risk was in comparison to others. To assess the risk perception of OA relevant aspects of this were explored in the survey. For example, participants were asked about the risks and benefits of OA, how they would assess these in relation to the environment, society and themselves. They were also asked about specific risks of OA such as whether OA is happening too fast to adapt to it and whether they agreed or disagreed with this statement and others.

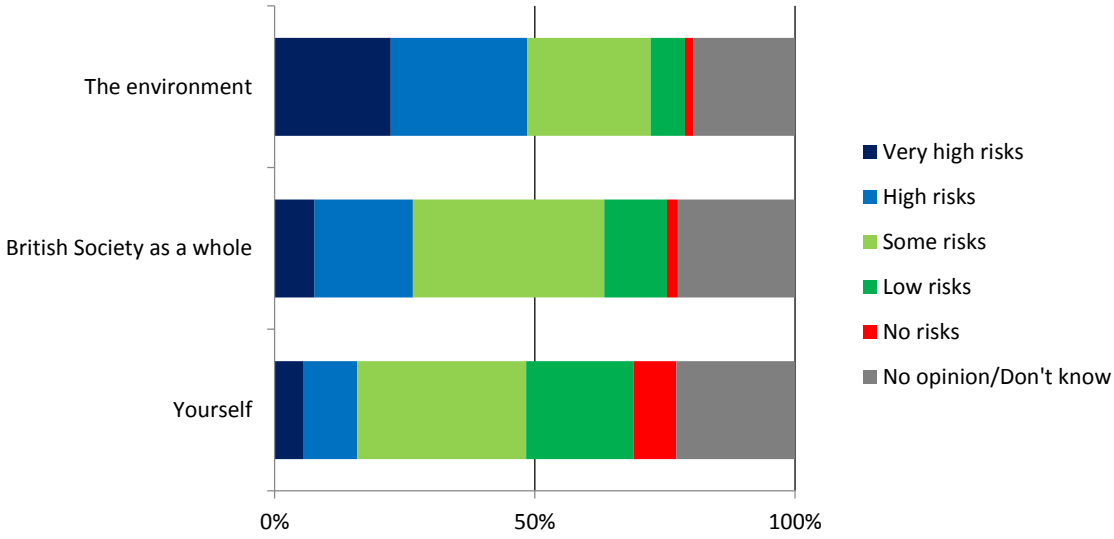


Figure 27. How would you assess the risks, if any, of ocean acidification for…

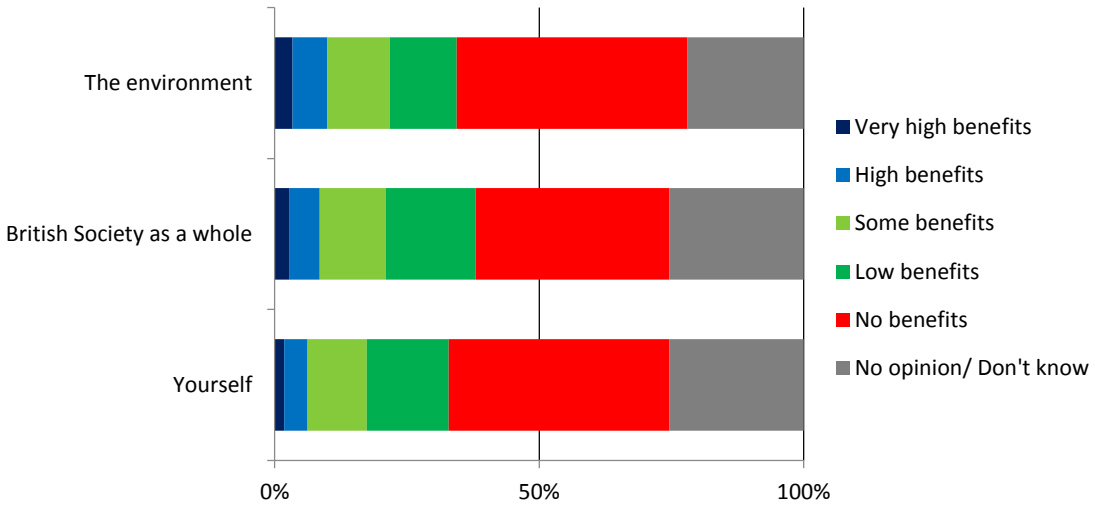


Figure 28. How would you assess the benefits, if any, of ocean acidification for…

As shown in Figure 27 and Figure 28 between 20 and 25 % of participants responded with 'No opinion/Don't know' for each item, which is a sizeable proportion of the sample, possibly because this is an unfamiliar risk and there is uncertainty what risks or benefits there may be for the environment, society or self. Despite this, the proportion of participants when asked about the benefits of OA mainly responded that there were no benefits of OA (43.6% - the environment, 36.6% - British society and 41.8% - yourself). When asked about the risks of OA it is clear that the majority of participants felt that the environment would be at most risk (48.6% selecting very high risks or high risks) with themselves at least risk (15.9% selecting very high risks or high risks).

As well as asking participants about the risks and benefits of OA on these different choices they were asked about their overall thoughts on risks and benefits of OA (see Figure 29). Similar to the previous questions about risks and benefits of OA, a large proportion of participants selected 'Don't know' as their response. The general trend does show an increase in those who think that there are more risks than benefits of OA with 8.7% answering that the benefits of OA outweigh the risks and 48.9% answering that the risks outweigh the benefits.

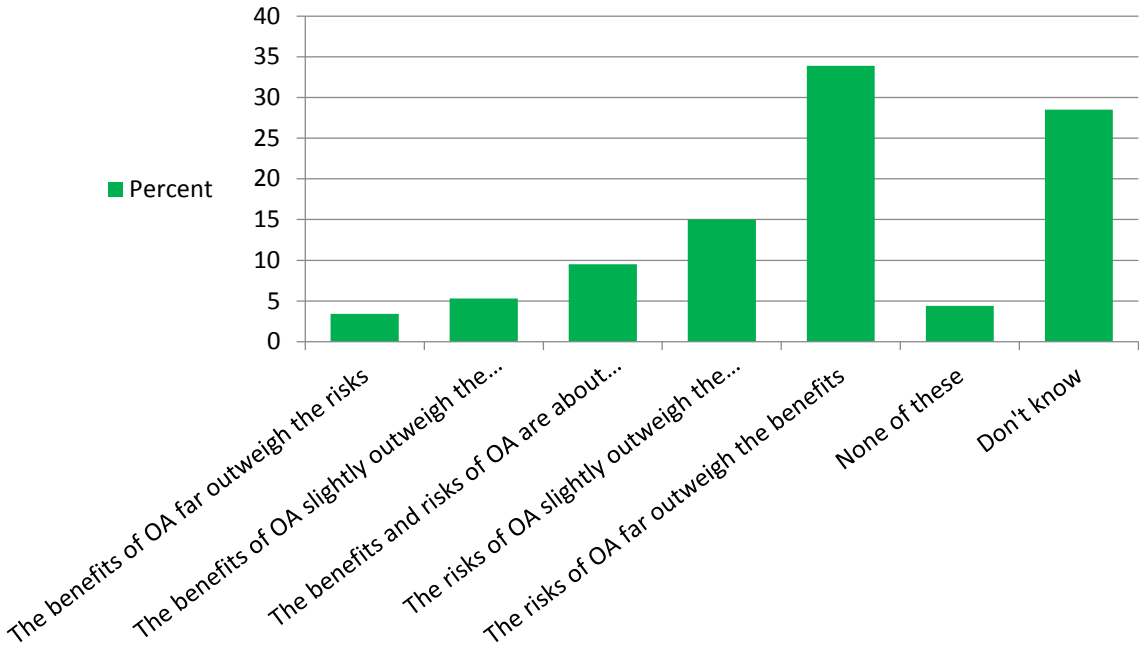


Figure 29. Risk/Benefits of OA

These results are not surprising as most participants had rated OA as negatively affective (see Figure 22 and Figure 23) with few saying that it made them feel happy or positive about the risk of OA.

5.3.2 Overall Summary

Survey participants had a low level of awareness about OA, which was reflected in how knowledgeable they were on the causes, impacts and responses to this risk issue. Similar to the interview data, pollution from chemical and industrial waste was thought to be the main cause of OA, with CO_2 in second place. However, CO_2 was not seen as a cause of OA in the interview sample, with only a couple of respondents stating that this was the main cause of OA. In the expert model, pollution from chemical and industrial waste was generally seen as only having a local impact.

Moving onto the impacts of OA, the survey sample matched the interview sample, with both groups agreeing that damage to coral reefs and impacts on marine organisms and food chains were most likely to occur from OA. This also matches up to the expert consensus with environmental impacts seen as potentially wide-ranging though uncertain. The three impacts mentioned were also selected when participants were asked to choose what they thought was the main impact of OA out of the range of

options given. The socioeconomic impacts identified in the interviews with regards to food availability and ocean resources were also agreed upon by the survey participants.

The majority of participants thought that river system run-off was the largest interaction with OA but also agreed that climate change and the rate of CO_2 emissions were important. These all feature in the expert model although river system run-off is a local interaction rather than a main interaction with OA.

Lastly, participants mainly thought that reducing chemical and industrial waste was the most important step to reduce OA with the reduction of CO_2 coming third after raising public awareness of OA. This was expected based on people's assumption that chemical and industrial waste was the main cause. In the interviews, respondents thought that legislation and communication with policymakers was key in reducing OA. CO_2 was mentioned by only a few people, though if those who talked about reducing pollution are taken into account this would be a greater number. In the survey, communication with policymakers was rated as the least effective solution.

The knowledge component of how the general public understand OA is only one part of the picture as has been seen in the interview data. From the survey data, it appears that there is agreement in the wider population on the main thoughts and ideas about OA found during the qualitative phase. One important difference is the agreement that CO_2 is an important cause of OA found in over half of those surveyed. Of course, as they were given pre-defined possible options and CO_2 emissions are commonly cited as causing environmental damage and climate change, it is possible that this could explain why it was a popular choice among participants rather than them knowing that CO_2 is a key cause of OA.

Though knowledge of OA was the basis of the expert model this only made up one aspect of the public mental model. Emotion and concern were particularly important elements of how OA was conceptualised and were also important in the survey data. In the interview phase OA was perceived to be highly negative and over half of the survey participants also felt that OA was negative. Three quarters of the sample also felt concerned about OA mirroring the interview findings.

When interview respondents were asked where they got their information about issues such as OA many stated that the internet was their main source along with the news, however, these sources were the least trusted. As expected, scientists were the most

trusted by both groups and were also cited as the main information source for survey participants alongside the internet. 'The internet' is quite a vague term and could mean a range of things; there is a need to make information source options more obvious as some are not precise enough. This option does not give an accurate representation of how this particular source might be used by people and therefore it is hard to quantify what this actually means for those sampled in this instance.

Finally, participants were asked about their risk perception of OA and how they would assess the risks and benefits of OA for the environment, British society and themselves. A quarter of the sample did not give a meaningful answer with the remaining sample rating the environment as likely to be at most risk and conversely least likely to benefit from OA. When asked overall about risks versus benefits of OA, most people felt that the risks far outweighed the benefits of OA. It is important to say again that about a quarter of participants responded, 'Don't Know' when asked this question. When compared to the interview data, OA was not considered to be an important issue with some interview respondents saying that they had not heard it mentioned in the media so did not see it as an issue. As seen in the interviews, when discussing the impacts of OA, respondents did feel that the environment would be at risk from OA which ties into survey findings placing the environment at high risk from this risk issue.

On the whole, it appeared that the public mental model of OA mapped from the interviews was generally found in the wider population. There are some differences such as CO_2 being more widely selected as a cause of OA but for the other knowledge factors and the remaining components of the model there was agreement.

This was only one way of looking at the data and only explored how the groups were similar in their responses across the topics identified from the initial literature review and interviews. The opportunity to find out what factors were responsible for the level of knowledge about OA, for example, allows for a greater understanding of how people understand OA and what influences them.

5.4 Relationships

OA is a novel risk with seemingly low awareness amongst those sampled within the public sphere. We have seen that public risk perceptions of OA do exist as people are concerned, have strong negative feelings and agree that there are serious environmental risks from OA. To further examine how perceptions of OA have been constructed within this group as well as whether a number of hypotheses were supported three multiple regressions were conducted; knowledge, acceptability and concern about OA.

The hierarchical modelling of knowledge, concern and acceptance of OA was informed by earlier phases of this research and previous mental models work. Knowledge of OA was very important in this thesis as the mental models developed from the interview phases had a key focus on how knowledgeable people were about OA. By assessing what influenced knowledge of OA will help develop effective risk communications to engage the public appropriately. Concern about OA was a crucial part of the analysis conducted in Capstick et al. (2016) and it was worth modelling concern about OA in this piece of research as well to further explore this aspect. The level of concern about OA was high in the interviews and survey data despite the low levels of awareness so it is important to establish why people were concerned about OA. Lastly, the acceptability of OA was modelled based on previous research that examined the acceptance of new technologies and unfamiliar hazards (e.g. Pidgeon et al., 2005). As OA is an unfamiliar hazard it is useful to consider what factors predict acceptance of OA and if these are similar to other environmental risks.

Before exploring the results of the regressions, I will explain how the scales were developed for the regression analyses and their level of reliability. For development of the knowledge scale see Appendix H and for the factor analyses of the scale development please see Appendix I. It is also necessary to explain the rationale and hypothesis behind each predictor included in these models which are laid out in Table 19, Table 21 and Table 23 which will follow the section on scale development. Different variables were included in each regression due to the exploratory nature of this thesis with each regression conduced on an individual basis. Across each regression demographic variables gender and age were included with the remaining variables chosen based on the literature (as set out in Table 19, Table 21 and Table 23).

The variables included in the regression testing knowledge varied the most from the other two regressions as concern in climate change was included in only this regression, with values and place attachment not included in this regression. As one of the key aims was to assess knowledge about OA following the mental models approach, it was important to explore the influence of concern and emotion. These were both important in the interviews and literature (e.g. Gelcich et al., 2014) so may play a role in how risk communications are developed. Assessing concern in climate change was also important as it could affect how messages about OA are framed. Values and place attachment were not included as they were not expected to predict knowledge about OA but were more important predictors of concern and acceptability of OA. The regression testing acceptability of OA excluded education but included risks and benefits of OA. As this regression incorporated a wide range of variables (e.g. values, concern, knowledge, place attachment, emotion) and the key predictors were risks and benefits, education was not included so as to limit the number of variables. It is clear that other predictors could have included in each of these three regressions, however, as each regression was informed by either the earlier findings of this research or by other relevant work (e.g. Capstick et al., 2016; Frisch et al., 2015; Pidgeon et al., 2005) the selection of variables varied accordingly.

SCALE PREDICTORS

Demographics

Age, gender and science education were used as key demographics with dummy coding used for each predictor variable. The dummy variable constructed for gender had 'male' as the reference; for age the central band (45 – 54) as the reference condition. A dummy variable was also constructed for science education with 'no formal science qualifications' treated as the reference group. After data collection, it was unclear if participants had answered the science education question appropriately and it was possible that they may have answered with regards to general education instead. The category 'vocational qualifications' was excluded as it was unclear what this was measuring in relation to level of education.

Pro-environmentalism

This scale (Q21.7 - .10) included the statements 'I consider myself to be environmentally conscious' and 'I would be embarrassed to be seen as having an environmentally-friendly lifestyle' with the four items loading onto one factor (α =

.770). Items Q21.7 and Q21.10 were reverse-coded. To measure their pro-environmental identity, participants had to indicate their agreement on a five-point scale (strongly agree – strongly disagree) to each statement.

Emotion

A range of emotions were included (15 in total) with 13 used to create an emotion scale (Q26.1 - .4, .6 - .14). These included emotions such as 'guilt' and 'sympathy'. Two items loaded onto a separate factor (though one of these would have needed to be reverse-coded for inclusion) and were dropped with the remaining items obtaining Cronbach's $\alpha = .958$. Responses were on a 10-point scale from 'not felt it at all' to 'felt it extremely'.

Values

Six items were used to measure cultural worldviews and produced two components from the factor analysis corresponding to the two cultural views expected. Egalitarianism (Q21.1 - .3) had an acceptable Cronbach's alpha ($\alpha = .677$) unlike Individualism (Q21.4 - .6) which had low reliability as $\alpha = .414$ so results of this measure should be taken with caution. Participants had to indicate their agreement on a five-point scale (strongly agree – strongly disagree) to each statement.

Risks/Benefits

Three items were used to measure the perceived risks of OA (Q34.1-.3), with the question asking participants how they would assess the risks of OA for themselves, for example. These items loaded onto one factor with high reliability ($\alpha = .931$). Responses to perceived benefits were measured on a 6-point scale from very high benefits to no benefits and a no opinion/don't know option. The items were the same for measuring perceived benefits with items loading onto one factor ($\alpha = .932$).

Place attachment

There were eight items that formed this scale (Q35.1 - .8) such as 'I feel the ocean is a part of me' and 'the ocean is very special to me'. All these items loaded onto one factor with a good reliability level as $\alpha = .946$. Participants responded on a five-point

scale from strongly agree to strongly disagree for each statement on how attached they felt to the ocean.

Psychological distancing

To measure psychological distancing four statements were presented, and asked participants to respond on a five-point scale from strongly disagree to strongly agree (Q28.1- .4) and included items 'my local area is likely to be affected by ocean acidification' and 'ocean acidification will mostly affect people in developing countries'. Items loaded onto a two-factor structure though not as expected (see Appendix I). Factor 1 was comprised of the two statements relating to local distance and Factor 2 of the other two statements relating to global distance of OA and did not measure distancing on geographical and social dimensions. As these items correlated weakly and had low reliability ($\alpha = .497$) this construct was dropped.

5.4.1 Knowledge of OA

The first regression was run to see if knowledge of OA could be predicted by a range of factors laid out in Table 19. The dependent variable was the summed knowledge scores for causes, consequences, interactions and measures to reduce OA (as shown in Appendix H). The mental models approach traditionally means that researchers focus on scientific knowledge and information testing to see how consistent a certain group of people or a national representative sample compare to those considered to be experts in a particular area or risk issue. The traditional knowledge-deficit model would mean designing risk communication materials to fill any knowledge gaps. However, the effectiveness of this type of approach would be influenced by a range of factors. Exploring risk perceptions of OA and how these predict levels of knowledge in people means that when messages are designed they can be tailored to specific groups to maximise engagement.

Variable	Rationale	Hypotheses	Outcome
Gender	Exploratory. Though women tend to have higher risk perceptions than men for some environmental risks (e.g. nuclear power, chemical contamination) gender is not expected to predict knowledge (Finucane, Slovic, Mertz, Flynn & Satterfield, 2000)	N/A	-
Age	Included for exploratory purposes to determine if age has any influence	N/A	-
Science Education	Exploratory variable as research is mixed on this with education relevant in some studies (Tobler, Visschers & Siegrist, 2012) but not in others	Might expect increased level of science education to correlate with increased knowledge of OA	Partially supported
Concern	This was high in interview respondents regardless of the level of knowledge, Gelcich et al. (2014) found level of informedness was linked to concern in numerous climate marine impacts though OA did have higher concern levels than expected	Those who are more concerned about OA should have a higher level of knowledge about OA as should those who are more concerned about climate change	Supported
Pro-environmentalism	Environmental identity is important when assessing knowledge on climate change so it is expected to have an influence on OA knowledge (Whitmarsh & O'Neill, 2010)	If participants report higher levels of pro-environmentalism they should have higher levels of knowledge as they are likely to seek information on environmental issues	Supported
Emotion	Capstick et al. (2016) reported an increase in concern after participants received information about OA so there may be a connection between knowledge and negative emotion	Participants who report negative emotions will be more knowledgeable about OA than those who do not feel strong negative emotions as they are more familiar with the risk issue	Supported

Table 19. Summary of variables included in regression to assess predictors of knowledge

A hierarchical linear regression was carried out to assess knowledge of OA and what predicted a higher score of knowledge about OA (see Table 20). The mean and standard deviation of the dependent variable was $M = 10.81$ ($SD = 4.42$). The model predicts 27% of the variance ($R^2 = .27$). Model 1 did not significantly improve prediction of the outcome variable compared to not fitting the model when only demographics were included. In the second model when emotion, concern about OA and climate change and pro-environmental identity were added the model was significant in improving prediction of knowledge. In model 1 education was the only significant variable but not in the way expected. Both the groups educated to GCSE level and degree level were significantly correlated with level of knowledge of OA, with other groups not reaching significance (the reference group was no qualifications achieved). The level of education achieved in the sample surveyed was variable with almost 29.4% of the sample reporting GCSE as the highest level of science education, whereas in the national sample this only accounts for 14% of the sample so this group is overrepresented. In model 2 those who achieved an undergraduate degree were also a significant predictor of knowledge about OA, indicating that level of science education was an inconsistent variable; achieving a higher level of education did not mean that participants were necessarily more knowledgeable about OA. More research is needed on science education as it has produced mixed results in previous work.

Model 1 – Demographics				
	b	SE B	β	*p*
(Constant)	10.51	.49		.00
Gender (Male)	-.19	.34	-.02	.59
Age (45 – 54)				
18-24	-.96	.75	-.05	.20
25-34	-.69	.53	-.06	.19
35-44	-.37	.53	-.03	.49
55-64	-.59	.54	-.05	.27
65-74	-.56	.64	-.04	.38
75+	.11	.59	.01	.85
Education level (no qualifications)				
GCSE	1.10	.46	.11	.02*
A levels	.88	.54	.08	.10
Degree	.99	.49	.10	.04*
Postgraduate	.55	.66	.03	.41
Model 2 – Concern, emotion and values				
(Constant)	-1.38	1.34		.30
Gender (Male)	.60	.30	.07	.05
Age (45 – 54)				
18-24	-.51	.65	-.03	.43
25-34	-.29	.46	-.02	.53
35-44	-.03	.46	.00	.95
55-64	-.60	.47	-.05	.20
65-74	-.49	.55	-.03	.37
75+	-.06	.51	.00	.91
Education level (no qualifications)				
GCSE	.86	.40	.09	.03*
A levels	.79	.46	.07	.09
Degree	.99	.42	.10	.02*
Postgraduate	.34	.57	.02	.56
Emotion	-.47	.19	-.09	.01*
Pro-environmentalism	1.30	.24	.22	.00***
Concern OA	.91	.17	.21	.00**
Concern climate change	.73	.22	.14	.00**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, $R^2 = .01$ for Step 1, $\Delta R^2 = .25$ for Step 2

Table 20. Regression results for knowledge of OA

In the second model, pro-environmentalism was the best predictor of knowledge about OA (β = .22, *p* < .00) followed by concern about OA (β = .21**,** *p* = .00), concern about climate change (β = .14, *p* = .00), degree and GCSE education (β = .10, *p* < .02, and β = .09, *p* < .03 respectively), and gender (β = .07, *p* < .05). Emotion was negatively correlated (β = -.09, *p* <.01) as the more positive that participants felt about OA the higher the score they assigned (1 very bad – 5 very good).

5.4.2 Acceptability of OA

The acceptability of OA can be predicted by numerous variables as set out in Table 21. Acceptability of risk can be measured based on the risks and benefits attributed to it as well as certain worldviews held by those asked (shown by Groot et al., 2013 assessing the acceptability of nuclear power). As OA is an unfamiliar risk it is useful to determine if findings in the literature on acceptability of environmental risks, such as nuclear power, are predicted in a similar way.

How acceptable OA is to those surveyed was predicted by a number of variables. The dependent variable was a single-item question ('On the whole, how acceptable or unacceptable is ocean acidification to you?'). In this regression, the final model accounted for 46% of the variability with each model significantly improving the outcome variable; acceptability of OA (see Table 22). The mean and standard deviation of the dependent variable was M = 3.63 (SD = 1.94). In the first model demographics were entered (age and gender) with gender and three age groups (25 – 34, 55 – 64 & 65 - 74) significant predictors of the acceptability of OA. Younger participants found OA to be more acceptable than those in the older age groups with men also more accepting of OA than women. In the second model, gender was no longer a significant predictor, with age groups 55 – 64 and 65 – 74, risks/benefits of OA, pro-environmentalism, egalitarianism and concern about OA responsible for the variability in the model. Lastly, emotion was entered in a third model and was also a significant predictor of acceptability of OA, however the contribution of other variables did change once emotion was added in with age no longer a significant predictor. In the final model benefits of OA were the strongest predictor of acceptability of OA ($\beta = .37$, $p < .00$) followed by emotion ($\beta = .26$, $p < .00$), risks ($\beta = -.20$, $p < .00$), and pro-environmentalism ($\beta = -.11$, $p < .00$). Participants who thought the benefits of OA were high also saw OA as more acceptable and participants who thought that the risks of OA were high saw OA as less acceptable as expected. Also, those who were more pro-environmental felt OA was less acceptable than people who felt less environmentally-friendly. Emotion predicted the acceptability of OA to a highly significant level accounting for a 5% increase in the final model; those who felt less positive about OA were less accepting of this risk.

Variable	Rationale	Hypothesis	Outcome
Gender	Women tend to have higher risk perceptions than men (Finucane et al., 2000)	Women find OA less acceptable than men	Not supported
Age	Climate change and OA research have shown that age can be a factor with older people less concerned (Whitmarsh, 2008; Frisch et al., 2015) so this may be found for acceptability	Younger participants will find OA more unacceptable than those who are older	Not supported
Risks/ Benefits	The balance between perceived risks and possible benefits is known to influence acceptability of risk. Generally people feel that risks associated with climate change outweigh the benefits	Participants will perceive more risks of OA as acceptability of OA goes down. Fewer benefits of OA will be seen as participants see OA as less acceptable.	Supported
Values	Cultural worldview is associated with environmental risk as egalitarians perceive more risk than individualists (Xue et al., 2014)	Egalitarians will find OA less acceptable than individualists	Not supported
Pro-environmentalism	A strong environmental identity should mean that unfamiliar risks are seen as less acceptable	Those with a strong pro-environmental identity will find OA less acceptable	Supported
Concern about OA	'Messing with nature' makes some technology less acceptable to people as they are concerned about the potential consequences (Corner et al., 2013)	Participants who are more concerned about OA will think it is less acceptable	Not supported
Place Attachment	Strong place attachment has been linked to low acceptance of e.g. wind farm projects (Devine-Wright, 2009) and other environmental projects or risks	Acceptability of OA will be lower in participants who feel attached to the ocean	Not supported
Knowledge	The more people knew about SRM the less they supported it (Corner, Pidgeon & Parkhill, 2012)	If participants have higher knowledge levels they will perceive OA as less acceptable	Not supported
Emotion	Risk perception involves judgement and feelings (Slovic et al., 2004) or 'risk as feelings' (Loewenstein et al., 2001) with negative affect associated with less acceptability.	Those who feel negative about OA will think it is less acceptable than those who feel more positive about it	Supported

Table 21. Summary of variables in regression predicting acceptability of OA

Model 1 - Demographics				
	B	Std. Error	Beta	Sig
(Constant)	3.47	0.18		0.00
Gender (Male)	0.44	0.16	0.11	0.01*
Age (45 – 54)				
18-24	0.44	0.34	0.06	0.20
25-34	0.58	0.25	0.11	0.02*
35-44	0.04	0.25	0.01	0.88
55-64	-0.53	0.25	-0.10	0.04*
65-74	-0.70	0.31	-0.10	0.02*
75+	-0.31	0.27	-0.06	0.25
Model 2 – Values, Risk/Benefit, Concern, Place attachment & Knowledge				
(Constant)	6.55	0.69		0.00
Gender (Male)	0.08	0.13	0.02	0.56
Age (45 – 54)				
18-24	-0.15	0.27	-0.02	0.58
25-34	0.24	0.20	0.05	0.23
35-44	-0.07	0.20	-0.01	0.73
55-64	-0.42	0.20	-0.08	0.03*
65-74	-0.48	0.25	-0.07	0.05
75+	-0.17	0.22	-0.03	0.43
Benefits of OA	0.74	0.05	0.45	0.00***
Risks of OA	-0.56	0.08	-0.26	0.00***
Egalitarianism	-0.06	0.08	-0.03	0.47
Individualism	0.01	0.09	0.00	0.92
Pro-environmentalism	-0.41	0.10	-0.15	0.00***
Concern OA	-0.07	0.07	-0.04	0.31
Place attachment	-0.01	0.07	0.00	0.91
Knowledge score	-0.03	0.02	-0.05	0.15
Model 3 - Emotion				
(Constant)	4.21	0.73		0.00
Gender	0.00	0.12	0.00	0.99
Age (45 – 54)				
18-24	-0.10	0.26	-0.01	0.71
25-34	0.28	0.19	0.05	0.15
35-44	0.00	0.19	0.00	0.98
55-64	-0.32	0.19	-0.06	0.10
65-74	-0.36	0.24	-0.05	0.13
75+	-0.11	0.21	-0.02	0.60
Benefits of OA	0.61	0.05	0.37	0.00***
Risks of OA	-0.43	0.08	-0.20	0.00***
Egalitarianism	-0.06	0.08	-0.03	0.44
Individualism	-0.01	0.08	0.00	0.91
Pro-environmentalism	-0.30	0.10	-0.11	0.00**
Concern OA	-0.02	0.07	-0.01	0.83
Place attachment	0.00	0.07	0.00	0.97
Knowledge score	-0.02	0.02	-0.04	0.26
Emotion	0.60	0.08	0.26	0.00***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, $R^2 = .06$ for Step 1, $\Delta R^2 = .36$ for Step 2 and $\Delta R^2 = .05$ for Step 3.

Table 22. Regression results for acceptability of OA

5.4.3 Concern about OA

Finally, concern about OA was explored through a regression analysis to see what predicted concern for this novel risk issue. The mean and standard deviation of the dependent variable was $M = 4.53$ ($SD = 1.02$). In this regression the dependent variable was a single-item question ('To what extent are you concerned about ocean acidification?'). A range of variables were included in this analysis as outlined in Table 23. From the interview data 75% of respondents said that they were concerned about OA despite it being an unfamiliar topic. Previous literature on climate change risk perceptions find that concern is influenced by numerous variables and those findings are expected to be similar for the risk of OA. Additionally, Capstick et al. (2016) also explored concern about OA so some similarities were expected to emerge in the results.

As shown in Table 24 the first regression model was not significant in improving the prediction of concern about OA when only demographics were entered. Gender and age 25 – 34 were unique significant predictors but nothing else was significant. The final model accounted for 32% of the variability with place attachment the strongest predictor ($\beta = -.25$, $p < .00$) followed by knowledge about OA ($\beta = .23$, $p < .00$), pro-environmentalism ($\beta = .19$, $p < .00$), emotion ($\beta = -.11$, $p < .00$), egalitarianism (($\beta = .08$, $p < .01$), and those educated to a postgraduate level ($\beta = .07$, $p < .05$). Participants who felt more strongly attached to the ocean were also more concerned about OA than those who did not feel a connection to the ocean. Those who scored more highly on the knowledge test were more likely to be more concerned about OA. Next, those who had strong pro-environmental identities were also more concerned about the risk of OA as were those who felt more egalitarian. Emotion was also significant with concern in OA increasing as people felt more negative about it. Finally, those with a postgraduate degree were also more likely to be concerned about OA.

Variable	Rationale	Hypothesis	Outcome
Gender	It is evident in the literature that women are more concerned about climate change than men (McCright, 2010)	Women will be more concerned about OA than men	Not supported
Age	Concern for OA was found to increase with age in Frisch et al. (2015).	Older participants will be less concerned about OA than younger participants	Not supported
Education	Frisch et al. (2015) had a trend that more education led to more concern about OA (though not significant finding)	Concern will be higher for those educated to a higher level	Partially supported
Knowledge	If someone is more ocean literate they tend to be more concerned about OA (Steel et al., 2005)	Participants with higher knowledge scores will be more concerned about OA	Supported
Values	Egalitarianism was a significant predictor of concern in Capstick et al. (2016) so want to replicate this finding	Egalitarians will be more concerned about OA than individualists	Partially supported
Pro-environmentalism	People who have strong environmental values tend to be more concerned about environmental risk (Corner et al., 2014)	For those who are more pro-environmental will also be more concerned about OA	Supported
Place attachment	In the interviews respondents associated the ocean with leisure and tourism and were concerned about impacts of OA	Concern will be high in people who feel more attached to the ocean	Supported
Emotion	All interview respondents discussed OA in a negative way and also stated their concern about OA being high	Participants will be more concerned about OA if they feel more negatively about OA	Supported

Table 23. Summary of variables in regression predicting concern about OA

Model 1 - Demographics				
	B	Std. Error	Beta	Sig
(Constant)	4.71	0.11		0.00
Gender	-0.17	0.08	-0.08	0.03*
Age (45 – 54)				
18-24	-0.06	0.17	-0.01	0.74
25-34	-0.23	0.12	-0.09	0.06
35-44	-0.14	0.12	-0.05	0.25
55-64	-0.10	0.12	-0.04	0.41
65-74	-0.11	0.15	-0.03	0.47
75+	0.02	0.13	0.01	0.88
GCSE	-0.02	0.11	-0.01	0.84
A-levels	0.00	0.12	0.00	1.00
Degree	-0.09	0.11	-0.04	0.44
Postgraduate	0.19	0.15	0.05	0.20
Model 2 – Values, pro-environmentalism, attachment, knowledge & emotion				
(Constant)	3.87	0.36		0.00
Gender	0.03	0.07	0.02	0.66
Age (45 – 54)				
18-24	0.04	0.14	0.01	0.78
25-34	-0.20	0.10	-0.07	0.06
35-44	-0.12	0.10	-0.04	0.25
55-64	-0.10	0.10	-0.04	0.34
65-74	-0.03	0.12	-0.01	0.78
75+	0.03	0.11	0.01	0.80
Educational level (no qualifications)				
GCSE	-0.08	0.09	-0.04	0.37
A levels	-0.07	0.10	-0.03	0.49
Degree	-0.07	0.10	-0.03	0.46
Postgraduate	0.26	0.13	0.07	0.04*
Egalitarianism	0.10	0.04	0.08	0.01*
Individualism	-0.06	0.05	-0.04	0.21
Proenvironmentalism	0.27	0.05	0.19	0.00***
Place attachment	-0.27	0.03	-0.25	0.00***
Knowledge score	0.06	0.01	0.23	0.00***
Emotion	-0.14	0.04	-0.11	0.00**

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, $R^2 = .02$ for Step 1, $\Delta R^2 = .32$ for Step 2

Table 24. Regression results for concern about OA

5.5 Summary

In the survey sample there was a low level of awareness around OA as people had generally not heard of this risk issue. Despite this, CO_2 was selected by almost a fifth of the sample as the main cause following pollution from chemical and industrial waste. Participants also identified the key impacts of OA such as damage to coral reefs and marine organisms. River system run-off was seen as the main interaction with OA and the reduction of chemical and industrial waste a key response to OA. Alongside the knowledge component of OA, emotion and concern were also explored with findings showing high levels of concern around OA with over half of the sample perceiving it to be a negative risk. Survey participants cited scientists as the most trusted information source and selected them as the main information source alongside the internet. Lastly, people felt that the risks far outweighed the benefits of OA.

From the multiple regressions analyses, it is clear that knowledge about OA - the acceptability of this risk issue and concern about OA - are all predicted by a number of variables though only a number were significant when exploring complete models.

The first regression that explored knowledge of OA was predicted (but not as expected) for some demographic variables. Gender and age were exploratory although men were found to be more knowledgeable than women with no effects found for age in relation to level of knowledge about OA. However, level of science education was significant for those at GCSE and degree level, which again was not expected (though was also an exploratory variable). The next three variables were all significantly correlated with knowledge in the direction expected. Those that were more concerned about OA had a higher level of knowledge about OA and also reported more negative emotion than those with lower knowledge scores. Finally, pro-environmentalism also influenced knowledge with those identifying as more pro-environmental having a higher knowledge score about OA. For the most part, results were as hypothesised and will be discussed in more detail shortly.

Exploring how acceptable OA was to those who took part in the survey was also informative with some of the proposed hypotheses met. In the final model demographics did not correlate significantly with acceptability, though age had initially, as older participants found OA less acceptable than younger participants. The risks and benefits of OA both correlated significantly in the direction expected (risks negatively and benefits positively) meaning that the riskier OA was to people the less

acceptable it was and the more beneficial OA was seen to be then the more acceptable OA seemed. Values did not predict acceptability of OA aside from pro-environmentalism, which was significant, showing that those who felt more pro-environmental were less accepting of OA. There was also no support for concern, place attachment and knowledge of OA in this model. Emotion was a strong predictor of the acceptability of OA with those who felt more negative about this risk issue also being far less accepting of OA.

Finally, a regression assessing concern about OA found many significant predictors in the final model. None of the demographic variables (age, science education and gender) contributed to this model aside from those educated to postgraduate degree level though this was the smallest predictor value. Everything else predicted concern about OA in the direction expected. Place attachment and knowledge were the strongest predictors of concern about OA, with those who felt more attached to the ocean and those with a higher knowledge score feeling more concerned about OA than those with a low level of knowledge about OA, or those feeling less attached to the ocean. With regards to worldviews only egalitarianism was significant with people who identified as more egalitarian also being more concerned about OA. Individualism was a weak scale item and was not a significant predictor in this model. However, pro-environmentalism once again was a significant predictor of concern as expected as well as emotion with those feeling more negative about OA also feeling more concerned about OA.

In summary, these analyses show that simply assessing knowledge of OA using the traditional mental models approach does not provide a full picture of how people perceive the risk of OA. Knowledge is only one aspect of how a person constructs their mental model of risk; factors such as affect and identity, though these are not 'knowledge issues', are important too. A full discussion of these results and how they relate to other relevant literature including climate change risk perceptions will now follow, as well as answering the research questions posed.

Chapter 6: Discussion

Chapter Summary

In this chapter, the extent to which the original research questions have been met is outlined before being discussed in the light of relevant public perceptions literature, including that of climate change. The chapter then moves onto make recommendations for future communications, focusing on how it could be framed, and discussing whether any such communications should be tied explicitly to climate change. Finally, some limitations and further research directions are explored before this thesis is concluded.

6.1 Research Questions

The aim of this thesis was to determine what public perceptions of OA were by following the mental models approach laid out by Morgan et al. (2002). Expert perceptions were compared to public perceptions to assess how these differed and shared similarities, in order to construct mental models of OA in these groups and to make recommendations for future risk communications for this risk issue based on the findings. There were three key research questions which shall now be explored and discussed:

1) What are expert perceptions of ocean acidification?

2) What are public perceptions of ocean acidification?

3) What are the differences and similarities between the experts and the public perceptions of ocean acidification?

What are expert perceptions of ocean acidification?

The influence diagram that was constructed from seven expert interviews and scientific literature illustrated that OA was perceived as a highly complex and uncertain risk issue. The mental model incorporated all the uncertainties brought up, although there are many other possible interactions and impacts. As expected there was consensus about the main cause and process of OA (the increase in CO_2 concentrations in the oceans from anthropogenic emissions) and agreement about some of the interactions such as climate change and temperature. The main area of uncertainty and disagreement was that of impacts as these are very difficult to predict; there are many possible interactions, various regions that organisms are tested in, or whether experiments are conducted in laboratories, microcosms, mesocosms or in the natural environment[5]. Lastly, the main response to OA was one on which the experts agreed; reduction of CO_2 emissions, though acknowledgement of other responses like reducing local inputs such as pollutants and nutrients, and looking after ecosystems like seagrass beds would help as they are natural carbon stores and extract CO_2. Establishing what the expert perceptions of OA were then enabled the construction of

[5] A mesocosm allows for experiments to be conducted as close to natural conditions as possible in a medium sized enclosed system. A microcosm is a small contained ecological system.

public mental models of OA and helped to establish how the public conceptualised OA.

What are public perceptions of ocean acidification?

It was hypothesised that there would be low awareness and knowledge about OA as it is an unfamiliar risk. CO_2 was not perceived to be the main cause of OA, with many attributing OA to pollution from chemical and industrial waste. CO_2 was the second most selected option in the survey data but was only mentioned by two interview respondents as a possible cause. The public successfully identified some of the possible impacts that OA could bring such as damage to coral reefs and other marine organisms. Socioeconomic impacts were also thought to be an issue but environmental impacts were selected as more likely to occur. Interactions such as river system run-off and CO_2 emissions were thought to be the most likely to interact with OA. Climate change was also seen as an important consideration. Finally, the public thought that reducing chemical and industrial waste would be the most effective response to OA with raising awareness about OA amongst the public also important.

As well as assessing 'knowledge' about OA other aspects contributed to people's perception of OA with three themes identified from the thematic analysis; emotion, information sources/trust, and risk. This risk issue was perceived as highly negative and of concern to participants. Trust in information was as expected, with scientists being trusted to give accurate information on this risk issue though the internet was also heavily relied upon to retrieve information. People did perceive OA as posing a serious risk to the environment but not as a personal risk. The importance of this risk issue was also seen as not particularly high. The results found in the survey were in line with the interview data for the most part, aside from the differences mentioned here (e.g. cause of OA perceived to be CO_2 much lower in interview respondents than survey participants).

It is fairly clear that experts and the public perceive OA from different perspectives with little overlap, and this will now be examined.

What are the differences and similarities between the experts' and the public perceptions of ocean acidification?

There are clear differences and similarities with the expert and public mental models explored in this thesis. The public recognised that human activity is causing OA and

established the ocean is reducing in acidity. However, pollution from chemicals and industrial waste was seen as the main cause with CO_2 less often identified. They also matched with the experts on impacts, particularly environmental impacts, though the public did mention more socioeconomic impacts than the experts but thought that there was more likelihood that impacts would be environmental. The sub-themes in interactions were also matched though how these would interact were confused (such as ice-melt); river system run-off was mentioned as being one of the main interactions. With regards to responses to OA there was agreement between the public and the expert samples, but the public emphasised a reduction in pollution of chemical and industrial waste as well as raising public awareness about OA. Reducing carbon emissions was not seen as important amongst the public though was the main response required, according to the experts.

6.2 Discussion

The unfamiliar risk of OA was closely examined to assess how this risk is understood in the general population. The main body of this chapter will provide a discussion of how the findings fit into the literature, particularly other mental models studies, climate change perceptions and any relevant theoretical implications.

6.2.1 Knowledge and mental models

It is important to consider how knowledge plays a role in determining public perceptions of OA. The findings in this piece of work showed that knowledge about OA was low amongst the public, with those in the interviews feeling that they could not answer the questions about OA confidently because they did not possess enough scientific knowledge. Some respondents claimed that they were trying to make sense of it as they talked, essentially 'constructing' their mental model during the interview (Pidgeon et al., 2012). Knowledge is important in engagement and risk communication for mental models work (as will be discussed later) but it is not key for creating a mental model of a risk.

Emerging risks are unfamiliar and people may lack a mental model for these (Fleishman-Mayer & Bruine de Bruin, 2013) but people were able to construct a mental model for OA. Comparing the earlier mental model work (e.g. Read et al., 1994) exploring climate change perceptions to the current work on OA showed that these risks could be conceptualised despite low levels of knowledge on the topics.

Other related knowledge was brought in to try and explain what these risks were (as you would expect in this approach) and though it resulted in misconceptions such as chemical and industrial waste which was perceived to be the main cause of OA as well as the solution (by reducing chemical and industrial waste), it was evident that people could use their knowledge to create a mental representation of OA.

The evolution of knowledge about climate change and increase in awareness of the issue over time (Capstick et al., 2015) may reflect how knowledge about OA will change over time. Though less people conflated global climate change and stratospheric ozone depletion and more people had correct knowledge about climate change when mental models were examined more recently (Reynolds et al., 2010), changes were not as large as expected by the authors. The traditional mental model work applied the 'deficit' model when exploring public understanding of risk issues such as climate change in order to develop risk communications. For climate change this approach does not seem to have improved public understanding despite the media coverage and political attention. There is no shortage of accessible information on the topic however it is possible that the public do not have the desire to fill this 'information-deficit' in order to help them take appropriate actions, as government and experts are seen as more knowledgeable and thus responsible for taking action.

OA is an emerging risk, but in the future may be a commonly recognised term in the same way as climate change is today. It is possible that some of the misconceptions that were found in this piece of work will endure and that people do not take appropriate actions having transferred responsibility to the government. Though this was a clear response in the interviews, participants who completed the survey thought that raising awareness in the public was very important and government response was not chosen as the main way to reduce OA. This difference may be down to the phrasing of the option with regards to government responding to OA, as it read 'Communication with policymakers' and was taken from the expert model. From a laypersons' point of view this may have affected the number of people selecting this option. Having said this, by selecting the option to reduce chemical and industrial pollution people may feel this is linked to government and business responsibility.

6.2.2 Addressing the 'knowledge-deficit'

By providing people with more information on OA one would hope to fill a knowledge gap and engage people with the risk issue at hand. Knowledge is not just about facts

but about understandings held within social, cultural and political contexts (Sturgis and Allum, 2004). By approaching people as 'rational actors', the importance of factors such as personal values, trust in the information source and identity are effectively ignored. The desire for more information about climate change (as seen in Darier & Schüle, 1999) and that of OA here should be addressed with information being provided. Public understanding of science is still of key importance and the confusion about the basic chemistry of OA and associations with more everyday understandings of acid, highlights the need for accessible scientific knowledge. By providing such information to boost knowledge and improve education, marine scientists believe engagement will be improved for issues such as OA (Guest et al., 2015; Fauville et al., 2011; 2013) but this thesis demonstrates why simply filling the 'knowledge-deficit' will not necessarily do this. Lion, Meertens and Bot (2002) found that those they surveyed about what information they would want about an unknown risk asked for information about what it was, exposure and the impacts. This is in line with what interview respondents said they wished to know about for OA, particularly for the impacts as well as what could be done about it.

6.2.3 Making the unfamiliar familiar

Prior knowledge is crucial in determining risk perceptions particularly for unfamiliar risks such as OA. It was clear from the interviews that the term 'ocean acidification' was associated with known risks which were both related to the terminology - e.g. acid rain - and also associated risks that were very general and well understood, e.g. pollution. Visschers, Meertens, Passchier and deVries (2007) tested how people make associations between unknown and known risks and determined that it could be explained by the semantic network model or spreading activation theory (Collins & Loftus, 1975). There was a semantic connection to OA for the associated risks that were mentioned by respondents which may provide an explanation for how respondents made OA familiar. If the semantic network model was applied to the interviews on OA it may follow this process: When respondents were asked about OA the term may have activated the concept of 'ocean risks' and spread to include 'water risks' resulting in concepts such as 'industrial and chemical pollution' and associations

like ‘acid rain’ being made. This is only one possible explanation but it may well have played a part in how OA was conceptualised.

Social representations of OA were seen through the imagery associated with the risk, the emotions evoked, and the causes and impacts identified by the public. For example, social representations of other risks that formed initial associations (such as acid rain, and pollution from chemicals and industrial waste) were applied to help create a mental model of OA. These associations helped to concretise and objectify OA once initial anchoring took place mainly through the negative affect experienced from this unknown risk, similar to that experienced with unfamiliar technology or emerging risks e.g. GM food and nanotechnology (Pidgeon, Harthorn & Satterfield, 2011). Though social representations theory is a useful lens for looking at how people have constructed their representations of OA, it is difficult to determine if the constructions are more individualistic or form part of a wider societal representation due to the unfamiliarity with this risk issue. In this thesis, social representations elaborate and create images of how OA is perceived to gain a deeper understanding of how OA is conceptualised. One of the main arguments with SRT is that it is too vague and too broad to explain how the public think about a risk. The complexity of the processes behind the formation of social representations are clear and it can be difficult to predict what representations will be formed (Joffe, 2003). SRT focuses on the complexity of common-sense thinking and the how and why social representations are created, and provide a starting point for understanding conceptualisations of OA.

Affective imagery has been shown to engage people with climate change and contribute to the formation of risk perceptions (Smith & Leiserowitz, 2012; Lorenzoni et al., 2006). The images were also important in helping to create mental models of OA. Research has shown that using negative affect to engage people is not the most effective strategy (O’Neill & Nicholson-Cole, 2009) but there is still interest in using affective imagery to help make issues like climate change or OA less abstract. Boomstra, Pahl and Andrade (2016) found that when participants were asked to recall environmental change messages mental imagery was more likely to be recalled than the textual information. The positive or negative affect frame of the message did not result in a difference between the vividness of mental imagery recall. Furthermore, this mental imagery could be positively associated with behavioural change intentions and with self-reported changes. This study was tentative and acknowledged that there was much more to explore to ascertain what other factors could influence this

approach. There is potential to use imagery in this way and explore how OA is framed in future risk communications. I would argue that 'ocean acidification' is far less abstract than climate change. Previous work showed that 'global warming' was more negatively affective than 'climate change' and made people feel more concerned (Leiserowitz et al., 2014; Whitmarsh, 2009b) but did not mean people were necessarily more engaged. The terminology around OA and how to frame it will have implications for those communicating this issue in the future.

6.2.4 Analytical vs. affective approach

Though mental models work tends to focus on the analytical approach whereby risk perceptions are formed by rational information processing systems, it is clear that affective risk evaluations play a significant role (Slovic et al., 2004; Thomas et al., 2015). Those interviewed were trying to make sense of an unknown risk based on any knowledge they deemed relevant but also through word associations, affect and links to other risks. Without using heuristics and affective means, responses would have been limited and produced a simplistic mental model because of the unfamiliarity and novelty of the risk. As we have seen in the literature and in the findings here, OA is perceived by the public as a negative risk which is of concern despite OA simultaneously being an unfamiliar risk issue (Gelcich et al., 2014; Frisch et al., 2015; Capstick et al., 2016). This is consistent with thinking within the psychometric paradigm as OA is an unknown risk that would be expected to score highly on the dread dimension, because OA is associated with a perceived lack of control and could potentially be catastrophic (Slovic, 1987). However, in the regression model exploring concern about OA there was a strong correlation with knowledge, as greater levels of knowledge were linked to greater concern so even when OA was more familiar and less unknown, it still scored highly on the dread dimension. Even if there is a higher degree of knowledge about OA it is still an uncertain risk with many unknowns so could still be classed as unfamiliar.

Affect also influenced the acceptability of OA with strong negative emotions shown in those who saw OA as less acceptable, similar to the findings of Spence et al. (2010) for nuclear power acceptance. The affect heuristic influences risk judgements made (Slovic & Peters, 2006) and the results suggested that OA was perceived as high risk with low benefits and elicited high levels of concern as expected. Previous work which examined public acceptance of unfamiliar technology (i.e. nuclear energy, genetic

modification and nanotechnology) have all shown acceptance is affected by positive versus negative feelings, and risks versus benefits (Spence et al., 2010; Pidgeon et al., 2005; Pidgeon et al., 2011). However, there are other factors which influence how acceptable a risk is perceived to be as shown in work by De Groot, Steg and Poortinga (2013). They found that values were part of the explanation behind the acceptability of nuclear energy with values directly related to perceived risks and benefits which in turn related to the acceptability of nuclear energy.

The importance of values in the formation of risk perceptions is highlighted in the literature examining climate change (Leiserowitz, 2006), and also appears to play a role in how OA is perceived. In this thesis two cultural worldviews were assessed; egalitarianism and individualism, which are seen to be the two most salient for predicting climate change perceptions (Capstick & Pidgeon, 2014a). Egalitarianism did not contribute to the acceptability of OA in the regression analysis though it was important with regards to concern about OA, replicating Capstick et al. (2016). The main consideration about the role of worldviews is the polarising effect of climate change (Kahan, 2012). Capstick et al. (2016) found that framing OA as part of climate change resulted in those with more individualistic worldviews being less concerned about OA than those who held a more egalitarian worldview. This will be discussed in detail later when risk communication strategies are explored but the association with climate change is likely to be a serious factor in risk communication.

6.2.5 Pro-environmentalism, place attachment and psychological distancing

Research has shown that a water environment is important as it is restorative, and being in a natural aquatic environment can help people to relax. White et al. (2010) show that it is seen as more positively affective and is generally preferred to a built environment absent of any water features. In this context, it makes sense that when marine environments are threatened people express high levels of concern. As anticipated place attachment was the strongest predictor in the regression analysis on concern. This emotional attachment to the ocean was unsurprising as the ocean is frequently associated with leisure and tourism and is important for many livelihoods. This was also mentioned in the current mental model interviews; where participants acknowledged potential socioeconomic impacts affecting communities dependent on the ocean including possible impacts on tourism and leisure industries. The impacts of OA have already affected people living on the US West Coast including Alaska, where

these impacts are both personal and have been economically damaging (Donkersloot, 2012). This population is attached to the ocean because people rely on marine resources and marine impacts could cause potentially serious issues for people. Under such circumstances OA is local and more 'visible' to those who are experiencing it, but this is not likely to be the case for wider society.

Barriers to engagement with less publicly-visible impacts like OA include psychological distancing (Lorenzoni et al., 2007) and we saw this in the interview data as people felt OA was a low personal risk and would affect others who heavily relied on the ocean in other parts of the world. Though OA is likely to be psychologically distant for most people, it is possible to localise the issue through the use of narratives as we have already seen (Feely et al., 2008). In the UK the issue is not as prominent as in America as there have not been any significant impacts yet (although these are possible, as set out in section 2.1.1). To localise OA in the UK highlighting the impacts of OA on the North Sea, which is a vulnerable region, may help to reduce distancing for UK respondents. It is possible that those who are more attached to the ocean will be more likely to engage with OA as was found by Scannell and Gifford (2013) with climate change. Both OA and climate change are global issues and we have already identified the challenges in framing messages for climate change. These could easily apply to OA as well and it is important to reduce the effect of distancing.

On a more general level, associations with the ocean tend to be positive and people feel an attachment to the ocean, with many holding fond memories of childhood holidays at the seaside or observing marine wildlife during boat trips. Hinds and Sparks (2008) found that participants who had grown up in a rural location identified more with the natural environment, had more positive affective connections and stronger behavioural intentions than those who had grown up in an urban environment. In the regression analyses environmental identity was a strong predictor, particularly for knowledge of OA, with affect also an important factor. Whitmarsh and O'Neill (2010) also found that strength of environmental identity could predict the likelihood that people would carry out pro-environmental behaviours. Affective connection to the environment along with environmental and place identity seem to be important in contributing to pro-environmental behaviour. Environmental identity, place and affect have been shown to be important variables in this thesis and could be very useful areas to explore in future when considering behavioural changes towards OA.

6.3 Communicating the risk of OA

Communication campaigns for climate change have yet to engage the public on a meaningful level despite this having serious impacts in parts of the world (Moser, 2010). Like OA the cause of climate change is not visible and there are no immediate visible impacts that can clearly be attributed to climate change. This is one of the main problems with OA; it is an invisible risk issue. This was acknowledged by Logan (2010) before there were any published surveys on public awareness of OA. Chilvers et al. (2014) had one respondent amongst 20 mention that OA visibility was low including a lack of media coverage on the issue, in contrast to other marine risks such as coastal erosion, similar to the interview data in this piece of work. Making OA more visible is possible and may help to make the issue more prominent for people. For example, BIOACID (the German research network on OA) published experiments which could easily be carried out to illustrate the basics of OA (BIOACID, 2012). One of these experiments involved filling a bottle with water along with a pH indicator and then blowing into the bottle to add CO_2. The indicator will change colour from green to yellow as the water becomes more acidic. Conducting these kinds of experiments and applying them locally to make OA more relevant will help to boost basic awareness, but it is hard to see how experiments like this would be done outside of an educational environment like schools, colleges or universities.

OA could be described as a hidden hazard as it is both hidden due to its nature, and the nature of societies or culture in which it occurs. Kasperson and Kasperson (1991) outlined an explanation for why some risks are attenuated even though they pose a real threat. They categorise these hidden hazards depending on the characteristics they possess. OA can be characterised as a 'global elusive hazard' as there is a lag time between activities or cause and effect; atmospheric CO_2 from anthropogenic emissions altering the chemistry of the ocean to a serious and noticeable degree. The slow process of OA means that many parts of the world, including the UK, are yet to be concerned or impacted by OA. Jefferson et al. (2014) also found that visible issues like plastic in the ocean were more prominent to the public than abstract invisible ones like OA. In this thesis, it was clear that people were concerned about OA and Capstick et al. (2016) found that concern levels increased once people received information about this risk issue. It would seem that for those receiving information this issue was amplified. However, during the interview respondents stated that on a day-to-day basis OA was unlikely to be of concern to them. Like climate change it was a secondary

concern compared to other issues within their daily lives (Lorenzoni & Pidgeon, 2006). Both of these risks are attenuated though OA unlike climate change is not a familiar risk with few people aware of it. OA is still fairly novel so it may simply be that it has not yet had the same media attention or coverage as climate change.

6.3.1 Trust and information sources

It is well-established that people trust scientists to provide accurate information to a greater degree than the media, government and industry on numerous risks (Poortinga & Pidgeon, 2003), with distrust in certain information sources including the mass media and industry who were seen as likely to exaggerate or make information biased (Lorenzoni et al., 2007). This was also found for OA with scientists chosen as the most likely source to get information about OA from, as well as being the most trusted information source. We have already seen the politicisation of climate change. Despite the issue receiving increased coverage and more people becoming aware of climate change, credibility behind the information has been damaged. Alongside media coverage it has become a divisive issue with increasing scepticism (Whitmarsh, 2011; Capstick & Pidgeon, 2014b).

With the increase in media coverage on OA this divisiveness has already begun, with a complaint over the misrepresentation of an article about OA as 'alarmist' reaching the press watchdog (see The Guardian, 2017 for an overview). According to James Delingpole (a well-known climate sceptic in the UK media), OA has been introduced because global warming is supposedly no longer occurring and interested parties have a political and financial agenda to continue with research projects, green investments etc. in relation to climate change. Though this viewpoint (that climate change is not happening or is a conspiracy) is only seen in a marginal population, the association with climate change could be damaging to successful future risk communications for those who do not believe in climate change.

The dissemination of information and how trustworthy it is will depend on the information source. Though people trust scientists to provide accurate information many use the internet and the news to get their information. Recent events have shown that as expertise has been downplayed, the distrust in media appears to have increased and social media has become more prevalent as an alternative information source. During the political events of 2016 including Brexit and the American presidential election, the introduction of terms such as 'post-truth' and the growing volume of a

new type of 'fake news'[6] will be a real threat to the ability of scientifically accurate information reaching the necessary audience.

6.3.2 The role of experts

As discussed in section 3.2.3, expertise appeared to be downplayed during the Brexit referendum campaign with experts derided in the media for making claims such as possible negative economic impacts affecting the UK if it left the EU. Of course, experts are not infallible (Fischhoff et al., 1982) as seen after Chernobyl and the impact on sheep movement. Following Chernobyl, restrictions on sheep movement and sales were applied by the UK Ministry of Agriculture with farmers' local knowledge about environmental conditions being discounted by scientists (Wynne, 1996). For example, farmers' expertise was ignored when experiments were being devised and carried out, resulting in experiments that did not work or were unrealistic. Despite their criticisms, the farmers recognised that they had to believe (if not trust) the experts about the contamination but they had their own beliefs too. Where there is controversy and debate expert and public views can diverge but even when credibility and trust has been lost, experts are generally perceived to be an authority and in control of the situation. The worth of expert views is likely to have been damaged after such events but after 'Climategate' individual factors such as cultural worldview were found to influence whether people trusted scientists about climate change (Leiserowitz, Maibach, Roser-Renouf, Smith & Dawson, 2013). Moving forward, the role of experts in communicating emerging risks such as OA will possibly become more important particularly for those risks which could be quite complex. Though there is consensus on the cause, process and response to OA, the impacts and to what degree certain interactions will affect the severity of OA are less certain. Throughout the interviews respondents focused on the impacts of OA and tried to envisage how it would impact on them in their lives or on society; a very uncertain area. Respondents also stated that this would be the main thing that they would want to know about if they could ask an expert.

[6] 'Post-truth' defined by OED as 'Relating to or denoting circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief'

'Fake news' can be described as fabricated or completely made up news stories, usually created to deliberately mislead readers rather than to entertain or generate income.

Scientific certainty on climate change is addressed by the IPCC in the assessment reports by providing confidence levels for its findings (IPCC, 2014). Others have used expert elicitations to illustrate expert judgements on uncertainties (Thomas, Pidgeon, Whitmarsh & Ballinger, 2016), however the authors make the point that these judgements may have been influenced by heuristics and future thinking. Experts have their own perspective on a particular risk issue which we saw in the construction of the expert mental model on OA. Landström, Hauxwell-Baldwin, Lorenzoni and Rogers-Hayden (2015) showed that experts thought that they understood scientific uncertainty differently from the public. Many of those interviewed simply thought that the public had a poor understanding of scientific uncertainty, with many referring to the media's flawed representation of it. This may be problematic in future communications of OA as scientists need to portray the risk of OA accurately with the certainties and uncertainties included. Landström et al. (2015) found that scientists wanted to give media interviews in order to communicate their research to the public despite their negative view of media coverage on risk issues. As discussed already, addressing the knowledge-deficit and informing the public about OA is not enough and there are a range of barriers to engagement with OA (Lorenzoni et al., 2007; Gifford, 2011).

6.3.3 Some thoughts about OA risk communication

It is important to consider the lessons learned from climate change communications and how these will influence OA communications. One contentious issue already discussed is how to frame OA, whether it should be contextualised and linked to climate change or kept as a separate issue in risk communications. The issue with OA as opposed to climate change is that it is potentially even more difficult to understand because of confusion over basic chemistry and misunderstanding of pH (Logan, 2010). However, unlike OA, climate change has been reported on a regular basis and for many decades in the media. As seen in mental models work the anthropogenic causes of climate change used to be confused with the hole in the ozone layer or climate used to be talked about simply as weather; both of these are still seen in public discourse but are less prevalent (Read et al., 1994; Reynolds et al., 2010).

Designing communications to engage people with OA also needs to consider framing effects. Framing OA as a part of climate change on the surface seems most appropriate, as the main objective would be to reduce CO_2 emissions because of the impacts on the

ocean. OA is caused by anthropogenic CO_2 and is an impact of climate change in the marine environment. One problem with framing this issue as part of climate change is that of climate fatigue, scepticism and the fluctuation in concern about climate change that has been seen over the years (Capstick et al., 2015). By linking OA to climate change there is a risk of OA being dismissed by some members of the public, particularly those with more individualistic values.

There are pros and cons to framing OA as a climate change impact or as a risk issue in itself. In the US cultural worldviews have been shown to polarise individuals in relation to climate change (Kahan, 2012) and Capstick et al. (2016) also showed this pattern in their UK sample when information on OA was framed as part of climate change. Accordingly, those who are more individualistic and less concerned about OA may be less likely to engage with the risk issue. Sceptics of climate change may also fall into this category, in which case OA will become just another polarising issue for them. However, the majority of the population do not share this view and believe in climate change while also claiming to be concerned about it. Egalitarians tend to be more environmentally aware and concerned about climate change so this should be reflected for OA.

When proposing solutions to climate change, there is more of an emphasis on adaptation measures or SRM techniques (though these are of minority interest), which may not be as useful for dealing with OA as it does not address the cause; CO_2. As concern about climate change continues to increase in the scientific community with discussions of thresholds and tipping points, the public need to be aware that some risks (like OA) are important in their own right. By framing it as part of climate change there is a danger that this may not be apparent; that OA has its own unique global consequences which climate change interacts with.

Framing OA is very difficult and though it may be more appropriate to frame it as a separate and individual risk issue, there are plenty of valid reasons to frame it as part of climate change. Climate change is a well-known topic and framing messages about OA as part of climate change may make OA less complex as the role of CO_2 can easily be connected. However, OA will need to be explained and there is an argument that it would be better to focus on one abstract issue without reference to climate change. The carbon cycle and the equilibrium that occurs between carbon sinks provides a clear scientific background and chemical changes can be demonstrated to show

acidification happening. As a separate issue, OA is clearly global with potentially serious impacts. It requires CO_2 reduction rather than other measures that do not mitigate the risk. Lastly, the connection to climate change seems apparent. As soon as CO_2 emissions and how these have impacted on the ocean are mentioned, climate change and environmental issues are likely to be associated.

Other frames may be more effective with the economy or health being the focus as image association is frequently on threats to marine organisms or ecosystems (Capstick et al., 2016). Schuldt et al. (2016) found that when the impact of OA on oysters was framed as an issue of public health it was more salient for people than if it had been framed as oyster health. Framing the issue is only one small aspect of the design of risk communications. Thought also needs to go into how communications can be done differently to climate change to engage people more effectively. There are many barriers which prevent public engagement and behaviour change with climate change and though there are some barriers which can be overcome or reduced when considering OA, there are still many others shared with climate change (Lorenzoni et al., 2007). The suggestions made will undoubtedly have further difficulties due to the multi-faceted challenges with communicating this risk issue (Moser, 2016).

6.4 Recommendations

In this thesis, we have seen the complexity of public perceptions of OA and how they conceptualise this risk issue. The exploration of psychological factors that help explain these risk perceptions along with previous climate change risk perceptions and engagement enables me to set out some recommendations for OA risk communications. Before discussing these, it is helpful to examine recent successful environmental campaigns which are connected to the ocean.

Visible pollution such as plastic is one of the most mentioned problems with the ocean according to the public (Jefferson et al., 2014). To engage people with this issue the impacts on marine life were highlighted with media showing images of dead fish and birds with stomachs full of plastic that they had consumed mistaking it for food (e.g. Daily Mail, 2014). Over time this coverage along with other environmental concerns about plastic resulted in plastic bag charges being applied nationally in the UK with legislation brought in to impose this and plastic bag usage dramatically reduced by around 80% (Poortinga, Sautkina, Thomas & Wolstenholme, 2016). Another

campaign which gained recognition more recently was also related plastic pollution but not one as visible or considered before. Microbeads used in toothpaste, facewashes and other cosmetics were highlighted using the same techniques and visual imagery resulting in some larger companies pledging to no longer use them. This is still an ongoing campaign with a call to pass legislation banning microbeads in products (BBC News, 2016).

Both these campaigns emphasised a connection to the sea and marine organisms. There is evidence for this as Grajal et al. (2017) found a relationship between a sense of connection to zoo and aquarium animals and self-reported pro-environmental behaviours. Associations with the ocean tend to be positive with people expressing concern for marine life such as seals, dolphins or whales (Howard & Parsons, 2006). People's connectedness was enhanced by the affective imagery used in media coverage. The affective response to OA and concern expressed in the public, along with concern about the impacts on marine organisms was clear in both the qualitative and quantitative data. In the interviews people referred to the attraction of coral reefs to holidaymakers and how damage to these would impact on tourism and leisure. In the survey over half of the sample found OA elicited a negative feeling with more than a third feeling neutral about it. For both those interviewed and those surveyed the impacts on organisms such as coral reef were cited as one of the main impacts as well as impacts on the marine food chain. We know that using visual representations are engaging and can be used for communicating complex information and this approach would also make OA visible (O'Neill & Smith, 2014). Designing OA communications in the same vein as the campaigns mentioned would be one way to engage people with OA and if presented suitably could encourage behaviour change. It is worth mentioning that the negative affect people associate with OA may present difficulties, so it is necessary to ensure the message also has a positive element and not to simply rely upon easy fear appeals which could then have the opposite effect (O'Neill & Nicholson-Cole, 2009). To successfully engage people with OA, a positive aspect should be incorporated (Pidgeon & Fischhoff, 2011) such as solutions to reduce and eventually mitigate this risk. Duarte et al. (2015) states that the disruptive changes to the ocean ecosystems need to be investigated thoroughly and scientists should try and confer hope to society. This is made more difficult as it is a global problem with an invisible cause; but the positive emotions associated with marine organisms can help to successfully engage the public if this is done appropriately.

Despite OA being a global issue local actions can lead to broader actions for coastal areas and even small-scale actions in a community are worthwhile (Cooley et al., 2016). Legislative action was taken in the Pacific Northwest US reducing the impacts of the OA that was causing serious problems for communities and local industries. Localising the issue is key such that it becomes closer in space, time and society as well as less uncertain for people (Spence et al., 2012). In the interviews visibility of the risk was most mentioned when respondents were asked for their first thoughts or images of OA:

"...we'll go down to the edge of the ocean and we'll still see it and we'll think yeah and we'll see the sun setting but underneath the surface of the ocean I think there could be a lot of serious, serious problems." (Darrel)

Those interviewed were concerned about OA on both a local and a global scale but very few mentioned local impacts. Including details about the UK seas, organisms and life around local coastlines in communications will help make OA more visible and relevant to people.

Communications should include the areas of scientific consensus and what is certain about OA including the way to mitigate or adapt to this risk. Capstick et al. (2016) found that participants that they surveyed felt that there was scientific consensus on what caused OA but this was linked to whether they perceived climate change to be natural or anthropogenic. However, in the mental models interviews many felt that there was consensus around the impacts and solutions but not the cause of OA. The framing of information around scientific consensus will be important, but it is clear that people are uncertain about the consensus on OA overall based on these findings. This may also be due to the low awareness around the risk issue more generally. The misconceptions that have been identified (e.g. OA being caused by acid rain, chemical waste, or that OA would burn skin) should also be rectified and messages should clarify what it is not (Danielson & Tanner, 2015). This may help reduce the fearful and negative imagery we have seen associated with OA.

There was a desire from respondents to know more about OA and what actions they could personally take. As stated earlier, providing some useful actions that can be taken at an individual or community level may increase engagement with the issue especially if associated with possible local impacts of OA. There were clear differences between the expert and public perceptions of OA as some public interview

respondents felt that priorities of policymakers should be to improve education amongst members of the public. They felt that it was important that policymakers should increase awareness of OA and its potential effects on the marine ecosystem (Logan, 2010). Interview respondents said that they felt embarrassed that they could not answer questions on OA or were annoyed that they had not heard about this risk issue. Suggestions made by respondents were to raise the profile of OA in the public domain through environmental campaigns or advertisements. The information source is crucial but the most popular sources used are not necessarily the most reliable or accurate. In the interviews the majority of people said that they accessed the internet (including news sites) or watched television news. In the surveys these resources were also heavily relied upon but scientists were also frequently cited as a trustworthy information source about OA. Fletcher et al. (2009) surveyed museum visitors and found that people were unsure where to go to get reliable information for web-hosted information on marine environmental issues yet this is one of the main sources used.

Experts will become more important in ensuring emerging risks are understood by members of the public. Cross-disciplinary communication is essential between natural and social scientists as they have different priorities but the same goal; determining the severity of the risk or how to successfully communicate the findings in order to provide society with accurate and up-to-date information. How trustworthy individuals find information sources will always be an issue and may be made more complicated by concepts such as motivated reasoning whereby people avoid a risk through dissonance (Festinger, 1962). Alternatively, trust may be influenced by confirmation bias whereby people consume or seek out information which matches their belief system (Nickerson, 1998).

These are only a few recommendations as the findings in this thesis are exploratory and there are many barriers to successful engagement and action (Gifford, 2011). As for any communication, it is important that four basic things are clear:

1. **Message**: What is the message? The content must be clear for the receiver and not contain superfluous information which detracts from the purpose of the communication. Pilot the content with a small sample to check that it is interpreted correctly. Terminology is important as we have seen with ‘ocean acidification’ posing problems. Of course, ‘ocean dealkalinisation’ though more appropriate is far more difficult to understand and pronounce!

2. **Presentation**: How should the information be presented? This will depend on who the audience is and what the aim of the communication is. This refers not only to the format of the information but also the location (e.g. classroom, museum or on the coast) and type of interaction (e.g. exhibitions, experiments or surveys)
3. **Audience**: Who is the message for? It must be set at the right level and not be overly simplified. This is harder to do for unfamiliar risk information but by piloting the communication material and checking against mental models study findings, this can be checked. As we have seen, despite unfamiliarity with OA people were still able to develop their initial thoughts and opinions based on the information provided, associative information and on social and cultural factors.
4. **Information source**: What information source is likely to be most effective? This may be determined by the location and type of interaction but will also depend on who the receivers are.

Even if all these criteria are met, risk communications on OA will still have many challenges as I have outlined throughout this thesis. It will take time for the public and policymakers to understand unfamiliar risks but developing risk communications are not the only strategy that should be adopted. The public engagement strategies used in Science and Technology Studies (STS) could be useful whilst OA is a new and unfamiliar risk. Though the purpose of mental models is to design risk communications based on how the experts or public understand a risk issue, scholars argue that public engagement is about how interests and politics influence framing and ascertaining what constitutes knowledge about 'risk' (Pidgeon & Rogers-Hayden, 2007). Rather than address a perceived knowledge-deficit through standard risk communications the public can form their opinions and preferences through informed debate.

As solutions for minimising the effects of OA may differ from climate change, involving the public in constructive dialogue about this risk issue and possible technologies through upstream engagement methodologies will help promote action rather than just provide information (Corner et al., 2012). Through effective dialogue around OA, the values people hold and the possible wider societal implications that OA may have will mean public engagement can move away from simply

understanding mental representations and raising awareness, to incorporating their preferences into proposed solutions and actions.

6.5 Future directions and limitations

Development of future communications of the risk of OA should take into consideration the numerous aspects explored in this research. Rather than being limited by the knowledge aspect of OA as laid out in the mental models approach, other factors including emotion, risk and trust have been shown to be a part of the public's conceptualisation of OA and are equally important for both our understanding of public perceptions and future communication efforts. It could be argued that these other aspects are an artefact of the method as interview questions were worded around these areas. However, these aspects are seen in a range of other public perceptions work and are compatible with established theoretical areas and theory such as the psychometric paradigm and the affect heuristic. The methodology for mental models approaches has clear limitations, some of which have been addressed already.

The first research phase was restricted somewhat by the fact that a pre-selected set of experts were interviewed about OA and the data was collected by another researcher. Although the mental model that was constructed incorporated a variety of disciplines, it would have been insightful to interview those outside of the UKOA research programme and from other disciplines. The overall picture of OA would possibly have contained more detail and new perspectives if this had been done, though the literature review was conducted in parallel to try and plug any apparent gaps. Inevitably, the models constructed for both the expert and public groups will have been influenced by the way they were expressed and interpreted, in turn affecting the research outcomes.

The main issue with the public interviews was the unfamiliarity with the topic and low awareness of OA. Though this had been anticipated it did prove to be problematic with a few participants requiring some form of prompt. Determining mental models of unfamiliar risks can be a challenge and though there was the opportunity to provide information before conducting interviews, this was not deemed necessary due to the success of earlier mental models work on climate change. Providing information about OA at an earlier stage may have resulted in a clearer mental model of this risk issue as there would have been less need for respondents to create an initial understanding of the risk simply based on associations with the term 'ocean acidification'. However,

framing information on OA would help to shape beliefs and understandings, but in turn might result in a different mental model. The terminology used here is worth exploring further as it resulted in a strong negative affect due to associations made with acid. For example, possible approaches may be to change the term and assess negative affect comparatively, or ask people what associations they make with the term 'ocean acidification', why these associations and how they feel about it. A conclusion here is that how OA is introduced to people in future communications or deliberations will be significant in how it is interpreted.

The online survey only allowed for certain psychological factors to be explored. There is a need to evaluate the influence of values for OA perception more closely as knowledge has been shown to be less important towards risk perceptions and engagement with a risk issue. As this was an exploratory study with a mental models approach, factors such as values were not examined in great detail and the measures used were very specific, looking at cultural worldviews and environmental identity instead. This decision was made due to space restrictions within the survey. For worldviews, the individualism scale had poor reliability and the worldviews used are on different dimensions following the grid-group model with group characterised by high or low group ethos (communitarian or individualist), and grid characterised by authoritative or egalitarian roles (Lupton, 1999).

Neither of the variables included in this work explored values more generally but the measures were very important so inclusion of a values measure like the NEP, which was important in earlier work (Capstick et al., 2016) would provide a greater understanding into risk perceptions of OA.

Further research should explore climate change beliefs and how they influence OA beliefs. The polarisation caused by climate change should be examined more closely, to ascertain whether the relationship seen in previous work is replicable and directly affects intentions to support or take action to reduce OA. Various frames of OA will give different results and should be tested including economic impacts, ocean health and climate change. Place attachment was also a strong predictor in the regression analyses on concern about OA, and though it may be worth assessing if attachment to the ocean is linked to how closely people live to the ocean, this was assessed in Capstick et al. (2016) and was not a significant factor in risk perception of OA. However, the latter authors did not include a place attachment measure. As the UK

has well-known coastal areas, some more attractive than others, it is likely that people are more attached to a particular coastline.

Other possible research directions suggested by the study could be to examine media representations of OA, including those appearing in social media. As discussed in section 5.3.1 events or news coverage on OA has driven social media and may allow for some insight into how novel issues are being perceived (Upwell, 2015). As well as textual content, it is important to identify how salient visual imagery shapes public understanding of OA. Lastly, stakeholder groups such as shellfisheries and fisheries communities more generally should be involved before the impacts are serious. Assessing how these groups understand OA is important as economic loss from fisheries would impact the UK. By including industry, the government would have more reason to adopt new policies to help ameliorate OA and prevent it becoming a serious issue.

Public perceptions and understandings of new and complex risk issues like OA, show that the public are concerned about emerging risks, despite their low levels of awareness about such issues including OA. Gelcich et al. (2014) found that experts recommended that OA should be allocated increased research efforts, which they felt corresponded to the public perception that there is a lack of information around OA. As I have stressed throughout this thesis, increasing awareness - though very important - should not be the main focus. Public engagement needs to become more co-operative and inclusive to encourage motivation to act or encourage political wills in the appropriate way and result in the introduction of policies aimed to mitigate or adapt to the problem of OA.

6.6 Conclusions

As the impacts of climate change become more apparent over time, it is likely that currently 'hidden' risk issues such as OA will gain greater salience and prevalence within society. Though there are a range of measures in place for tackling climate change, there has been less thought about OA up to this point. It is clear that adapting to climate change is not necessarily a particularly effective strategy for coping with OA.

This thesis explored public risk perceptions of OA, and established that there is low public awareness around this issue. Though this has grown over the past few years,

how this issue is approached and communicated will be important to ensure that people can become successfully engaged with OA and are motivated to take action. OA has been shown to be viewed very negatively amongst the public with high levels of concern elicited, especially for the environment and marine organisms. The findings in this thesis also matched up to earlier work on public perceptions research on OA.

The mental models approach was successful in that it enabled this initial exploration of how people understand the complex risk of OA. This thesis has shown that the traditional mental models approach, which focuses on knowledge, can be built upon with contextual factors, such as affect and identity; important in determining risk perceptions of OA. Further public perceptions and engagement must be carried out to ensure that effective risk communications can be created for OA and other emerging risk issues.

References

Albright, R., Caldeira, L., Hosfelt, J., Kwiatkowski, L., Maclaren, J. K., Mason, B. M., ... & Rivlin, T. (2016). Reversal of ocean acidification enhances net coral reef calcification. *Nature*, *531*(7594), 362-365.

Altman, I., & Low, S. (1992). *Place Attachment*. New York: Plenum Press.

Atman, C. J., Bostrom, A., Fischhoff, B., & Morgan, M. G. (1994). Designing risk communications: Completing and correcting mental models of hazardous processes, Part I. *Risk Analysis*, *14*(5), 779-788.

Australian Academy of Science. (2014). Response to the draft reef 2050 sustainability plan. Available at https://www.science.org.au/supporting-science/science-policy/submissions-government/response%E2%80%94draft-reef-2050-long-term

Aze, T., Barry, J., Bellerby, R. G., Brander, L., Byrne, M., Dupont, S., ... & Hauton, C. (2014). An updated synthesis of the impacts of ocean acidification on marine biodiversity: Montreal, Canada, Secretariat of the Convention on Biological Diversity, Technical Series 75, 99 pp. http://www.cbd.int/doc/publications/cbd-ts-75-en.pdf

Bakun, A. (1990). Global climate change and intensification of coastal ocean upwelling. *Science*, *247*(4939), 198-201.

Balnaves, M., & Caputi, P. (2001). *Introduction to quantitative research methods: An investigative approach*. London: Sage.

Barker, S., & Ridgwell, A. (2012). Ocean acidification. *Nature Education Knowledge*, *3*(10), 21.

BBC News (2013, 17 November). Emissions of CO_2 driving rapid oceans 'acid trip'. Retrieved from http://www.bbc.co.uk/news/science-environment-24904143.

BBC News (2014, 24 October). Science chief warns on acid oceans. Retrieved from http://www.bbc.co.uk/news/science-environment-29746880

BBC News. (2016, 3 September). Plastic microbeads to be banned by 2017, UK government pledges. Retrieved from http://www.bbc.co.uk/news/uk-37263087

BBC. (2016, 9 November). Climate change: Nations will push with plans despite Trump. Retrieved from http://www.bbc.co.uk/news/science-environment-37928593

Beaumont, N. J., Austen, M. C., Mangi, S. C., & Townsend, M. (2008). Economic valuation for the conservation of marine biodiversity. *Marine Pollution Bulletin*, *56*(3), 386-396.

Billé, R., Kelly, R., Biastoch, A., Harrould-Kolieb, E., Herr, D., Joos, F., ... & Gattuso, J. -P. (2013). Taking action against ocean acidification: a review of management and policy options. *Environmental Management*, *52*(4), 761-779.

BIOACID. (2012). The other CO_2-problem: Ocean acidification. Eight experiments for students and teachers. Retrieved from http://www.bioacid.de/upload/downloads/press/BIOACID_Experiments_en.pdf

Böhm, G. (2003). Emotional reactions to environmental risks: Consequentialist versus ethical evaluation. *Journal of Environmental Psychology*, *23*(2), 199-212.

Boomsma, C., Pahl, S., & Andrade, J. (2016). Imagining change: An integrative approach toward explaining the motivational role of mental imagery in pro-environmental behavior. *Frontiers in Psychology*, *7*, 1780.

Bord, R. J., O'Connor, R. E., & Fisher, A. (2000). In what sense does the public need to understand global climate change?. *Public Understanding of Science*, *9*(3), 205-218.

Bostrom, A., Morgan, M. G., Fischhoff, B., & Read, D. (1994). What do people know about global climate change? 1. Mental models. *Risk Analysis*, *14*(6), 959-970.

Boyatzis, R. E. (1998). *Transforming qualitative information: Thematic analysis and code development*. London: Sage.

Brander, L. M., Van Beukering, P., & Cesar, H. S. (2007). The recreational value of coral reefs: a meta-analysis. *Ecological Economics*, *63*(1), 209-218.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101.

Breakwell, G. M. (2010). Models of risk construction: Some applications to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(6), 857-870.

Breakwell, G. M. (2014). *The psychology of risk*. Cambridge: Cambridge University Press.

Breitburg, D. L., Salisbury, J., Bernhard, J. M., Cai, W. J., Dupont, S., Doney, S. C., ... & Miller, S. H. (2015). And on top of all that…: Coping with ocean acidification in the midst of many stressors. *Oceanography*, *28*(2), 48 - 61.

Brügger, A., Dessai, S., Devine-Wright, P., Morton, T. A., & Pidgeon, N. F. (2015). Psychological responses to the proximity of climate change. *Nature Climate Change*, *5*, 1031-1037.

Bruine de Bruin, W. B., & Bostrom, A. (2013). Assessing what to address in science communication. *Proceedings of the National Academy of Sciences*, *110*(Supplement 3), 14062-14068.

Bryman, A. (1988). *Quantity and Quality in Social Research*. London: Routledge.

Bryman, A. (2008) *Social research methods* (3rd ed.). Oxford: Oxford University Press.

Buckley, P., Pinnegar, J. K., Dudek, A., & Arquati, A. (2011). *Report on European public awareness and perception of marine climate change risks and impacts,*

Climate Change Impacts on the Marine Environment: Research Results and Public Perception, Seventh Framework Programme, ENV.2009.1.1.6.3 FP7-2009-1-244132. Suffolk, UK, CLAMER.

Bulkeley, H. (2000). Common knowledge? Public understanding of climate change in Newcastle, Australia. *Public Understanding of Science*, *9*(3), 313-334.

Busch, D. S., O'Donnell, M. J., Hauri, C., Mach, K. J., Poach, M., Doney, S. C., & Signorini, S. R. (2015). Understanding, characterizing, and communicating responses to ocean acidification: Challenges and uncertainties. *Oceanography*, *28*(2), 30-39.

Callaway, R., Shinn, A. P., Grenfell, S. E., Bron, J. E., Burnell, G., Cook, E. J., . . . Shields, R. J. (2012). Review of climate change impacts on marine aquaculture in the UK and Ireland. *Aquatic Conservation: Marine and Freshwater Ecosystems, 2*, 389 – 421.

Cao, L., & Caldeira, K. (2010). Can ocean iron fertilization mitigate ocean acidification?. *Climatic Change*, *99*(1), 303-311.

Capstick, S. B., & Pidgeon, N. F. (2014a). Public perception of cold weather events as evidence for and against climate change. *Climatic Change*, *122*(4), 695-708.

Capstick, S. B., & Pidgeon, N. F. (2014b). What is climate change scepticism? Examination of the concept using a mixed methods study of the UK public. *Global Environmental Change*, *24*, 389-401.

Capstick, S. B., Pidgeon, N. F., Corner, A. J., Spence, E. M., & Pearson, P. N. (2016). Public understanding in Great Britain of ocean acidification. *Nature Climate Change*, *6*, 763 – 767.

Capstick, S., Whitmarsh, L., Poortinga, W., Pidgeon, N., & Upham, P. (2015). International trends in public perceptions of climate change over the past quarter century. *Wiley Interdisciplinary Reviews: Climate Change*, *6*(1), 35-61.

Carr, A. M. (2016). Continuing to Lead: Washington state's efforts to address ocean acidification. *Washington Journal of Environmental Law and Policy, 6*, 543 – 598.

Cerrano, C., Cardini, U., Bianchelli, S., Corinaldesi, C., Pusceddu, A., & Danovaro, R. (2013). Red coral extinction risk enhanced by ocean acidification. *Scientific Reports*, *3*, 1457.

Chan, F., Boehm, A.B., Barth, J.A., Chornesky, E.A., Dickson, A.G., Feely, R.A., Hales, B., … & Whiteman, E.A. (2016). *The West Coast Ocean Acidification and Hypoxia Science Panel: Major findings, recommendations, and actions.* California Ocean Science Trust, Oakland, CA, USA.

Chilvers, J., Lorenzoni, I., Terry, G., Buckley, P., Pinnegar, J. K., & Gelcich, S. (2014). Public engagement with marine climate change issues: (Re) framings, understandings and responses. *Global Environmental Change*, *29*, 165-179.

Clayton, S., Devine-Wright, P., Stern, P. C., Whitmarsh, L., Carrico, A., Steg, L., ... & Bonnes, M. (2015). Psychological research and global climate change. *Nature Climate Change*, *5*(7), 640-646.

Clean Water Act of 1972, 33 U.S.C. § 1251et seq. (2002). Retrieved from http://epw.senate.gov/water.pdf

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, *82*(6), 407-428.

Collins, H. M., & Evans, R. (2002). The third wave of science studies: Studies of expertise and experience. *Social Studies of Science, 32*(2), 235-296.

Commonwealth of Australia. (2015). Reef 2050 long-term sustainability plan. Available at http://www.environment.gov.au/marine/gbr/long-term-sustainability-plan

Cooley, S. R., & Doney, S. C. (2009). Anticipating ocean acidification's economic consequences for commercial fisheries. *Environmental Research Letters*, *4*(2), 024007.

Cooley, S. R., Ono, C. R., Melcer, S., & Roberson, J. (2016). Community-level actions that can address ocean acidification. *Frontiers in Marine Science*, *2*, 128.

Corner, A., & Pidgeon, N. (2014). Geoengineering, climate change scepticism and the 'moral hazard' argument: An experimental study of UK public perceptions. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *372*(2031), 20140063.

Corner, A., Capstick, S., & Pidgeon, N. (2014). *Public perceptions of ocean acidification: Summary findings of two nationally representative surveys of the British public conducted during September 2013 and May 2014.* Understanding Risk Research Group Working Paper 14-01, Cardiff University.

Corner, A., Markowitz, E., & Pidgeon, N. (2014). Public engagement with climate change: The role of human values. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(3), 411-422.

Corner, A., Parkhill, K., Pidgeon, N., & Vaughan, N. E. (2013). Messing with nature? Exploring public perceptions of geoengineering in the UK. *Global Environmental Change, 23*, 938 – 947.

Corner, A., Pidgeon, N., & Parkhill, K. (2012). Perceptions of geoengineering: Public attitudes, stakeholder perspectives, and the challenge of 'upstream'engagement. *Wiley Interdisciplinary Reviews: Climate Change*, *3*(5), 451-466.

Cox, P., Niewöhner, J., Pidgeon, N., Gerrard, S., Fischhoff, B., & Riley, D. (2003). The use of mental models in chemical risk protection: Developing a generic workplace methodology. *Risk Analysis*, *23*(2), 311-324.

Craik, K. J. W. (1943). *The nature of explanation*. New York: Cambridge University Press.

Daily Mail. (2014, 10 December). Shocking image of dead albatross's stomach stuffed with plastic reveals just how much garbage is in our oceans. Retrieved from http://www.dailymail.co.uk/sciencetech/article-2868708/More-five-TRILLION-pieces-plastic-litter-seas-oceans.html

Damasio, A. R. (1994). Descartes' error: Emotion, reason and the human brain. New York: Putman Publishing.

Danielson, K. I., & Tanner, K. D. (2015). Investigating Undergraduate Science Students' Conceptions and Misconceptions of Ocean Acidification. *CBE-Life Sciences Education*, *14*(3), ar49, 1-11.

Darier, E., & Schüle, R. (1999). Think globally, act locally'? Climate change and public participation in Manchester and Frankfurt. *Local Environment*, *4*(3), 317-329.

De Groot, J. I., Steg, L., & Poortinga, W. (2013). Values, perceived risks and benefits, and acceptability of nuclear energy. *Risk Analysis*, *33*(2), 307-317.

DECC. (2016). *Public attitudes tracking survey: Wave 9 – Summary of headline findings*. London: Department of Climate Change and Energy. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/519488/PAT_Wave_17_Summary_of_key_findings.pdf

Demski, C., Butler, C., Parkhill, K. A., Spence, A., & Pidgeon, N. F. (2015). Public values for energy system change. *Global Environmental Change*, *34*, 59-69.

Demski, C., Capstick, S., Pidgeon, N., Sposato, R. G., & Spence, A. (2017). Experience of extreme weather affects climate change mitigation and adaptation responses. *Climatic Change*, *140*(2), 149-164.

Devine Wright, P. (2009). Rethinking NIMBYism: The role of place attachment and place identity in explaining place protective action. *Journal of Community & Applied Social Psychology*, *19*(6), 426-441.

Devine-Wright, P. (2013). Think global, act local? The relevance of place attachments and place identities in a climate changed world. *Global Environmental Change*, *23*(1), 61-69.

Devine-Wright, P., & Howes, Y. (2010). Disruption to place attachment and the protection of restorative environments: A wind energy case study. *Journal of Environmental Psychology*, *30*(3), 271-280.

Donkersloot, R. (2012). *Ocean acidification and Alaska fisheries: Views and voices of Alaska's fishermen, marine industries and coastal residents*. [Pamphlet] Anchorage. AK: Alaska Marine Conservation Council. Retrieved from http://www.akmarine.org/wp-content/uploads/2014/06/AMCC_ocean-acidification-views-voices-04-01-12.pdf

Douglas, M., & Wildavsky, A. (1983). *Risk and culture: An essay on the selection of technological and environmental dangers*. Berkeley and Los Angeles CA: University of California Press.

Duarte, C. M. (2014). Global change and the future ocean: a grand challenge for marine sciences. *Frontiers in Marine Science*, *1*, 63.

Duarte, C. M., Fulweiler, R. W., Lovelock, C. E., Martinetto, P., Saunders, M. I., Pandolfi, J. M., ... & Nixon, S. W. (2015). Reconsidering ocean calamities. *BioScience*, *65*(2), 130-139.

Dunlap, R. E., Van Liere, K. D., Mertig, A. G., & Jones, R. E. (2000). New trends in measuring environmental attitudes: Measuring endorsement of the new ecological paradigm: A revised NEP scale. *Journal of Social Issues*, *56*(3), 425-442.

Eddy, T. D. (2014). One hundred-fold difference between perceived and actual levels of marine protection in New Zealand. *Marine Policy*, *46*, 61-67.

Ekstrom, J. A., Suatoni, L., Cooley, S. R., Pendleton, L. H., Waldbusser, G. G., Cinner, J. E., ... & Wellman, K. (2015). Vulnerability and adaptation of US shellfisheries to ocean acidification. *Nature Climate Change*, *5*(3), 207-214.

Epstein, S. (1994). Integration of the cognitive and the psychodynamic unconscious. *American Psychologist*, *49*(8), 709-724.

FAO. (2016). The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all. Rome. 200 pp. Retrieved from http://www.fao.org/3/a-i5555e.pdf

Fauville, G., Hodin, J., Dupont, S., Miller, P., Haws, J., Thorndyke, M., & Epel, D. (2011). Virtual ocean acidification laboratory as an efficient educational tool to address climate change issues. In W.L. Filho (Ed.), *The Economic, Social and Political Elements of Climate Change, Climate Change Management* (pp 825 – 836). New York: Springer.

Fauville, G., Säljö, R., & Dupont, S. (2013). Impact of ocean acidification on marine ecosystems: educational challenges and innovations. *Marine Biology, 160*, 1863 – 1874.

Feely, R. A., Sabine, C. L., Hernandez-Ayon, J.M., Ianson, D., & Hales, B. (2008). Evidence for upwelling of corrosive "acidified" water onto the continental shelf. *Science, 320*, 1490 – 1492.

Festinger, L. (1962). Cognitive dissonance. *Scientific American*, *207*, 93-102.

Finucane, M. L., Alhakami, A., Slovic, P., & Johnson, S. M. (2000). The affect heuristic in judgments of risks and benefits. *Journal of Behavioral Decision Making*, *13*(1), 1-17.

Finucane, M. L., Slovic, P., Mertz, C. K., Flynn, J., & Satterfield, T. A. (2000). Gender, race, and perceived risk: The 'white male' effect. *Health, risk & society*, *2*(2), 159-172.

Fischhoff, B., Slovic, P., & Lichtenstein, S. (1982). Lay foibles and expert fables in judgments about risk. *The American Statistician*, *36*(3b), 240-255.

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S., & Combs, B. (1978). How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. *Policy Sciences*, *9*(2), 127-152.

Fleishman - Mayer, L. A., & Bruine de Bruin, W. (2013). The 'Mental Models' Methodology for Developing Communications. In J. Arvai & Rivers III, L. (Eds.), *Effective Risk Communication* (pp. 165-189). New York: Routledge.

Fleming, L. E., Broad, K., Clement, A., Dewailly, E., Elmir, S., Knap, A., ... & Walsh, P. (2006). Oceans and human health: Emerging public health risks in the marine environment. *Marine Pollution Bulletin*, *53*, 545-560.

Fletcher, S., Potts, J. S., Heeps, C., & Pike, K. (2009). Public awareness of marine environmental issues in the UK. *Marine Policy*, *33*(2), 370-375.

Flick, U. (2014). *The sage handbook of qualitative data analysis* (5th ed.). London: Sage.

Frisch, L. C., Mathis, J. T., Kettle, N. P., & Trainor, S. F. (2015). Gauging perceptions of ocean acidification in Alaska. *Marine Policy*, *53*, 101-110.

Gaskell, G. (2000). Individual and group interviewing. In M. Bauer & G. Gaskell (Eds.), *Qualitative researching with text, image and sound* (pp. 38-56). London: Sage.

Gattuso, J. -P., Mach, K. J., & Morgan, G. (2013). Ocean acidification and its impacts: An expert survey. *Climatic Change*, *117*(4), 725-738.

Gattuso, J. -P., Magnan, A., Billé, R., Cheung, W. W. L., Howes, E. L., Joos, F., ... & Turley, C. (2015). Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios. *Science*, *349*(6243), doi: 10.1126/science.aac4722.

Gattuso, J.-P. & Hansson, L. (2011). *Ocean acidification*. Oxford: Oxford University Press.

Gelcich, S., Buckley, P., Pinnegar, J. K., Chilvers, J., Lorenzoni, I., Terry, G., ... & Duarte, C. M. (2014). Public awareness, concerns, and priorities about anthropogenic impacts on marine environments. *Proceedings of the National Academy of Sciences*, *111*(42), 15042-15047.

Gifford, R. (2011). The dragons of inaction: psychological barriers that limit climate change mitigation and adaptation. *American Psychologist*, *66*(4), 290-302.

Glaser, B., & Strauss, A. (1967). *The discovery of grounded theory*. Weidenfield & Nicolson: London.

Grajal, A., Luebke, J. F., Clayton, S., Kelly, L. A. D., Karazsia, B. T., Saunders, C. D., ... & Mann, M. E. (2017). The complex relationship between personal sense of connection to animals and self-reported proenvironmental behaviors by zoo visitors. *Conservation Biology, 31*, 322–330. doi:10.1111/cobi.12780

Gubrium, J. F., & Holstein, J. A. (2002). *Handbook of interview research: Context and method*. Thousand Oaks, CA: Sage.

Guest, H., Lotze, H. K., & Wallace, D. (2015). Youth and the sea: Ocean literacy in Nova Scotia, Canada. *Marine Policy*, *58*, 98-107.

Harrould-Kolieb, E. R. & Herr, D. (2012). Ocean acidification and climate change: Synergies and challenges of addressing both under the UNFCCC. *Climate Policy, 12*, 378 – 389.

Hauser, D. D., Tobin, E. D., Feifel, K. M., Shah, V., & Pietri, D. M. (2016). Disciplinary reporting affects the interpretation of climate change impacts in global oceans. *Global Change Biology*, *22*(1), 25-43.

Heaton, J. (2000) *Secondary analysis of qualitative data: a review of the literature.* Full Research report ESRC 1752. Social Policy Research Unit: University of York.

Heaton, J. (2004). *Reworking qualitative data*. London: Sage.

Heaton, J. (2008). Secondary analysis of qualitative data: An overview. *Historical Social Research/Historische Sozialforschung*, 33-45.

Henwood, K. L., & Pidgeon, N. F. (1992). Qualitative research and psychological theorizing. *British Journal of Psychology*, *83*(1), 97-111.

Hewson, C., Vogel, C., & Laurent, D. (2016). *Internet research methods* (2nd ed.). London: Sage.

Hinds, J., & Sparks, P. (2008). Engaging with the natural environment: The role of affective connection and identity. *Journal of Environmental Psychology*, *28*(2), 109-120.

Hinzman, L. D., Bettez, N. D., Bolton, W. R., Chapin, F. S., Dyurgerov, M. B., Fastie, C. L., ... & Jensen, A. M. (2005). Evidence and implications of recent climate change in northern Alaska and other arctic regions. *Climatic Change*, *72*(3), 251-298.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., ... & Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science*, *318*, 1737-1742.

Hohenemser, C., Kasperson, R. E, & Kates, R. W. (1985). Causal Structure. In R. W. Kates, C. Hohenemser, & J. X. Kasperson (Eds.), *Perilous Progress: Managing the Hazards of Technology* (pp. 25-42). Boulder, CO: Westview Press.

Höijer, B. (2010). Emotional anchoring and objectification in the media reporting on climate change. *Public Understanding of Science*, *19*(6), 717-731.

Hönisch, B., Ridgwell, A., Schmidt, D. N., Thomas, E., Gibbs, S. J., Sluijs, A., ... & Kiessling, W. (2012). The geological record of ocean acidification. *Science*, *335*(6072), 1058-1063.

Honjo, S., Eglinton, T. I., Taylor, C. D., Ulmer, K. M., Sievert, S. M., Bracher, A., ... & Van Mooy, B. (2014). Understanding the role of the Biological Pump in the Global Carbon Cycle: An imperative for Ocean Science. *Oceanography*, *27*(3), 10-16.

Howard, C., & Parsons, E. C. (2006). Attitudes of Scottish city inhabitants to cetacean conservation. *Biodiversity and Conservation*, *15*(14), 4335-4356.

Hughes, T. P., Day, J. C., & Brodie, J. (2015). Securing the future of the Great Barrier Reef. *Nature Climate Change*, *5*(6), 508-511.

Hynes, S., Norton, D., & Corless, R. (2014). Investigating societal attitudes towards the marine environment of Ireland. *Marine Policy*, *47*, 57-65.

IGBP, IOC, & SCOR. (2013). Ocean Acidification Summary for Policymakers – Third symposium on the ocean in a high-CO_2 world. International Geosphere-Biosphere Programme, Stockholm, Sweden. Retrieved from http://www.igbp.net/download/18.30566fc6142425d6c91140a/1385975160621/OA_spm2-FULL-lorez.pdf

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (Eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. (2014). Annex II: Glossary. In Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, … J. C. Minx (Eds*.), Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jaspal, R., & Nerlich, B. (2014). When climate science became climate politics: British media representations of climate change in 1988. *Public Understanding of Science*, *23*(2), 122-141.

Jefferson, R. L., Bailey, I., Laffoley, D., d'A., Richards, J. P. & Attrill, M. J. (2014). Public perceptions of the UK marine environment. *Marine Policy, 43*, 327 – 337.

Jefferson, R., McKinley, E., Capstick, S., Fletcher, S., Griffin, H., & Milanese, M. (2015). Understanding audiences: making public perceptions research matter to marine conservation. *Ocean & Coastal Management*, *115*, 61-70.

Joffe, H. (2003). Risk: From perception to social representation. *British Journal of Social Psychology*, *42*(1), 55-73.

Joffe, H. (2012). Thematic analysis. *Qualitative research methods in mental health and psychotherapy: A guide for students and practitioners*, *1*, 210-223.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), 14–26.

Jones, B. M., Iglesias-Rodriguez, M. D., Skipp, P. J., Edwards, R. J., Greaves, M. J., Young, J. R., ... & O'Connor, C. D. (2013). Responses of the Emiliania huxleyi proteome to OA. *PloS one*, *8*(4), e61868.

Jordan, A., Rayner, T., Schroeder, H., Adger, N., Anderson, K., Bows, A., ... & Whitmarsh, L. (2013). Going beyond two degrees? The risks and opportunities of alternative options. *Climate Policy*, *13*(6), 751-769.

Kahan, D. M. (2012). Cultural cognition as a conception of the cultural theory of risk. Hillerbrand, R., Sandin, P., Roeser, S., Peterson, M. (Eds.). *Handbook of Risk Theory: Epistemology, Decision Theory, Ethics and Social Implications of Risk* (pp. 725-759). London: Springer London Limited.

Kasperson, R. E., & Kasperson J. X. (1991). Hidden hazards. In Kasperson, J. X., & Kasperson, R. E.. *The social contours of risk: publics, risk communication and the social amplification of risk* (Vol. 1) (pp. 115 – 132). London: Earthscan.

Kasperson, J.X., Kasperson, R., Pidgeon, N.F., & Slovic, P. (2003) The social amplification of risk: assessing fifteen years of research and theory. In N.F. Pidgeon, R.K. Kasperson and P. Slovic (Eds.) *The Social Amplification of Risk* (pp. 13-46). Cambridge, Cambridge University Press.

Kasperson, R. E., Renn, O., Slovic, P., Brown, H. S., Emel, J., Goble, R., ... & Ratick, S. (1988). The social amplification of risk: A conceptual framework. *Risk Analysis*, *8*(2), 177-187.

Kelder, J. (2005). Using someone else's data: Problems, pragmatics and provisions. *Forum Qualitative Social Research*, *6*(1), Article 39.

Kelley, A.L., Hanson, P.R., & Kelley, S. A. (2015). Demonstrating the effects of ocean acidification on marine organisms to support climate change understanding. *The American Biology Teacher*, 77 (4), 258-263.

Kelly, R. P., & Caldwell, M. M. R. (2013). Ten ways states can combat ocean acidification (and why they should). *Harvard Environmental Law Review*, *37*(1), 57 – 103.

Kelly, R. P., Cooley, S. R. & Klinger, T. (2014). Narratives can motivate environmental action: The Whiskey Creek ocean acidification story. *AMBIO: A Journal of the Human Environment*, *43*, 592 – 599. doi http://dx.doi.org/10.1007/s13280-013-0442-2.

Kempton, W. (1991). Lay perspectives on global climate change. *Global Environmental Change*, *1*(3), 183-208.

King, N., & Horrocks, C. (2010). *Interviews in Qualitative Research*. London: Sage.

Köhler, P., Abrams, J. F., Völker, C., Hauck, J., & Wolf-Gladrow, D. A. (2013). Geoengineering impact of open ocean dissolution of olivine on atmospheric CO2, surface ocean pH and marine biology. *Environmental Research Letters*, *8*(1), 014009.

Kroeker, K. J., Kordas, R. L., Crim, R., Hendriks, I. E., Ramajo, L., Singh, G. S., ... & Gattuso, J. P. (2013). Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. *Global Change Biology*, *19*(6), 1884-1896.

Krosnick, J. A., Holbrook, A. L., Berent, M. K., Carson, R. T., Hanemann, W. M., Kopp, R. J., ... & Moody, W. R. (2002). The impact of" no opinion" response options on data quality: Non-attitude reduction or an invitation to satisfice?. *Public Opinion Quarterly*, *66*(3), 371-403.

Laffoley, D. d'A., & Baxter, J.M. (2012). *Ocean acidification: The knowledge base 2012. Updating what we know about ocean acidification and key global challenges.* EPOCA, UKOA, BIOACID and MedSeA, 8pp. Retrieved from https://www.iaea.org/nael/relfiles/OA.2012.English.low_res.pdf

Landström, C., Hauxwell-Baldwin, R., Lorenzoni, I., & Rogers-Hayden, T. (2015). The (mis) understanding of scientific uncertainty? How experts view policy-makers, the media and publics. *Science as Culture*, *24*(3), 276-298.

Lee, T. M., Markowitz, E. M., Howe, P. D., Ko, C. Y., & Leiserowitz, A. A. (2015). Predictors of public climate change awareness and risk perception around the world. *Nature Climate Change*, *5*(11), 1014-1020.

Leiserowitz, A. (2006). Climate change risk perception and policy preferences: The role of affect, imagery, and values. *Climatic Change*, *77*(1), 45-72.

Leiserowitz, A. A., Maibach, E. W., Roser-Renouf, C., Smith, N., & Dawson, E. (2013). Climategate, public opinion, and the loss of trust. *American Behavioral Scientist*, *57*(6), 818-837.

Leiserowitz, A., Feinberg, G., Rosenthal, S., Smith, N., Anderson, A., Roser-Renouf, C., & Maibach, E. (2014). *What's in a name? Global warming vs. climate change*. New Haven: CT, Yale University: Yale Project on Climate Change Communication.

Leiserowitz, A., Smith, N., & Marlon, J. R. (2010). *Americans' knowledge of climate change*. New Haven, CT, Yale University: Yale Project on Climate Change Communication.

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S., & Schellnhuber, H. J. (2008). Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences*, *105*, 1786-1793.

Lion, R., Meertens, R. M., & Bot, I. (2002). Priorities in information desire about unknown risks. *Risk Analysis*, *22*(4), 765-776.

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as Feelings. *Psychological Bulletin*, *127*(2), 267-286.

Logan, C. A. (2010). A review of ocean acidification and America's response. *Bioscience*, *60*, 819-828.

Lorenzoni, I., & Pidgeon, N. F. (2006). Public views on climate change: European and USA perspectives. *Climatic Change*, *77*(1), 73-95.

Lorenzoni, I., Leiserowitz, A., de Franca Doria, M., Poortinga, W., & Pidgeon, N. F. (2006). Cross national comparisons of image associations with "Global Warming" and "Climate Change" Among laypeople in the United States of America and Great Britain 1. *Journal of Risk Research*, *9*(03), 265-281.

Lorenzoni, I., Pidgeon, N. F., & O'Connor, R. E. (2005). Dangerous climate change: The role for risk research. *Risk Analysis*, *25*(6), 1387-1398.

Lorenzoni, I., Nicholson-Cole, S., & Whitmarsh, L. (2007). Barriers perceived to engaging with climate change among the UK public and their policy implications. *Global Environmental Change, 17*, 445 – 459.

Lowe, T., Brown, K., Dessai, S., de França Doria, M., Haynes, K., & Vincent, K. (2006). Does tomorrow ever come? Disaster narrative and public perceptions of climate change. *Public Understanding of Science*, *15*(4), 435-457.

Lowe, T. D., & Lorenzoni, I. (2007). Danger is all around: Eliciting expert perceptions for managing climate change through a mental models approach. *Global Environmental Change*, *17*(1), 131-146.

Lupton, D. (1999). *Risk and sociocultural theory: New directions and perspectives*. Cambridge: Cambridge University Press.

Mabardy, R. A., Waldbusser, G. G., Conway, F., & Olsen, C. S. (2015). Perception and response of the US west coast shellfish industry to ocean acidification: The voice of the canaries in the coal mine. *Journal of Shellfish Research*, *34*(2), 565-572.

MacDiarmid, A., McKenzie, A., Sturman, J., Beaumont, J., Mikaloff-Fletcher, S., & Dunne, J. (2012). Assessment of anthropogenic threats to New Zealand marine habitats. *New Zealand Aquatic Environment and Biodiversity Report No*, *93*. Wellington, NZ: Ministry of Agriculture and Forestry.

Macnaghten, P. (2003). Embodying the environment in everyday life practices. *The Sociological Review*, *51*(1), 63-84.

Mamadouh, V. (1999). Grid-group cultural theory: an introduction. *GeoJournal*, *47*(3), 395-409.

Marx, S. M., Weber, E. U., Orlove, B. S., Leiserowitz, A., Krantz, D. H., Roncoli, C., & Phillips, J. (2007). Communication and mental processes: Experiential and analytic processing of uncertain climate information. *Global Environmental Change*, *17*, 47–58. doi:10.1016/j.gloenvcha.2006.10.004

Mathesius, S., Hofmann, M., Caldeira, K., & Schellnhuber, H. J. (2015). Long-term response of oceans to CO2 removal from the atmosphere. *Nature Climate Change*, *5*, 1107-1113.

Matthews, H. D., Cao, L., & Caldeira, K. (2009). Sensitivity of ocean acidification to geoengineered climate stabilization. *Geophysical Research Letters*, *36*, L10706.

McCright, A. M. (2010). The effects of gender on climate change knowledge and concern in the American public. *Population and Environment, 32*(1), 66-87.

McKinley, E., & Fletcher, S. (2010). Individual responsibility for the oceans? An evaluation of marine citizenship by UK marine practitioners. *Ocean & Coastal Management*, *53*(7), 379-384.

McLellan, E., MacQueen, K. M., & Neidig, J. L. (2003). Beyond the qualitative interview: Data preparation and transcription. *Field Methods, 15*(1), 63-84.

Morgan, M.G., Fischhoff, B., Bostrom, A., & Atman, C. (2002). *Risk communication: The mental models approach.* New York: Cambridge University Press.

Moscovici, S. (1984). The Phenomenon of Social Representations. In. R. Farr, & S. Moscovici (Eds.), *Social Representations* (pp. 3-69). Cambridge, Cambridge University Press.

Moscovici, S. (1988). Notes towards a description of social representations. *European Journal of Social Psychology*, *18*(3), 211-250.

Moser, S. C. (2010). Communicating climate change: history, challenges, process and future directions. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(1), 31-53.

Moser, S. C. (2016). Reflections on climate change communication research and practice in the second decade of the 21st century: What more is there to say?. *Wiley Interdisciplinary Reviews: Climate Change*, *7*(3), 345-369.

NASA. (2016, 18 January). NASA, NOAA data show 2016 warmest year on record globally. Retrieved from http://climate.nasa.gov/news/2537/nasa-noaa-data-show-2016-warmest-year-on-record-globally/

Neuman, L. W. (2011). *Social research methods: Qualitative and quantitative approaches*, (7th ed.). Boston: Pearson.

Nickerson, R. S. (1998). Confirmation Bias: A ubiquitous phenomenon in many guises. *Review of General Psychology*, *2*(2), 175-220.

Niewöhner, J., Cox, P., Gerrard, S., & Pidgeon, N. (2004). Evaluating the efficacy of a mental models approach for improving occupational chemical risk protection. *Risk Analysis*, *24*(2), 349-361.

Nisbet, M. (2016). Climate denial's Trump card. *New Scientist*, *230*(3077), 18-19.

Nordhaus, W. D. (1994). Expert opinion on climatic change. *American Scientist*, *82*(1), 45-51.

O'Connor, R. E., Bord, R. J., & Fisher, A. (1999). Risk perceptions, general environmental beliefs, and willingness to address climate change. *Risk Analysis*, *19*(3), 461-471.

Oliver, D. G., Serovich, J. M., & Mason, T. L. (2005). Constraints and opportunities with interview transcription: Towards reflection in qualitative research. *Social Forces, 84*(2), 1273-1289.

O'Neill, S. J., & Hulme, M. (2009). An iconic approach for representing climate change. *Global Environmental Change*, *19*(4), 402-410.

O'Neill, S. J., & Nicholson-Cole, S. (2009). "Fear won't do it": Promoting positive engagement with climate change through visual and iconic representations. *Science Communication*, *30*(3), 355-379.

O'Neill, S. J., & Smith, N. (2014). Climate change and visual imagery. *Wiley Interdisciplinary Reviews: Climate Change, 5*, 73–87. doi:10.1002/wcc.249

Orr, J. C. (2011). Recent and future changes in ocean carbonate chemistry. In J.P Gattuso & L. Hansson (Eds.) *Ocean acidification* (pp. 41-66). Oxford: Oxford University Press.

Palmgren, C. R., Morgan, M. G., Bruine de Bruin, W., & Keith, D. W. (2004). Initial public perceptions of deep geological and oceanic disposal of carbon dioxide. *Environmental Science & Technology*, *38*(24), 6441-6450.

Parliamentary Office of Science and Technology (POST). (2009). *Ocean acidification*. POSTnote 343. Retrieved from http://www.parliament.uk/documents/post/postpn343.pdf

Pearson, P. N., & Nicholas, C. J. (2014). Layering in the Paleocene/Eocene boundary of the Millville core is drilling disturbance. *Proceedings of the National Academy of Sciences*, *111*(12), E1064-E1065.

Pearson, P. N., & Thomas, E. (2015). Drilling disturbance and constraints on the onset of the Paleocene-Eocene boundary carbon isotope excursion in New Jersey. *Climate of the Past*, *11*(1), 95-104.

Pidgeon, N. F. (2012). Public understanding of, and attitudes to, climate change: UK and international perspectives and policy. *Climate Policy*, *12*(S1), S85-S106.

Pidgeon, N., Corner, A., Parkhill, K., Spence, A., Butler, C., & Poortinga, W. (2012). Exploring early public responses to geoengineering. *Philosophical Transactions of the Royal Society, 370*, 4176 – 4196.

Pidgeon, N., Parkhill, K., Corner, A., & Vaughan, N. (2013). Deliberating stratospheric aerosols for climate geoengineering and the SPICE project. *Nature Climate Change*, *3*(5), 451-457.

Pidgeon, N., & Fischhoff, B. (2011). The role of social and decision sciences in communicating uncertain climate risks. *Nature Climate Change*, *1*(1), 35-41.

Pidgeon, N., Harthorn, B., & Satterfield, T. (2011). Nanotechnology risk perceptions and communication: Emerging technologies, emerging challenges. *Risk Analysis*, *31*(11), 1694-1700.

Pidgeon, N., & Henwood, K. (1997). Using grounded theory in psychological research. In N. Hayes (Ed.), *Doing qualitative analysis in psychology* (pp. 245 – 273). Hove: Psychology Press.

Pidgeon, N. F., Lorenzoni, I., & Poortinga, W. (2008). Climate change or nuclear power—No thanks! A quantitative study of public perceptions and risk framing in Britain. *Global Environmental Change*, *18*(1), 69-85.

Pidgeon, N. F., Poortinga, W., Rowe, G., Horlick Jones, T., Walls, J., & O'Riordan, T. (2005). Using surveys in public participation processes for risk decision making: The case of the 2003 British GM nation? Public debate. *Risk Analysis*, *25*(2), 467-479.

Pidgeon, N., & Rogers-Hayden, T. (2007). Opening up nanotechnology dialogue with the publics: risk communication or 'upstream engagement'?. *Health, Risk & Society*, *9*(2), 191-210.

Poland, B. D. (2002). Transcription quality. In J. F. Gubrium and J.A. Holstein (Eds.). *Handbook of interview research: Context and method* (pp. 629 – 649). Thousand Oaks, CA: Sage.

Poortinga, W., Bickerstaff, K., Langford, I., Niewöhner, J., & Pidgeon, N. (2004). The British 2001 foot and mouth crisis: A comparative study of public risk perceptions, trust and beliefs about government policy in two communities. *Journal of Risk Research*, *7*(1), 73-90.

Poortinga, W., & Pidgeon, N. F. (2003). Exploring the dimensionality of trust in risk regulation. *Risk Analysis*, *23*(5), 961-972.

Poortinga, W., Sautkina, E., Thomas, G., & Wolstenholme, E. (2016). *The English plastic bag charge: Changes in attitudes and behaviour*. Cardiff: Welsh School of Architecture/School of Psychology, Cardiff University.

Poortinga, W., Spence, A., Whitmarsh, L., Capstick, S., & Pidgeon, N. F. (2011). Uncertain climate: An investigation into public scepticism about anthropogenic climate change. *Global Environmental Change*, *3*(21), 1015-1024.

Potter, J., & Hepburn, A. (2005). Qualitative interviews in psychology: Problems and possibilities. *Qualitative Research in Psychology*, *2*(4), 281-307.

Potts, T., O'Higgins, T., Mee, L., & Pita, C. (2011) *Public perceptions of Europe's Seas - A Policy Brief.* EU FP7 KNOWSEAS Project. ISBN 0-9529089-3-X

Read, D., Bostrom, A., Morgan, M. G., Fischhoff, B., & Smuts, T. (1994). What do people know about global climate change? 2. Survey studies of educated laypeople. *Risk Analysis*, *14*(6), 971-982.

Renn, O. (2011). The social amplification/ attenuation of risk framework: application to climate change. *WIREs Climate Change, 2,* 154–169.

Reynolds, T. W., Bostrom, A., Read, D., & Morgan, M. G. (2010). Now what do people know about global climate change? Survey studies of educated laypeople. *Risk Analysis*, *30*(10), 1520-1538.

Ridgwell, A., & Schmidt, D. N. (2010). Past constraints on the vulnerability of marine calcifiers to massive carbon dioxide release. *Nature Geoscience*, *3*(3), 196-200.

Riebesell, U., & Gattuso, J. -P. (2015). Lessons learned from ocean acidification research. *Nature Climate Change*, *5*(1), 12-14.

Rodrigues, L. C., van den Bergh, J. C., & Ghermandi, A. (2013). Socio-economic impacts of ocean acidification in the Mediterranean Sea. *Marine Policy*, *38*, 447-456.

Rohrmann, B., & Renn, O. (2000). Risk perception research – An introduction In O. Renn & B. Rohrmann (Eds.*). Cross-cultural risk perception – A survey of empirical studies.* (pp. 11-54). The Netherlands: Springer US.

Rose, C., Dade, P., & Scott, J. (2008). *Qualitative and Quantitative Research into Public Engagement with the Undersea Landscape in England.* Natural England Research Reports, NERR019. Natural England: Kenda, Cumbria.

Royal Society. (2005). *Ocean acidification due to increasing atmospheric carbon dioxide*. Policy document 12/05. The Royal Society, London.

Royal Society. (2009). *Geoengineering the Climate: Science, Governance and Uncertainty*. Science Policy Centre Report 10/09. The Royal Society, London.

Rudd, M. A. (2014). Scientists' perspectives on global ocean research priorities. *Frontiers in Marine Science*, *1*, 36.

Sandman P.M. (1989). Hazard versus outrage in the public perception of risk. In: V. T. Covello, D. B. McCallum, & M. T. Pavlova (Eds.). *Effective Risk Communication: The Role and Responsibility of Government and Nongovernment Organizations* (pp. 45-49). New York, NY: Plenum Press.

Scannell, L., & Gifford, R. (2013). Personally relevant climate change: The role of place attachment and local versus global message framing in engagement. *Environment and Behavior*, *45*(1), 60-85.

Schaeffer, N. C., & Presser, S. (2003). The science of asking questions. *Annual Review of Sociology*, *29*(1), 65-88.

Schaller, M. F., Fung, M. K., Wright, J. D., Katz, M. E., & Kent, D. V. (2016). Impact ejecta at the Paleocene-Eocene boundary. *Science*, *354*(6309), 225-229.

Schmutter, K., Nash, M., & Dovey, L. (2016). Ocean acidification: Assessing the vulnerability of socioeconomic systems in Small Island Developing States. *Regional Environmental Change*, 1-15.

Schuldt, J. P., McComas, K. A., & Byrne, S. E. (2016). Communicating about ocean health: theoretical and practical considerations. *Philosophical Transactions of the Royal Society. B*, *371*(1689), 20150214.

Schwartz, S. H. (1994). Are there universal aspects in the structure and contents of human values?. *Journal of Social Issues*, *50*(4), 19-45.

Scruggs, L., & Benegal, S. (2012). Declining public concern about climate change: Can we blame the great recession?. *Global Environmental Change*, *22*(2), 505-515.

Shi, J., Visschers, V. H., Siegrist, M., & Arvai, J. (2016). Knowledge as a driver of public perceptions about climate change reassessed. *Nature Climate Change*, *6*(8), 759-762.

Siegrist, M., & Sütterlin, B. (2014). Human and nature caused hazards: The affect heuristic causes biased decisions. *Risk Analysis*, *34*(8), 1482-1494.

Sillmann, J., Lenton, T. M., Levermann, A., Ott, K., Hulme, M., Benduhn, F., & Horton, J. B. (2015). Climate emergencies do not justify engineering the climate. *Nature Climate Change*, *5*(4), 290-292.

Sjöberg, L. (2000). Factors in risk perception. *Risk analysis*, *20*(1), 1-12.

Skarlatidou, A., Cheng, T., & Haklay, M. (2012). What do lay people want to know about the disposal of nuclear waste? A mental model approach to the design and development of an online risk communication. *Risk Analysis*, *32*(9), 1496-1511.

Slimak, M. W., & Dietz, T. (2006). Personal values, beliefs, and ecological risk perception. *Risk Analysis*, *26*(6), 1689-1705.

Slovic, P. (1987). Perception of risk. *Science, 236* (4799), 280 – 285.

Slovic, P. (2010). *The feeling of risk: New perspectives on risk perception*. London: Earthscan.

Slovic, P., & Peters, E. (2006). Risk perception and affect. *Current Directions in Psychological Science*, *15*(6), 322-325.

Slovic, P., Finucane, M. L., Peters, E., & MacGregor, D. G. (2004). Risk as analysis and risk as feelings: Some thoughts about affect, reason, risk, and rationality. *Risk Analysis, 24*(2), 311-322. doi:10.1111/j.0272-4332.2004.00433.x

Slovic, P., Finucane, M. L., Peters, E., & MacGregor, D. G. (2007). The affect heuristic. *European Journal of Operational Research*, *177*, 1333-1352.

Smith, N. W., & Joffe, H. (2009). Climate change in the British press: The role of the visual. *Journal of Risk Research*, *12*(5), 647-663.

Smith, N., & Joffe, H. (2013). How the public engages with global warming: A social representations approach. *Public Understanding of Science*, *22*(1), 16-32.

Smith, N., & Leiserowitz, A. (2012). The rise of global warming skepticism: Exploring affective image associations in the United States over time. *Risk Analysis*, *32*(6), 1021–1032. doi:10.1111/j.1539-6924.2012.01801.x

Spence, A., & Pidgeon, N. (2010). Framing and communicating climate change: The effects of distance and outcome frame manipulations. *Global Environmental Change*, *20*(4), 656-667.

Spence, A., Poortinga, W., & Pidgeon, N. (2012). The psychological distance of climate change. *Risk Analysis*, *32*(6), 957-972.

Spence, A., Poortinga, W., Butler, C., & Pidgeon, N. F. (2011). Perceptions of climate change and willingness to save energy related to flood experience. *Nature Climate Change*, *1*(1), 46-49.

Spence, A., Poortinga, W., Pidgeon, N., & Lorenzoni, I. (2010). Public perceptions of energy choices: The influence of beliefs about climate change and the environment. *Energy & Environment*, *21*(5), 385-407.

Spence, A., Venables, D., Pidgeon, N., Poortinga, W., & Demski, C. (2010). *Public Perceptions of Climate Change and Energy Futures in Britain: Summary Findings of a Survey Conducted in January-March 2010.* Technical Report (Understanding Risk Working Paper 10-01). Cardiff, UK: Understanding Risk Group, School of Psychology Cardiff University.

Steel, B. S., Smith, C., Opsommer, L. Curiel, S. & Warner-Steel, R. (2005). Public ocean literacy in the United States. *Ocean and Coastal Management, 48*, 97 – 114.

Stern, P. C. (2000). New environmental theories: Toward a coherent theory of environmentally significant behavior. *Journal of Social Issues*, *56*(3), 407-424.

Strong, A. L., Kroeker, K. J., Teneva, L. T., Mease, L. A., & Kelly, R. P. (2014). Ocean acidification 2.0: Managing our changing coastal ocean chemistry. *BioScience*, *64*(7), 581-592.

Sturgis, P., & Allum, N. (2004). Science in society: Re-evaluating the deficit model of public attitudes. *Public Understanding of Science*, *13*(1), 55-74.

Tashakkori, A., & Teddlie, C. (Eds.). (2010). *Sage handbook of mixed methods in social & behavioral research* (2nd ed.). London: Sage.

The Guardian (2017, 5 January). James Delingpole article calling ocean acidification 'alarmism' cleared by press watchdog. Retrieved from https://www.theguardian.com/environment/2017/jan/05/james-delingpole-article-calling-ocean-acidification-alarmism-cleared-by-press-watchdog

The Guardian. (2016, 27 May). Few Britons have ever heard of ocean acidification. https://www.theguardian.com/environment/radical-conservation/2016/may/27/ocean-acidification-polling-uk-climate-change

The National Academies of Sciences, Engineering, and Medicine. (2011). Ocean acidification: Starting with the science. Retrieved from http://dels.nas.edu/global/osb/ocean-acidification

The White House, Office of the Press Secretary. (2017). *Statement by President Trump on the Paris Climate Accord* [Press Release]. Retrieved from https://www.whitehouse.gov/the-press-office/2017/06/01/statement-president-trump-paris-climate-accord

Thomas, M., Pidgeon, N., Whitmarsh, L., & Ballinger, R. (2015). Mental models of sea-level change: A mixed methods analysis on the Severn Estuary, UK. *Global Environmental Change*, *33*, 71-82.

Thomas, M., Pidgeon, N., Whitmarsh, L., & Ballinger, R. (2016). Expert judgements of sea-level rise at the local scale. *Journal of Risk Research*, *19*(5), 664-685.

Tobler, C., Visschers, V. H. M., & Siegrist, M. (2012). Consumers‟ knowledge about climate change. *Climatic Change, 114*(2), 189-209.

Tran, L. U. (2009). *Children and adults' understanding of ocean and climate sciences*. Washington, D.C.: Paper prepared for the Committee for the Review of the NOAA Education Program.

Trope, Y., & Liberman, N. (2010). Construal-level theory of psychological distance. *Psychological Review*, *117*(2), 440-463.

Turley, C. & Boot, K. (2010). *Environmental Consequences of Ocean Acidification: A Threat to Food Security*. UNEP Emerging Issues Bulletin, Nairobi, Kenya. Retrieved from http://www.fao.org/fileadmin/user_upload/fsn/docs/HLPE/Environmental_Consequences_of_Ocean_Acidification.pdf

Turley, C., & Boot, K. (2011). The ocean acidification challenges facing science and society. In J.-P. Gattuso & L. Hansson, (Eds.). *Ocean acidification.* (pp. 249-271). Oxford: Oxford University Press.

Turley, C., Eby, M., Ridgwell, A. J., Schmidt, D. N., Findlay, H. S., Brownlee, C., ... & Gattuso, J. -P. (2010). The societal challenge of ocean acidification. *Marine Pollution Bulletin*, *60*(6), 787-792.

Turley, C., Findlay, H. S., Mangi, S., Ridgwell, A., & Schmidt, D. N. (2009). CO2 and ocean acidification in Marine Climate Change Ecosystem Linkages Report Card 2009. (J.M. Baxter, P.J. Buckley & M.T Frost (Eds.), *Online Science Reviews*. 25 pp. Retrieved from http://www.mccip.org.uk/special-topic-report-cards/exploring-ecosystem-linkages-report-card-2009/co2-and-ocean-acidification/

Turley, C., & Gattuso, J. -P. (2012). Future biological and ecosystem impacts of ocean acidification and their socioeconomic-policy implications. *Current Opinion in Environmental Sustainability*, *4*(3), 278-286.

Turley, C., Keizer, T., Williamson, P., Gattuso, J. P., Ziveri, P., Monroe, R., ... & Huelsenbeck, M. (2012). Hot, Sour and Breathless–Ocean under stress. *Plymouth Marine Laboratory, UK Ocean Acidification Research Programme, European Project on Ocean Acidification, Mediterranean Sea Acidification in a Changing Climate project, Scripps Institution of Oceanography at UC San Diego, OCEANA*, *6*.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases.
Science, *185*(4157), 1124–1131.

Tyrrell, T. (2011). Anthropogenic modification of the oceans. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *369*(1938), 887-908.

UK Ocean Acidification. (2016, July 27). About the UK ocean acidification research programme. Retrieved from http://www.oceanacidification.org.uk/About-Us.

UNFCCC. (2007). *Uniting on Climate: A Guide to the Climate Change Convention and the Kyoto Protocol* available at http://unfccc.int/resource/docs/convkp/kpeng.pdf

UNFCCC. (2015). The Paris Agreement available at http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

Upwell. (2015) Ocean acidification: The state of the online conversation May 2012-November 2014. Retrieved from http://www.upwell.us/oceanacidification/

Visschers, V. H., Meertens, R. M., Passchier, W. F., & DeVries, N. K. (2007). How does the general public evaluate risk information? The impact of associations with other risks. *Risk Analysis*, *27*(3), 715-727.

Washington State Blue Ribbon Panel on Ocean Acidification (2012). *Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response.* H. Adelsman & L. Whitely Binder (Eds). Washington Department of Ecology, Olympia, Washington. Publication no. 12-01-015.

Weber, E. U. (2006). Experience-based and description-based perceptions of long-term risk: Why global warming does not scare us (yet). *Climatic Change*, *77*(1), 103-120.

Weber, E. U. (2010). What shapes perceptions of climate change?. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(3), 332-342.

Weir, T., Dovey, L., & Orcherton, D. (2016). Social and cultural issues raised by climate change in Pacific Island countries: an overview. *Regional Environmental Change*, 1-12. doi: 10.1007/s10113-016-1012-5

Welch, C. (2009, June 14). Oysters in deep trouble: Is Pacific Ocean's chemistry killing sea life? Seattle Times. Retrieved from http://seattletimes.com/html/localnews/2009336458_oysters14m.html

White, M., Smith, A., Humphryes, K., Pahl, S., Snelling, D., & Depledge, M. (2010). Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes. *Journal of Environmental Psychology*, *30*(4), 482-493.

Whitmarsh, L. (2008). Are flood victims more concerned about climate change than other people? The role of direct experience in risk perception and behavioural response. *Journal of Risk Research 11*(3), 351-374. doi: 10.1080/13669870701552235

Whitmarsh, L. (2009a). Behavioural responses to climate change: asymmetry of intentions and impacts. *Journal of Environmental Psychology, 29*, 13–23.

Whitmarsh, L. (2009b). What's in a name? Commonalities and differences in public understanding of "climate change" and "global warming". *Public Understanding of Science 18*(4), 401-420. doi: 10.1177/0963662506073088

Whitmarsh, L. (2011). Scepticism and uncertainty about climate change: dimensions, determinants and change over time. *Global Environmental Change*, *21*(2), 690-700.

Whitmarsh, L., & O'Neill, S. (2010). Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *Journal of Environmental Psychology*, *30*(3), 305-314.

Whitmarsh, L., Seyfang, G., & O'Neill, S. (2011). Public engagement with carbon and climate change: To what extent is the public 'carbon capable'?. *Global Environmental Change*, *21*(1), 56-65.

Williams, D. R., & Vaske, J. J. (2003). The measurement of place attachment: Validity and generalizability of a psychometric approach. *Forest Science*, *49*(6), 830-840.

Williamson P., Turley C. M., Brownlee C., Findlay H. S., Ridgwell A. J., Schmidt D., … & Pinnegar J. K. (2013). Impacts of ocean acidification. *MCCIP Science Review 2013*, 34-48. doi: 10.14465/2013.arc05.034-048

Williamson, P., & Turley, C. (2012). Ocean acidification in a geoengineering context. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *370*(1974), 4317-4342.

Williamson, P., Watson, R. T., Mace, G., Artaxo, P., Bodle, R., Galaz, V., … & E. Woods (2012). Impacts of Climate-Related Geoengineering on Biological Diversity. Part I of: *Geoengineering in Relation to the Convention on Biological Diversity: Technical and Regulatory Matters*. Secretariat of the Convention on Biological Diversity. Montreal, Technical Series No. 66, 152 pp. https://www.cbd.int/doc/publications/cbd-ts-66-en.pdf

Willig, C. (2013). *Introducing qualitative research in psychology* (3rd ed). UK: McGraw-Hill Education.

Wolf, J., & Moser, S. C. (2011). Individual understandings, perceptions, and engagement with climate change: insights from in depth studies across the world. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(4), 547-569.

Woodward, A., Smith, K. R., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q., ... & Confalonieri, U. (2014). Climate change and health: On the latest IPCC report. *The Lancet*, *383*(9924), 1185-1189.

Wright, J. D., & Schaller, M. F. (2013). Evidence for a rapid release of carbon at the Paleocene-Eocene thermal maximum. *Proceedings of the National Academy of Sciences*, *110*(40), 15908-15913.

Wynne, B. (1996). May the sheep safely graze? A reflexive view of the expert-lay knowledge divide. In Lash, S., Szerszynski, B., & Wynne, B. (Eds.). *Risk, environment and modernity: Towards a new ecology*, *40*, (pp. 44-83). London: Sage.

Xue, W., Hine, D. W., Loi, N. M., Thorsteinsson, E. B., & Phillips, W. J. (2014). Cultural worldviews and environmental risk perceptions: A meta-analysis. *Journal of Environmental Psychology, 40,* 249-258.

Yamamoto-Kawai, M., McLaughlin, F. A., Carmack, E. C., Nishino, S., & Shimada, K. (2009). Aragonite undersaturation in the Arctic Ocean: effects of ocean acidification and sea ice melt. *Science*, *326*(5956), 1098-1100.

Zachos, J. C., Röhl, U., Schellenberg, S. A., Sluijs, A., Hodell, D. A., Kelly, D. C., ... & Kroon, D. (2005). Rapid acidification of the ocean during the Paleocene-Eocene thermal maximum. *Science*, *308*, 1611-1615.

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist*, *35*(2), 151-175.

Zeebe, R. E. (2012). History of seawater carbonate chemistry, atmospheric CO2, and ocean acidification. *Annual Review of Earth and Planetary Sciences*, *40*, 141-165.

Zeebe, R. E., & Ridgwell, A. (2011). Past changes of ocean carbonate chemistry. In J. -P. Gattuso & L. Hansson (Eds.). *Ocean acidification* (pp. 21-40). Oxford: Oxford University Press.

Zeebe, R. E., Zachos, J. C., Caldeira, K. & Tyrrell, T. (2008). Carbon emissions and acidification. *Science, 321*, 51 – 52.

APPENDICES

APPENDIX A: EXPERT INTERVIEW PROTOCOL

Below are the broad questions which provide an indication of the line of the questioning to be taken. The interviews will be semi-structured, with the participant free to discuss relevant topics not raised by the interviewer.

Opening questions

- What is your main area of expertise?
- What is your background in ocean acidification (OA) research?

Discussion questions – general

- Can you explain in general terms what is meant by OA?
- What are the most important impacts and risks arising from OA for ecosystems?
- What are the most important impacts and risks arising from OA for human society?
- Are there any potential benefits of OA? (If so, what are these?)
- What are the main areas of consensus, and the key uncertainties, in OA research at the present time?
- What are the outstanding questions within OA research, that should be answered in future studies?
- What are your main concerns about OA?
- What do you think are the most important aspects of OA that should be understood by the public?
- What do you think are the most important aspects of OA that should be understood by policy makers?
- In which ways has OA research shaped or influenced policy debates?
- What do you see as the future consequences and likely progression of OA?
- In which ways does OA interact with climate change?
- In which ways does OA interact with other natural or anthropogenic processes which affect the oceans?

Discussion questions – project specific

- What have been the main research questions and areas of interest for your own UKOA project?
- What research methods and approaches do you use in your research?
- What have been the most important outputs and findings from your UKOA project?
- How is your OA project of wider relevance to the public and policy makers?
- What are the outstanding questions arising from this research, that should be answered in future studies?

APPENDIX B: PUBLIC INFORMATION, CONSENT AND DEBRIEF FORMS FOR INTERVIEWS

Public Risk Perceptions of Ocean Health

Project description and research aims

This research is being undertaken by Elspeth Spence, a postgraduate student, based within the Schools of Psychology and Earth and Ocean Sciences at Cardiff University. Broadly, this research aims to investigate public perceptions and understandings of the health of the oceans and possible risks to the ocean. Public knowledge and perceptions are very important as they help to enable suitable future communications to be developed as current understandings of the public on these issues can be taken into account.

What will your participation involve?

Should you decide to take part in the research your participation will involve you taking part in an interview that is expected to last for between 60-90 minutes and will be recorded with audio equipment, before being transcribed.

The interview will be a qualitative semi-structured interview and will take the form of a guided conversation. There are certain topics the interview will be addressing and the interviewer will deliver some broad questions throughout the interview to guide the conversation. The direction of the interview will however be largely determined by your answers and discussion. Additionally I will ask for some demographic detail (gender, age and profession) to ensure I have covered a wide range of people. You are free to refrain from answering any of these questions if you wish, this will not affect your participation.

If at any point you change your mind about taking part in the research you can withdraw at any time by contacting us on the details provided below. You may also withdraw in person during the interview or at any other time. You may be asked if you would be willing to be contacted later in the study, to review or clarify issues identified in the interview.

Who is being interviewed?

The researcher intends to conduct interviews with various members of the public who live or work locally around the Cardiff area.

Anonymity and confidentiality

All data will remain confidential in accordance with British Psychological Society (BPS) 'Ethical principles for conducting research on human participants'. In addition, all participants will be given an alias which will be used by the project team in day to day discussion of the research**.** In all related publications, participant's quotes will be made anonymous. In that context, only non-identifying generic terms (e.g., gender, age) and the alias will be used to describe participants. The interview recordings will be stored in a secure location at Cardiff University.

Who will have access to the data?

The audio recordings and transcripts will be shared among the researcher and her supervisory team, and with their permission, with other relevant researchers. Participants may ask to see the data or request that it be destroyed at any time, up until the date that the data is anonymised.

How will the data be used?

The data will be used in academic research and will be used to produce reports, presentations, conference papers, and academic publications. The data and/or subsequent publications may also be used for teaching purposes.

Who is funding the research?

The funding for this project is provided by Cardiff University through the President's Scholarship.

The research team

Principle investigator: Elspeth Spence (postgraduate student)
Supervisory team: Prof. Nick Pidgeon (pidgeonn@cardiff.ac.uk)
Prof. Paul Pearson (pearsonp@cardiff.ac.uk)

Contact details

Elspeth Spence (postgraduate student)
Address: 51a Park Place,
School of Psychology, Cardiff, CF10 3AT
Email: spencee@cardiff.ac.uk
Phone: 02920 870837

School of Psychology Ethics Committee
Address: School of Psychology, Cardiff, CF10 3AT
Email: psychethics@cardiff.ac.uk
Phone: 02920 870360

School of Psychology, Cardiff University

Consent Form – Use of Data

I understand that my participation in this project will involve taking part in a semi-structured interview which will take approximately 60-90 minutes of my time. I understand that I may be contacted after the interview to review, validate and clarify issues or elaborate on themes. I understand that the interview will be recorded with audio equipment.

I understand that participation in this study is entirely voluntary and that I can withdraw from the study at any time (up until the date when data is anonymised) without giving a reason and without loss of the monetary gift I will receive. I understand that I do not have to answer all the questions and that I am free to ask any questions at any time. I am free to withdraw or discuss my concerns with postgraduate student Elspeth Spence. I agree that data obtained in the session may be utilised in discussion with other researchers, in any ensuing presentations, reports, publications, websites, broadcasts, and in teaching.

I understand that the information provided by me will be held anonymously, using pseudonyms, so that once the audio recording of the discussion has been transcribed into a written transcript no-one except the experimenter (Elspeth Spence) and her supervisors (Professor Nick Pidgeon and Professor Paul Pearson) will be able to trace my information back to me. I understand that in all publications any information provided will be made anonymous with only pseudonyms and generic identifying features (e.g. gender and age) used as identifying features.

I understand that I will be paid £10 for my participation in the study. I also understand that at the end of the interview I will be provided with additional information and feedback about the purpose of the study.

I have been provided with sufficient information on the project to give *informed* consent to the interview session.

I, _____**(PRINT NAME)** consent to participate in the study led by Professor Nick Pidgeon, School of Psychology, Cardiff University.

Signed: Date:

School of Psychology, Cardiff University

Consent Form – Participant Database

I am willing for my name and contact details to be held in a list (database) so that I may be contacted in future and asked further questions (for the purposes of reviewing/clarifying issues and elaborating on themes), as agreed below.

I understand that I am consenting only to receive a request to answer further questions, and that I am under no obligation to answer these questions.

I understand that this list will be used only for the purpose described here and will not be made available to anyone beyond those agreed below.

I understand that the contact details provided by me will be held confidentially, such that only the experimenter (postgraduate student Elspeth Spence) and her supervisor team (Professor Nick Pidgeon and Professor Paul Pearson) can trace this information back to me individually.

I understand that I may remove my name from the list at any time by emailing Elspeth Spence (SpenceE@cardiff.ac.uk).

I, _____ **(PRINT NAME)** consent to enter my contact details onto the list held by postgraduate student Elspeth Spence, Professor Nick Pidgeon and Professor Paul Pearson.

Signed: Date:

School of Psychology, Cardiff University

Participant Debrief Form

Public Perceptions of Ocean Acidification

Thank you

Thank you for taking part in this study. I hope it was interesting. Please feel free to ask the researcher (postgraduate student Elspeth Spence) any questions you have. Please note that some of the information contained on this form is a repeat of what might be found on the Participant Information Sheet, which you should already have and can keep.

What was the purpose of the study?

The purpose of this project is to examine public perceptions of ocean acidification and its potential impacts. This project will examine public perceptions of this risk in detail through these interviews. Ultimately this will allow for more effective communication methods to be developed. Establishing knowledge and understanding in the public will allow future research to build effective public communications about these risks and also possible responses.

What will happen to the data obtained in the study?

The data will be used in academic research and will be used to produce reports, presentations, conference papers, and academic publications. The data and/or subsequent publications may also be used for teaching purposes.

You have the right to access the information you have given and to request to see your interview transcript. You can also ask for the information you have given to be deleted up until the point that it has been integrated into the PhD analysis and published findings.

In case of any queries or complaints, or if you would like to learn more about the project, please do not hesitate to contact us via the details below. Alternatively if you wish for more information on this topic please visit these following websites:

http://www.oceanacidification.org.uk/

http://www.epoca-project.eu/

Thank you again for your time.

Contact Details		
Elspeth Spence (postgraduate)	**Prof. Nick Pidgeon (supervisor)**	**Psychology Ethics Committee Secretary**
Understanding Risk Group	School of Psychology	School of Psychology
51A Park Place	Cardiff University	Cardiff University
School of Psychology	Tower Building	Tower Building
Cardiff University	Park Place	Park Place
Cardiff	Cardiff	Cardiff
CF10 3AT	CF10 3AT	CF10 3AT
Email:	Email: PidgeonN@Cardiff.ac.uk	Email: psychethics@cf.ac.uk

APPENDIX C: INTERVIEW PROTOCOL AND INFORMATION ABOUT OA FOR PUBLIC INTERVIEWS

Basic Prompts:

Anything else?
Can you tell me more?
Can you explain why?
You told me that… Can you tell me more about that?

Opening Questions

_____ What do you think might be benefits of the ocean?
_____ What do you think might be problems with the ocean?

Draw a blank (try in order):

Have you ever heard of the term ocean acidification? Can you remember anything at all about it?
Let me see if I can jog your memory a bit. Ocean acidification refers to the decrease in ocean pH levels. Does that help?
Many people have not heard of ocean acidification. Ocean acidification is caused by the absorption of CO_2 from the atmosphere resulting in a change in sea chemistry. Have you ever heard of such a thing?

UNDERSTANDING/PERSONAL OPINION OF OCEAN ACIDIFICATION

_____ What do you understand by 'ocean acidification'?
_____ What are the first thoughts or images that come to mind when you think of ocean acidification?
_____ Why those images?

_____ Can you tell me about possible advantages or disadvantages of ocean acidification?
_____ How do you personally feel about ocean acidification?

FOLLOW UP, FURTHER FOCUS ON OCEAN ACIDIFICATION

CAUSES

_____ Can you tell me about the causes of ocean acidification? (if not already mentioned)

EFFECTS/IMPACTS

_____ Can you tell me about the changes that can result from ocean acidification?
__ Can you tell me (more) about how ocean acidification could affect you/species?
__ Does ocean acidification affect some species/people more than others?

RESPONSES/SOLUTIONS

_____ Can you tell me about ways to reduce ocean acidification?
__ Can you tell me (more) about ways the ocean may respond to ocean acidification?
__ Can you tell me (more) about other solutions to ocean acidification?
__ Do you think technology can significantly contribute to preventing ocean acidification? *(if not mentioned)*

RISK ASSESSMENT AND MANAGEMENT

_____ Where have you heard or read about ocean acidification? Trust in information sources?
_____ Do you have a sense of how certain or uncertain scientists are about the risk of ocean acidification?
_____ Where have you heard about things that can be done about managing ocean acidification risks?
_____ Who do you think is responsible for reducing ocean acidification?

INTERACTIONS/RISK COMPARISONS

_____ If you look into the future what do you think the state of the oceans will be in? How much do you think they will have changed by:
_____ 20 years (2034)
_____ 50 years (2064)
_____ 2100
_____ What role will ocean acidification play? As opposed to other threats?
_____ Do you think you will see a substantial increase in ocean acidification in the future?
_____ Is ocean acidification really a significant risk in society, or is it one of those risks that is not all that important?
_____ Can you give me some idea of how the risk of ocean acidification compares with other risks such as pollution?
_____ Any interactions ocean acidification may have with other risks?

PERSONAL RISK

_____ What can you tell me about ocean acidification locally?
_____ Do you have any reason to believe that your own risk from ocean acidification is high or low?
_____ What are your impressions of ocean acidification? Do you have any concerns?
_____ How would you feel about ocean acidification occurring in UK oceans? Would this alter your opinion?
_____ What do you think other people think about ocean acidification (family, friends, people important to you, general public)?

_____ In the UK do you think people would feel positive or negative about ocean acidification?

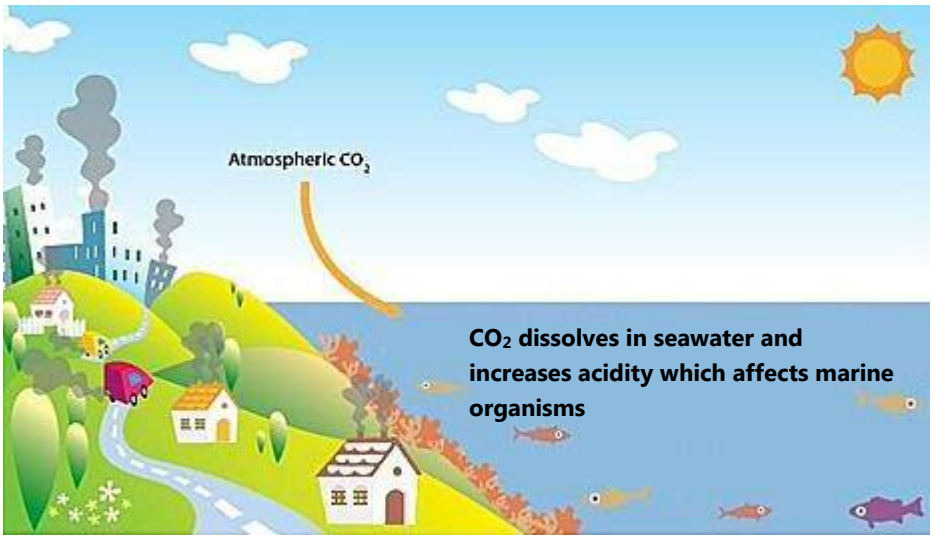
CLIMATE CHANGE

_____ Do you think it is happening? Why (cause by humans)?
_____ Do you think climate change is something to be concerned about for you personally? Why/Why not?
_____ What action should be taken to reduce climate change?
_____ What do you think are the main risks of climate change to society?
_____ Who should be responsible for it?
_____ What would be best to tackle climate change?
_____ Have you considered a link between ocean acidification and climate change? Why?

Section 4 – Task/ Final

Participants will be shown a short narrative about ocean acidification (next page) and then asked some final questions:
_____ What do you think about ocean acidification?
_____ If you could ask the expert on ocean acidification only one question, which question would you ask?
_____ Can you please rate how positive or negative you feel about ocean acidification?
_____ Is there anything else you would like to say on your views about ocean acidification?

Please read the following short text about ocean acidification



The oceans naturally absorb carbon dioxide (CO_2) from the atmosphere. Due to human activities which use fossil fuels (such as producing electricity, heating, transport and manufacturing), additional carbon dioxide is being released and taken up by the ocean resulting in 'ocean acidification'. Ocean acidification means that the oceans are gradually becoming more acidic as a result of the extra carbon dioxide they are absorbing.

Scientific research has suggested that ocean acidification might affect coral reefs, animals which form shells (such as sea snails), and plankton (tiny, floating organisms). There may also be consequences for fish and other large animals; e.g. their ability to reproduce and the availability of their food supply. It is possible there will be knock-on effects for human societies, especially for people who rely on the oceans. Scientists are confident in their understanding of the basic chemical processes of ocean acidification, however there is still a great deal they do not understand about these wider consequences of ocean acidification.

APPENDIX D: SALIENCE OF THEMES AND MENTAL MODEL COMPLETENESS SCORES

Causes of OA	
23%	Burning fossil fuels
18%	Anthropogenic CO_2
8%	Increase in CO_2
5%	Local pH alteration
3%	Climate change
0%	Carbon Capture and Storage (CCS)
0%	Change in wind pattern
0%	Change in upwelling
Process of OA	
53%	pH decline
5%	Increase of dissolved CO_2
0%	Change in bicarbonate ions
0%	Decrease in carbonate ions
Impacts of OA	
95%	Environmental Impacts
93%	Organisms affected
58%	Socioeconomic impacts
50%	Commercial species affected (mussels, fish etc)
50%	Extinction
48%	Corals
45%	Energy source (accessibility)
35%	Regional variability
28%	Primary production (phytoplankton)
23%	Ecosystems altered
18%	Coastal areas variability
10%	Surface ocean organisms (used to variability)
10%	Change in community structure
8%	Deep ocean organisms
5%	Dissolution
3%	Reproduction (stage of life cycle)
3%	Arctic
0%	Pteropods
0%	Coccolithophorids
0%	Change in phenology
0%	Larval stage vulnerable (selected species)
0%	Energy regulation adapted
0%	Saturation state altered
0%	Lowered in polar oceans
0%	Timescale uncertain

0%	Southern
0%	2100 (annual average)
0%	North Sea large variability
0%	Biological pump affected (reduced buffering capacity)
0%	Calcification rate altered
0%	Past impacts
0%	PETM
0%	Extinction
0%	Migration
0%	Slower event
0%	Surface ocean pH drop
Interactions	
55%	Climate change
28%	River systems (run-off)
15%	Temperature
13%	Rate of ice melt
13%	Ocean circulation
10%	Anthropogenic global warming
0%	CO_2 emission rate
0%	Upwelling
0%	Deoxygenation
0%	Centennial/Millennial
Responses to OA	
93%	Human responses
68%	Communication with policymakers
58%	Environmental responses
45%	Monitoring
43%	Adaptation (inter-species included)
35%	Calcium carbonate added to ocean
15%	Migration
10%	Genetic mutation
10%	Reduce CO_2
8%	Ecosystem
8%	Shift in dominant species
3%	Species acclimation
3%	Geoengineering (CRD)
0%	Natural adaptation vs. Responsive adaptation
0%	Annual/inter-annual cycle changed
0%	Ocean fertilisation

Mental Model Completeness Score for Public Respondents

Allan	20
Sophie	19
Philip	18
Stuart	17
Joe	15
George	14
Fiona	13
Karen	12
Stan	12
Adam	12
Edward	11
Emma	11
Charlotte	10
Helen	10
Abi	9
Darrel	9
Steve	8
Tricia	7
Margaret	7
Annie	5

APPENDIX E: PUBLIC SURVEY

This 30 minute survey is part of a study being carried out by Elspeth Spence, a Cardiff University researcher interested in what people think about the health of the oceans. However, you do not need to know anything about the oceans health to take part in the survey, and more information will be provided about it as you go through. The research is being supervised by Professor Nick Pidgeon and Professor Paul Pearson and has been approved by the Cardiff School of Psychology Ethics Committee. It is funded by a President's Research Scholarship at the University.

Contacts

Please do not hesitate to contact us via the details below if you have any questions or concerns.

Contact Details		
Elspeth Spence (postgraduate)	**Prof. Nick Pidgeon (supervisor)**	**Psychology Ethics Committee Secretary**
Understanding Risk Group	School of Psychology	School of Psychology
51A Park Place	Cardiff University	Cardiff University
School of Psychology	Tower Building	Tower Building
Cardiff University	Park Place	Park Place
Cardiff	Cardiff	Cardiff
CF10 3AT	CF10 3AT	CF10 3AT
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Consent

Before you move onto the questionnaire, please read the following statements carefully:

I understand that my participation in this project will involve completing an online questionnaire about my views on the health of the oceans, which will require approximately **30 minutes** of my time.

I understand that participation in this study is entirely **voluntary,** that I do not have to complete all of the questions if I don't want to, and that I can withdraw from the study at any time without giving a reason.

I understand that I am free to **contact** the researchers at any time with any questions or concerns I may have.

I understand that the information provided by me will be held totally **anonymously**, so that it is impossible to trace this information back to me individually.

I understand that the **data** will be held indefinitely and will be used as part of Elspeth Spence's doctoral thesis and for presentations, reports and publications.

I also understand that at the end of the study I will be provided with additional information and feedback about the purpose of the study.

If you give your consent to participate in the study, please tick the box below:

❍ Yes, I consent to participate in this study

Thank you very much for your time. Please click >> to begin the survey. Important: please do not use your browser 'back' button as this will result in your data being lost.

These questions are designed to make sure that we have asked a range of people about the health of the oceans, and to allow us to compare responses between different groups. All answers are anonymous.

Q1 How old are you? Please select one option.

❍ 18 - 24
❍ 25 - 34
❍ 35 - 44
❍ 45 -54
❍ 55-64
❍ 65 - 74
❍ 75 +

Q2 Please indicate your gender:

❍ Male
❍ Female
❍ Prefer not to say

Q3 Please select which party you feel most affiliated with, if any:

- ❍ Labour
- ❍ Conservative
- ❍ Liberal Democrats
- ❍ UK Independence Party
- ❍ Plaid Cymru
- ❍ Scottish National Party
- ❍ Green
- ❍ Democratic Party
- ❍ Would not vote
- ❍ Undecided
- ❍ Other/Prefer not to say

Q4 Do you live in..

- ❍ Wales
- ❍ England
- ❍ Scotland
- ❍ N Ireland

Q5 Approximately, how close do you live to the coast?

- ❍ 0 - 10 miles
- ❍ 10 - 30 miles
- ❍ 30 - 50 miles
- ❍ More than 50 miles
- ❍ Don't know

Q6 What is the first part of your postcode? (e.g. AB1)

Q7 What is the highest level of science-based education that you have?

- ❍ No formal science qualifications
- ❍ GCSE/O Level/Standard Grades
- ❍ A-Level/Higher/BTEC
- ❍ Vocational/NVQ
- ❍ Degree or equivalent
- ❍ Postgraduate Qualification
- ❍ Other

Q8 Please specify any environmental organisations (such as Greenpeace, Friends of the Earth etc.) that you belong to:

Q9 With regards to media consumption, how often do you do the following:

	Never	Rarely	Sometimes	Weekly	Daily
Read newspapers (online or print)	❍	❍	❍	❍	❍
Watch TV news	❍	❍	❍	❍	❍
Watch programmes about science (online or on the TV)	❍	❍	❍	❍	❍
Read articles about science in magazines, newspapers or online	❍	❍	❍	❍	❍
Other (please specify)	❍	❍	❍	❍	❍
None of these	❍	❍	❍	❍	❍

Q10 Please tick the main issues that you believe will affect the ocean now or will in the next 20 years. If you do not think there are any issues please tick the final box:

- ❑ Climate change/global warming
- ❑ Ocean acidification
- ❑ Overfishing
- ❑ Sea level rise
- ❑ Pollution
- ❑ Litter (such as plastic waste)
- ❑ Temperature
- ❑ Other
- ❑ There are no issues

Q11 Have you heard of ocean acidification before today?

- ❍ Yes
- ❍ No

Q12 How much, if anything, would you say you know about ocean acidification?

- ❍ I had not heard of ocean acidification before taking part in this survey
- ❍ I have heard of ocean acidification, but I know almost nothing about it
- ❍ I know just a little bit about ocean acidification
- ❍ I know a fair amount about ocean acidification

The following questions focus on ocean acidification. It is not a test. Some questions will ask about your general knowledge of ocean acidification, and others will ask more about your thoughts and feelings. If you do not know an answer, this does not matter – just give it your best shot.

Q13 One or more of the following could be considered causes of ocean acidification. To what extent do you agree or disagree that each is a cause of ocean acidification?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
Increase in seawater temperatures from climate change	❍	❍	❍	❍	■
Acid rain entering the ocean	❍	❍	❍	❍	■
Carbon dioxide in the atmosphere from human activities (such as burning fossil fuels) being absorbed by the oceans	■	❍	❍	❍	❍
Overfishing leading to a disruption of ocean food chains	❍	❍	❍	❍	■
Pollution from chemical and industrial waste	❍	❍	❍	❍	■
Natural cycles of change in ocean chemistry	❍	❍	❍	❍	■
Naturally-occurring carbon dioxide in the atmosphere being absorbed by the oceans	❍	❍	❍	❍	■
Climate change altering wind patterns and ocean circulation	■	❍	❍	❍	❍
Carbon dioxide leaks from carbon capture and storage systems	❍	■	❍	❍	❍
Litter (such as plastics) in the ocean	❍	❍	❍	❍	■
Pollution from ships, such as from oil spills and discharge of waste products	❍	❍	❍	❍	■

Q14 What do you think is the main cause of ocean acidification? Please select one.

- ❍ Increase in seawater temperatures from climate change
- ❍ Acid rain entering the ocean
- ❍ **Carbon dioxide in the atmosphere from human activities (such as burning fossil fuels) being absorbed by the oceans**
- ❍ Overfishing leading to a disruption of ocean food chains
- ❍ Pollution from chemical and industrial waste
- ❍ Natural cycles of change in ocean chemistry
- ❍ Naturally-occurring carbon dioxide in the atmosphere being absorbed by the oceans
- ❍ Climate change altering wind patterns and ocean circulation
- ❍ Carbon dioxide leaks from carbon capture and storage systems
- ❍ Litter (such as plastics) in the ocean
- ❍ Pollution from ships, such as from oil spills and discharge of waste products
- ❍ None of these

Q15 One or more of the following could be considered consequences of ocean acidification. To what extent do you agree or disagree that each is a consequence of ocean acidification?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
Damage to coral reefs	■	❍	❍	❍	❍
Increased ability of the ocean to absorb carbon dioxide from the atmosphere	❍	❍	❍	❍	■
Reduced ability of the ocean to absorb carbon dioxide from the atmosphere	❍	❍	■	❍	❍
Damage to the marine food chain	■	❍	❍	❍	❍
Skin damage from contact with ocean (e.g. swimmers)	❍	❍	❍	❍	■
More favourable conditions for some larger marine organisms (including fish and mammals)	❍	❍	❍	❍	■
Less favourable conditions for some larger marine organisms (including fish and mammals)	■	❍	❍	❍	❍
Problem for people reliant on ocean resources for their livelihood	■	❍	❍	❍	❍
Impact on food availability for people	■	❍	❍	❍	❍
Tourism and leisure will be affected negatively by ocean acidification	■	❍	❍	❍	❍
More favourable conditions for some tiny marine organisms (including plankton)	❍	❍	■	❍	❍

Less favourable conditions for some tiny marine organisms (including plankton)	■	❍	❍	❍	❍
Availability of drinking water impacted	❍	❍	❍	❍	■
Extinction of some marine organisms	■	❍	❍	❍	❍
Natural systems affected (such as weather patterns and currents)	❍	❍	■	❍	❍

Q16 What do you think is the main consequence of ocean acidification? Please select one.

- ❍ Damage to coral reefs
- ❍ Increased ability of the ocean to absorb carbon dioxide from the atmosphere
- ❍ Reduced ability of the ocean to absorb carbon dioxide from the atmosphere
- ❍ **Damage to the marine food chain**
- ❍ Skin damage from contact with ocean (e.g. swimmers)
- ❍ More favourable conditions for some larger marine organisms (including fish and mammals)
- ❍ Less favourable conditions for some larger marine organisms (including fish and mammals
- ❍ Problem for people reliant on ocean resources for their livelihood
- ❍ Impact on food availability for people
- ❍ Tourism and leisure will be affected negatively by ocean acidification
- ❍ More favourable conditions for some tiny marine organisms (including plankton)
- ❍ Less favourable conditions for some tiny marine organisms (including plankton)
- ❍ Availability of drinking water impacted
- ❍ Extinction of some marine organisms
- ❍ Natural systems affected (such as weather patterns and currents)

Q17 Which of the following measures do you feel would be most effective in reducing ocean acidification? Please select one

- ❍ **Reduce carbon emissions**
- ❍ Recycling household waste
- ❍ Introduce alkaline substances into the ocean to rebalance it
- ❍ Reduction of chemical and industrial waste
- ❍ Creating more marine protected areas
- ❍ Monitoring ocean acidification
- ❍ Increasing public awareness of the risks of ocean acidification
- ❍ Restricting fishing of affected organisms
- ❍ Planting more trees
- ❍ Switch to renewable and clean energy
- ❍ Leaving the ocean alone to balance itself out over time
- ❍ Communication with policymakers

Q18 To what extent do you agree that each of the following would interact with ocean acidification (e.g. make its effects worse)?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree	Don't Know
Temperature increases from man-made global warming	■	❍	❍	❍	❍	❍
Temperature increases from natural changes	❍	❍	❍	❍	■	❍
Climate change	■	❍	❍	❍	❍	❍
River system run-off (such as pollution, chemicals and sewerage)	❍	❍	❍	❍	■	❍
Rate of ice-melt	■	❍	❍	❍	❍	❍
Ocean circulation (mixing and movement of oceans)	■	❍	❍	❍	❍	❍
Rate of carbon dioxide emissions	■	❍	❍	❍	❍	❍

Q19 To what extent are you concerned about ocean acidification?

- ❍ Not at all concerned
- ❍ Not very concerned
- ❍ A little concerned
- ❍ Fairly concerned
- ❍ Very concerned
- ❍ No opinion

Please read the following short text about ocean acidification. You will be able to advance shortly and we will then ask you some further questions.

Ocean acidification is caused by the absorption of carbon dioxide from the atmosphere. This is a natural process, but as well as absorbing naturally occurring carbon dioxide, the oceans have taken up over a quarter of the carbon dioxide emitted as a result of human activities over the past 200 years. Carbon dioxide is released when we burn fossil fuels (coal, oil and gas) to heat our homes, produce electricity, and in transport and manufacturing, and by deforestation and cement manufacture. Research suggests that ocean acidification might affect coral reefs, animals which form shells (such as oysters and clams) and plankton (tiny, floating organisms). Fish and other large animals may also be affected indirectly such as their ability to reproduce or the availability of food. Additionally human societies may also be affected, especially those who rely on the oceans to make a living. There is uncertainty around the impacts of ocean acidification, however scientists are confident in the basic chemical processes of ocean acidification.

20 Below are some steps we might take as a society to decrease the amount of greenhouse gases (e.g. CO2) released to the atmosphere. Keeping in mind that all these proposals might be associated with considerable cost to the taxpayer, please indicate for each of these steps how would you vote in a national referendum.

	Definitely Yes	Probably yes	Unsure	Probably No	Definitely No
Ban the driving of cars in certain areas	❍	❍	❍	❍	❍
Ban the production of vehicles with gas/fuel mileage below 75 miles per gallon (very fuel efficient)	❍	❍	❍	❍	❍
Requirement for fossil fuel power stations to implement carbon capture and storage procedures	❍	❍	❍	❍	❍
Increased fuel and diesel taxes	❍	❍	❍	❍	❍
Increased household electricity taxes	❍	❍	❍	❍	❍
Use iron to boost sea plankton growth (absorbs CO2 from the atmosphere)	❍	❍	❍	❍	❍
Congestion charging on busy roads	❍	❍	❍	❍	❍
Use of sulphur compounds in the high atmosphere (to reflect sunlight and counteract further warming)	❍	❍	❍	❍	❍
Air travel taxation (e.g. on ticket prices)	❍	❍	❍	❍	❍
Tax for the protection of tropical rain forest	❍	❍	❍	❍	❍
Increasing general taxation to pay for public transport	❍	❍	❍	❍	❍
Subsidies for electric (emission-free) vehicles	❍	❍	❍	❍	❍

Subsidies for house insulation	❍	❍	❍	❍	❍
Information campaigns about negative effects on the oceans caused by car and aeroplane travel	❍	❍	❍	❍	❍
Introducing labels stating carbon content	❍	❍	❍	❍	❍
Teach children about the causes, consequences and potential solutions to ocean acidification	❍	❍	❍	❍	❍
Install space mirrors to block incoming solar radiation	❍	❍	❍	❍	❍
Subsidies for the household production of green energy (e.g. small wind turbines and solar panels)	❍	❍	❍	❍	❍

Q21 To what extent do you agree or disagree about the following statements.

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
Discrimination against minorities is still a very serious problem in our society	❍	❍	❍	❍	❍
The world would be a better place if its wealth were divided equally among nations	❍	❍	❍	❍	❍
In my ideal society, all basic needs such as food, housing, education and health care would be guaranteed by the government for everyone	❍	❍	❍	❍	❍
People should be allowed to make as much money as they can for themselves, even if others are not able to	❍	❍	❍	❍	❍
When I have problems, I try to solve them on my own	❍	❍	❍	❍	❍
If the government spent less time trying to fix everybody's problems we'd all be better off	❍	❍	❍	❍	❍
I consider myself to be environmentally conscious	❍	❍	❍	❍	❍
Being environmentally- friendly is an important part of who I am	❍	❍	❍	❍	❍
I think of myself as someone who is concerned about the environment	❍	❍	❍	❍	❍
I would be embarrassed to be seen as having an environmentally-friendly lifestyle	❍	❍	❍	❍	❍

Q22 Which source of information do you trust the most to give correct information about ocean acidification? Please select one.

- ❍ Social media
- ❍ TV news
- ❍ Family and friends
- ❍ Internet
- ❍ Scientists
- ❍ Government
- ❍ Television programmes (documentaries)
- ❍ Newspapers
- ❍ Non-governmental organisations
- ❍ Environmental groups
- ❍ Industry and business

Q23 Which one of these sources of information would you most likely get your information about ocean acidification? Please select one.

- ❍ Social media
- ❍ TV news
- ❍ Family and friends
- ❍ Internet
- ❍ Scientists
- ❍ Government
- ❍ Television programmes (documentaries)
- ❍ Newspapers
- ❍ Non-governmental organisations
- ❍ Environmental groups
- ❍ Industry and business

Q24 Please rank these sources of information from most trusted to least trusted. Drag and drop the items into the desired order.

_____ Social media
_____ TV news
_____ Family and friends
_____ Internet
_____ Scientists
_____ Government
_____ Television programmes (documentaries)
_____ Newspapers
_____ Non-governmental organisations
_____ Environmental groups
_____ Industry and business

Q25 On a scale of 1 to 10 how positive or negative do you feel about ocean acidification?

	1	2	3	4	5	6	7	8	9	10
Ocean Acidification	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Q26 When you think about ocean acidification how strongly, if at all, do you feel each of the following emotions? Please rate each emotion on a scale of 1 to 10 where 1 means you have not felt it at all and 10 means you have felt it extremely.

	1	2	3	4	5	6	7	8	9	10
Sadness	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Worry	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Anger	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Sympathy	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Indifference	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Guilt	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Regret	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Fear	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Contempt	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Shame	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Disgust	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Outrage	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Disappointment	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Hopelessness	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Hope	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Q27 Please select one of the following options. As a whole, does ocean acidification make you feel...

- ❍ Very bad
- ❍ Bad
- ❍ Neutral
- ❍ Good
- ❍ Very good

Q28 To what extent do you agree with the following statements about ocean acidification?

	Strongly Disagree	Tend to Disagree	Neither Agree nor Disagree	Tend to Agree	Strongly Agree
My local area is likely to be affected by ocean acidification	❍	❍	❍	❍	❍
Ocean acidification will mostly affect areas that are far from here	❍	❍	❍	❍	❍
Ocean acidification will mostly affect people in developing countries	❍	❍	❍	❍	❍
Ocean acidification is likely to have a big impact on people like me	❍	❍	❍	❍	❍

Q29 When, if at all, do you think Britain will start feeling the effects of ocean acidification?

- ❍ We are already feeling the effects
- ❍ In the next 10 years
- ❍ In the next 20 years
- ❍ In the next 50 years
- ❍ In the next 100 years
- ❍ Beyond the next 100 years
- ❍ Never
- ❍ Don't know
- ❍ No opinion

Q30 To what extent to you agree or disagree with the following statements?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
I am concerned about the potential negative impact of ocean acidification on the marine environment	❍	❍	❍	❍	❍
I think that ocean acidification will affect the reproduction and physiology of organisms	❍	❍	❍	❍	❍
I don't think that we know enough about the long-term effects of ocean acidification	❍	❍	❍	❍	❍
I am worried that there will be an impact on food availability	❍	❍	❍	❍	❍
I think that ocean acidification is a serious risk for tourism and leisure	❍	❍	❍	❍	❍
I am concerned that ocean acidification will pose a serious personal risk	❍	❍	❍	❍	❍
I believe that ocean acidification is happening too fast to adapt	❍	❍	❍	❍	❍

Q31 From what you know or have heard about ocean acidification, on balance, which of these statements, if any, most closely reflects your own opinion?

- ❍ The benefits of ocean acidification far outweigh the risks
- ❍ The benefits of ocean acidification slightly outweigh the risks
- ❍ The benefits and risks of ocean acidification are about the same
- ❍ The risks of ocean acidification slightly outweigh the benefits
- ❍ The risks of ocean acidification far outweigh the benefits
- ❍ None of these
- ❍ Don't know

Q32 On the whole, how acceptable or unacceptable is ocean acidification to you?

- ❍ Extremely acceptable
- ❍ Very acceptable
- ❍ Fairly acceptable
- ❍ Slightly acceptable
- ❍ Neither acceptable nor unacceptable
- ❍ Slightly unacceptable
- ❍ Fairly unacceptable
- ❍ Very unacceptable
- ❍ Extremely unacceptable

Q33 How would you assess the benefits, if any, of ocean acidification for...

	Very high benefits	High benefits	Some benefits	Low benefits	No benefits	No opinion/ Don't know
British Society as a whole	❍	❍	❍	❍	❍	❍
Yourself	❍	❍	❍	❍	❍	❍
The environment	❍	❍	❍	❍	❍	❍

Q34 How would you assess the risks, if any, of ocean acidification for...

	Very high risks	High risks	Some risks	Low risks	No risks	No opinion/Don't know
British Society as a whole	❍	❍	❍	❍	❍	❍
Yourself	❍	❍	❍	❍	❍	❍
The environment	❍	❍	❍	❍	❍	❍

Q35 Please indicate to what extent you agree or disagree about the following statements about the ocean.

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
I feel the ocean is a part of me	❍	❍	❍	❍	❍
The ocean is the best place for what I like to do	❍	❍	❍	❍	❍
I am very attached to the ocean	❍	❍	❍	❍	❍
Visiting the ocean says a lot about who I am	❍	❍	❍	❍	❍
The ocean is very special to me	❍	❍	❍	❍	❍
No other place can compare to the ocean	❍	❍	❍	❍	❍
I get more satisfaction out of visiting the ocean more than any other place	❍	❍	❍	❍	❍
I identify very strongly with the ocean	❍	❍	❍	❍	❍

This set of questions will ask you about your thoughts and opinions on climate change.

Q36 How concerned, if at all, are you about climate change (sometimes referred to as global warming)?

- ❍ Very concerned
- ❍ Fairly concerned
- ❍ Not very concerned
- ❍ Not at all concerned
- ❍ Don't know
- ❍ No opinion

Q37 As far as you know, do you personally think the world's climate is changing, or not?

- ❍ Yes
- ❍ No

Q38 Thinking about the causes of climate change, which, if any, of the following best describes your opinion?

- ❍ Climate change is entirely caused by natural processes
- ❍ Climate change is mainly caused by natural processes
- ❍ Climate change is partly caused by natural processes and partly caused by human activity
- ❍ Climate change is mainly caused by human activity
- ❍ Climate change is entirely caused by human activity
- ❍ There is no such thing as climate change

Q39 Which of the following groups, if any, do you trust to give you correct information on climate change?

- ❑ The government
- ❑ Business and industry
- ❑ Environmental groups
- ❑ Government scientists
- ❑ Independent scientists (such as University Research centres)
- ❑ The media
- ❑ Friends and family
- ❑ Other
- ❑ None of these

Q40 To what extent do you agree or disagree with the following statements?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
We can trust scientists to tell us the truth about climate change	❍	❍	❍	❍	❍
Climate change will have consequences for me or my family	❍	❍	❍	❍	❍
There is very little I can personally do to help address climate change	❍	❍	❍	❍	❍
Climate change is likely to be a serious problem for Great Britain	❍	❍	❍	❍	❍
Climate change will mostly affect developing countries	❍	❍	❍	❍	❍

Q41 How high or low a priority should it be for the UK government to take action on climate change?

- ❍ Very low priority
- ❍ Fairly low priority
- ❍ Medium priority
- ❍ Fairly high priority
- ❍ Very high priority

Q42 On a scale of -5 to 5 how positive or negative do you feel about climate change?

	-5	-4	-3	-2	-1	0	1	2	3	4	5
Climate Change	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

Thank you

Thank you for completing this survey; your participation is very much appreciated. As stated earlier, all data provided will be held anonymously and although it will be kept indefinitely it will not be possible for your responses to be traced back to you. The data may also be used in publications and/or presentations.

What was the purpose of the study?

The purpose of this project is to examine public perceptions of ocean acidification and its potential impacts. Ultimately this will allow for more effective communication methods to be developed. Establishing knowledge and understanding in the public will allow future research to build effective public communications about these risks and also possible responses.

Ocean acidification occurs as a result of carbon dioxide being absorbed into the ocean from the atmosphere. As carbon emissions have increased from human activities the oceans have taken up larger amounts of carbon dioxide. This chemical process is resulting in oceans becoming more acidic (i.e. having a lower pH). Many scientists believe that a wide range of marine organisms will be affected by the changes. For example some organisms use calcium carbonate in the water to build their shells and skeletons (like corals, sea snails and oysters). There may be a change in the food available for other organisms and larger animals as well as other effects. Ocean acidification is not thought to cause skin damage to people or impact on ice shelves, however if it damages fish stocks this may impact on people's livelihoods and food supply.

Please visit the links below if you wish to learn more about ocean acidification.

http://www.oceanacidification.org.uk/

http://www.epoca-project.eu/

Thank you again for your time. Finally, please click >> to submit your data and re-direct to Maximiles.

Contact Details		
Elspeth Spence (postgraduate)	**Prof. Nick Pidgeon (supervisor)**	**Psychology Ethics Committee Secretary**
Understanding Risk Group	School of Psychology	School of Psychology
51A Park Place	Cardiff University	Cardiff University
School of Psychology	Tower Building	Tower Building
Cardiff University	Park Place	Park Place
Cardiff	Cardiff	Cardiff
CF10 3AT	CF10 3AT	CF10 3AT
Email: SpenceE@Cardiff.ac.uk Phone: 02920 870837	Email: PidgeonN@Cardiff.ac.uk	Email: psychethics@cf.ac.uk Phone:+44 (0)29 208 70360

APPENDIX F: DEMOGRAPHICS

Sample demographics and comparison to national sample:

Gender

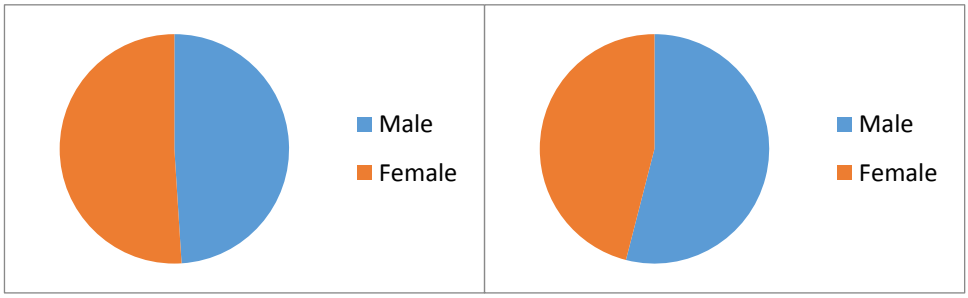

Figure 1. % of males and females in population (L – Census 2011, R – Survey sample)

Age

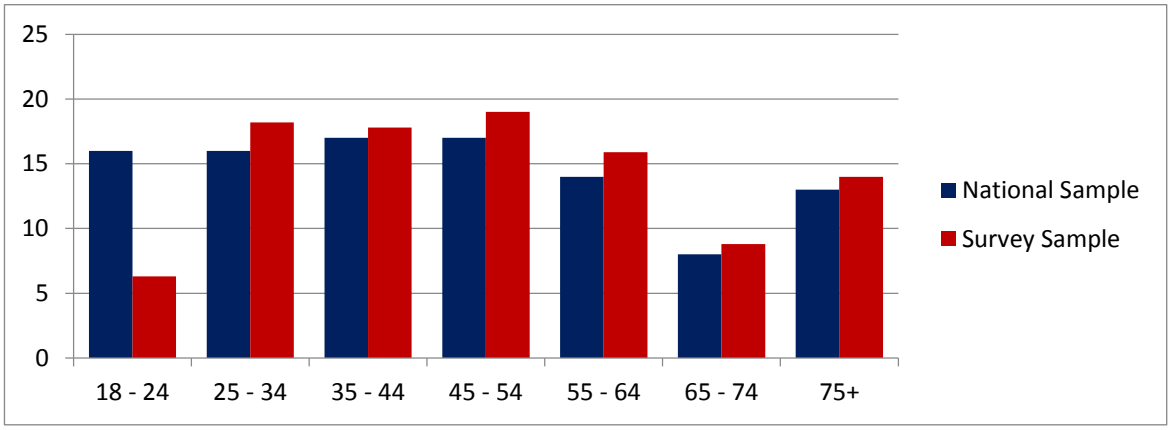

Figure 2. % of sample in age categories of census 2011 and survey sample

Education

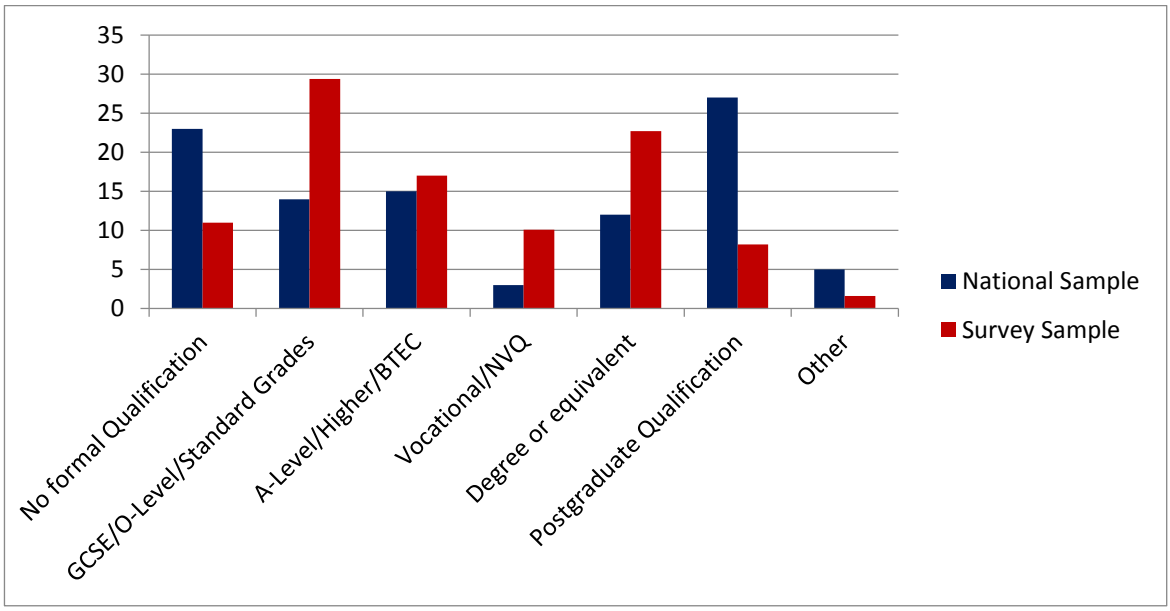

Figure 3. % of sample that has achieved a certain level of education

Voting Preferences

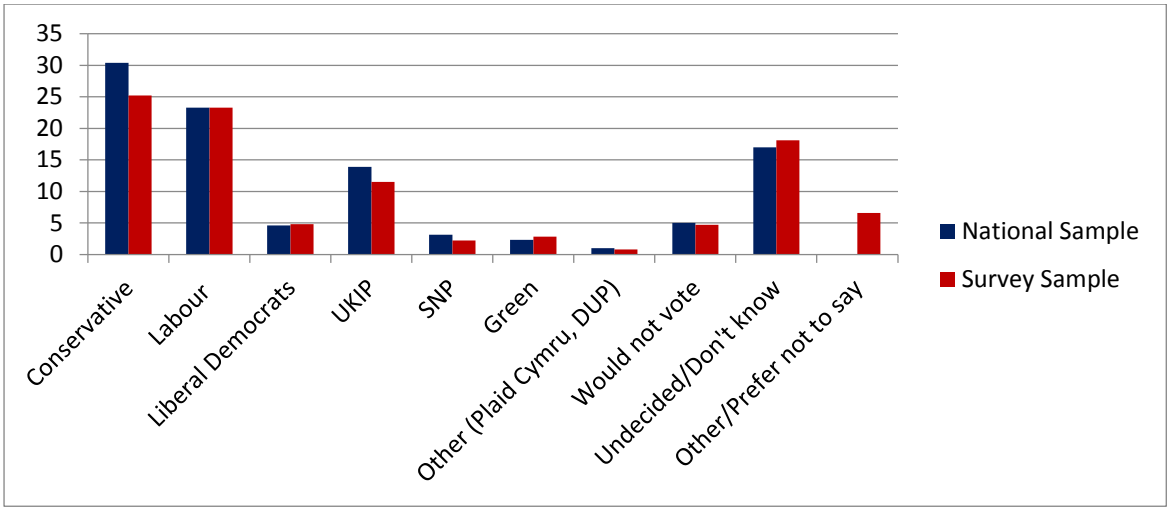

Figure 4. % of sample affiliated to a particular political party (voting intentions measured in Jan 2016 for national sample)

APPENDIX G: TOPLINE SURVEY FINDINGS

The topline survey findings are given in this appendix with figures showing percentages of the sample responses, unless otherwise stated.

Q1. How old are you?

	Frequency	Percent
18 - 24	59	6.3
25 - 34	171	18.2
35 - 44	168	17.8
45 -54	179	19.0
55-64	150	15.9
65 - 74	83	8.8
75 +	132	14.0
Total	942	100

Q2. Please indicate your gender:

	Frequency	Percent
Female	500	53.6
Male	429	46.0
Total	929	99.6

Q3. Please select which party you feel most affiliated with, if any:

	Frequency	Percent
Conservative	238	25.2
Labour	220	23.3
UK Independence Party	109	11.5
Liberal Democrats	45	4.8
Scottish National Party	21	2.2
Green	26	2.8
Plaid Cymru	7	0.7
Democratic Party	1	0.1
Would not vote	44	4.7
Undecided	171	18.1
Other/Prefer not to say	62	6.6
Total	944	100

Q4. Do you live in..

Country	Frequency	Percent
England	790	85.6
Scotland	78	8.5
Wales	53	5.7
N Ireland	2	.2
Total	923	100

Q5. Approximately, how close do you live to the coast?

	Frequency	Percent
0 - 10 miles	243	25.8
10 - 30 miles	208	22.1
30 - 50 miles	162	17.2
More than 50 miles	269	28.6
Don't know	59	6.3
Total	941	100

Q6. What is the highest level of science-based education that you have?

	Frequency	Percent
No formal science qualifications	105	11.0
GCSE/O Level/Standard Grades	280	29.4
A-Level/Higher/BTEC	162	17.0
Vocational/NVQ	96	10.1
Degree or equivalent	216	22.7
Postgraduate Qualification	78	8.2
Other	15	1.6
Total	952	100

Q7. Please specify any environmental organisations (such as Greenpeace, Friends of the Earth etc.) that you belong to:

WWF
Woodland Trust
RSPB
National Trust
Greenpeace
Friends of the Earth
Avaaz
CIEEM
Go Green
English Heritage
National Geographic
Wildlife Trust
Sustainable Merton
Wrenthorpe Environmental Society
Whitley Wildlife Conservation Trust

Q8. With regards to media consumption, how often do you do the following:

	Never	Rarely	Sometimes	Weekly	Daily	Total
	%	%	%	%	%	Frequency
Read newspapers (online or print)	12.7	16.9	20.0	15.8	34.5	950
Watch TV news	3.5	8.3	15.3	11.0	61.9	952
Watch programmes about science (online or on the TV)	7.0	17.8	43.1	25.1	6.9	951
Read articles about science in magazines, newspapers or online	17.8	23.0	37.1	16.9	5.2	951
Other (please specify)	64.8	7.3	11.7	9.3	6.9	247

Other (please specify):

Browse online news
Documentaries
DVD
Gadgets/IT
Go to science talks
Hazardex - the truth behind safety issues
Hear science programmes on the radio
Quarterly Assistive Technology Magazine
Radio
Radio news
Read books
Read books about science and discoveries online or in print
Study science at school
Use online media such as MSN news
YouTube

Q9. Please tick the main issues that you believe will affect the ocean now or will in the next 20 years. If you do not think there are any issues please tick the final box.

	Frequency	Percent
Pollution	700	73.4
Litter (such as plastic waste)	681	71.4
Climate change/global warming	597	62.6
Overfishing	537	56.3
Sea level rise	472	49.5
Temperature	435	45.6
Ocean acidification	244	25.6
There are no issues	38	4
Other	9	0.9
Total	954	100

Q10. Have you heard of ocean acidification before today?

	Frequency	Percent
Yes	280	29.4
No	674	70.6
Total	954	100

Q11. How much, if anything, would you say you know about ocean acidification?

	Frequency	Percent
I had not heard of ocean acidification before taking part in this survey	634	66.5
I have heard of ocean acidification, but I know almost nothing about it	166	17.4
I know just a little bit about ocean acidification	132	13.8
I know a fair amount about ocean acidification	22	2.3
Total	954	100

Q12. One or more of the following could be considered causes of ocean acidification. To what extent do you agree or disagree that each is a cause of ocean acidification?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
Pollution from chemical and industrial waste	35.3%	43.0%	19.5%	1.4%	.8%
Pollution from ships, such as from oil spills and discharge of waste products	31.2%	42.8%	21.5%	3.6%	.9%
Litter (such as plastics) in the ocean	27.0%	38.4%	27.3%	6.2%	1.1%
Carbon dioxide in the atmosphere from human activities (such as burning fossil fuels) being absorbed by the oceans	21.6%	41.7%	32.1%	2.8%	1.7%
Acid rain entering the ocean	17.9%	43.8%	32.8%	4.3%	1.2%
Overfishing leading to a disruption of ocean food chains	15.3%	32.1%	36.4%	13.4%	2.6%
Carbon dioxide leaks from carbon capture and storage systems	15.1%	32.8%	44.6%	6.0%	1.5%
Climate change altering wind patterns and ocean circulation	11.6%	29.7%	43.4%	12.3%	3.0%
Increase in seawater temperatures from climate change	11.4%	34.6%	40.0%	11.7%	2.3%
Naturally-occurring carbon dioxide in the atmosphere being absorbed by the oceans	11.1%	35.7%	43.1%	7.9%	2.2%
Natural cycles of change in ocean chemistry	9.8%	32.2%	48.0%	8.4%	1.6%

Q13. What do you think is the main cause of ocean acidification? Please select one.

	Frequency	Percent
Pollution from chemical and industrial waste	237	24.9
Carbon dioxide in the atmosphere from human activities (such as burning fossil fuels) being absorbed by the oceans	176	18.5
Pollution from ships, such as from oil spills and discharge of waste products	125	13.1
Acid rain entering the ocean	86	9.0
None of these	69	7.2
Litter (such as plastics) in the ocean	69	7.2
Natural cycles of change in ocean chemistry	45	4.7
Climate change altering wind patterns and ocean circulation	39	4.1
Naturally-occurring carbon dioxide in the atmosphere being absorbed by the oceans	36	3.8
Increase in seawater temperatures from climate change	34	3.6
Overfishing leading to a disruption of ocean food chains	21	2.2
Carbon dioxide leaks from carbon capture and storage systems	16	1.7
Total	953	100

Q14. One or more of the following could be considered consequences of ocean acidification. To what extent do you agree or disagree that each is a consequence of ocean acidification?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
Damage to coral reefs	34.0%	40.9%	22.6%	2.1%	.4%
Extinction of some marine organisms	28.5%	43.4%	25.1%	2.6%	.3%
Damage to the marine food chain	26.8%	46.1%	24.4%	2.2%	.4%
Less favourable conditions for some tiny marine organisms (including plankton)	22.8%	40.8%	32.3%	3.8%	.3%
Problem for people reliant on ocean resources for their livelihood	22.2%	46.0%	28.3%	3.2%	.4%
Less favourable conditions for some larger marine organisms (including fish and mammals)	21.8%	43.3%	30.9%	3.7%	.3%
Impact on food availability for people	16.5%	42.3%	34.7%	5.9%	.6%
Reduced ability of the ocean to absorb carbon dioxide from the atmosphere	14.9%	36.2%	43.9%	4.2%	.8%
Natural systems affected (such as weather patterns and currents)	11.8%	39.0%	40.3%	7.9%	1.1%
Tourism and leisure will be affected negatively by ocean acidification	9.2%	37.1%	42.4%	10.0%	1.3%
Increased ability of the ocean to absorb carbon dioxide from the atmosphere	9.0%	23.1%	51.1%	12.8%	3.9%
Skin damage from contact with ocean (e.g. swimmers)	8.7%	29.7%	45.2%	14.2%	2.2%
Availability of drinking water impacted	8.4%	26.5%	48.0%	13.9%	3.3%
More favourable conditions for some tiny marine organisms (including plankton)	7.3%	19.1%	47.6%	20.4%	5.6%
More favourable conditions for some larger marine organisms (including fish and mammals)	6.8%	17.7%	46.3%	21.9%	7.2%

Q15. What do you think is the main consequence of ocean acidification? Please select one.

	Frequency	Percent
Damage to the marine food chain	176	18.5
Extinction of some marine organisms	156	16.4
Damage to coral reefs	124	13.0
Reduced ability of the ocean to absorb carbon dioxide from the atmosphere	86	9.0
Less favourable conditions for some larger marine organisms (including fish and mammals	79	8.3
Natural systems affected (such as weather patterns and currents)	72	7.6
Less favourable conditions for some tiny marine organisms (including plankton)	58	6.1
Problem for people reliant on ocean resources for their livelihood	54	5.7
Impact on food availability for people	36	3.8
Availability of drinking water impacted	32	3.4
Increased ability of the ocean to absorb carbon dioxide from the atmosphere	30	3.2
Tourism and leisure will be affected negatively by ocean acidification	16	1.7
Skin damage from contact with ocean (e.g. swimmers)	13	1.4
More favourable conditions for some tiny marine organisms (including plankton)	11	1.2
More favourable conditions for some larger marine organisms (including fish and mammals)	8	0.8
Total	951	100

Q16. Which of the following measures do you feel would be most effective in reducing ocean acidification? Please select one.

	Frequency	Percent
Reduction of chemical and industrial waste	259	27.3
Increasing public awareness of the risks of ocean acidification	130	13.7
Reduce carbon emissions	121	12.7
Monitoring ocean acidification	87	9.2
Switch to renewable and clean energy	87	9.2
Leaving the ocean alone to balance itself out over time	77	8.1
Recycling household waste	44	4.6
Planting more trees	39	4.1
Creating more marine protected areas	38	4.0
Introduce alkaline substances into the ocean to rebalance it	37	3.9
Restricting fishing of affected organisms	18	1.9
Communication with policymakers	13	1.4
Total	950	100

Q17. To what extent do you agree that each of the following would interact with ocean acidification (e.g. make its effects worse)?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree	Don't Know
River system run-off (such as pollution, chemicals and sewerage)	26.2%	46.0%	19.6%	2.0%	.7%	5.5%
Rate of carbon dioxide emissions	19.8%	42.6%	27.9%	1.9%	.9%	6.9%
Climate change	17.2%	39.8%	29.3%	5.8%	1.7%	6.3%
Temperature increases from man-made global warming	17.0%	37.1%	30.6%	6.6%	2.1%	6.6%
Rate of ice-melt	9.8%	30.3%	37.6%	12.5%	2.5%	7.4%
Temperature increases from natural changes	8.7%	36.2%	37.3%	9.0%	1.7%	7.0%
Ocean circulation (mixing and movement of oceans)	8.0%	29.3%	44.1%	9.0%	1.2%	8.5%

Q18. To what extent are you concerned about ocean acidification?

	Very concerned	Fairly concerned	A little concerned	Not very concerned	Not at all concerned	No opinion	Total
Frequency	151	268	296	96	29	113	953
Percent	15.8	28.1	31.1	10.1	3.0	11.9	100

Q19. Below are some steps that we might take as a society to decrease the amount of greenhouse gases (e.g. CO_2) released to the atmosphere. Keeping in mind that all these proposals might be associated with considerable costs to the taxpayer, please indicate for each of these steps how you would vote in a national referendum.

	Definitely Yes	Probably yes	Unsure	Probably No	Definitely No
Teach children about the causes, consequences and potential solutions to ocean acidification	48.1%	34.1%	14.2%	2.6%	.9%
Requirement for fossil fuel power stations to implement carbon capture and storage procedures	31.9%	39.7%	23.8%	2.9%	1.7%
Subsidies for the household production of green energy (e.g. small wind turbines and solar panels)	28.3%	40.7%	24.4%	4.3%	2.4%
Information campaigns about negative effects on the oceans caused by car and aeroplane travel	27.9%	39.9%	25.5%	5.0%	1.7%
Subsidies for house insulation	27.4%	40.7%	26.5%	4.3%	1.2%
Subsidies for electric (emission-free) vehicles	22.6%	39.9%	27.4%	7.0%	3.0%
Increased fuel and diesel taxes	8.6%	21.7%	32.2%	24.0%	13.6%
Increasing general taxation to pay for public transport	5.9%	24.0%	32.3%	21.3%	16.5%
Air travel taxation (e.g. on ticket prices)	14.5%	25.7%	32.5%	18.6%	8.7%
Increased household electricity taxes	4.4%	13.7%	32.6%	27.0%	22.4%
Introducing labels stating carbon content	18.6%	38.1%	32.9%	8.0%	2.4%
Ban the production of vehicles with gas/fuel mileage below 75 miles per gallon (very fuel efficient)	17.4%	30.9%	32.9%	11.9%	6.8%
Congestion charging on busy roads	14.0%	28.9%	33.3%	15.5%	8.3%
Tax for the protection of tropical rain forest	16.3%	27.0%	36.1%	13.3%	7.2%
Use iron to boost sea plankton growth (absorbs CO2 from the atmosphere)	14.8%	34.1%	43.3%	5.3%	2.5%
Install space mirrors to block incoming solar radiation	7.3%	19.4%	48.5%	16.4%	8.4%
Use of sulphur compounds in the high atmosphere (to reflect sunlight and counteract further warming)	9.2%	22.4%	51.5%	10.7%	6.2%

Q20. To what extent do you agree or disagree about the following statements.

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
Egalitarianism	%	%	%	%	%
In my ideal society, all basic needs such as food, housing, education and health care would be guaranteed by the government for everyone	29.5	33.2	23.9	8.7	4.7
Discrimination against minorities is still a very serious problem in our society	26.2	33.8%	27.8	8.9	3.3
The world would be a better place if its wealth were divided equally among nations	19.3	29.8%	31.4	12.8	6.7
Individualism	%	%	%	%	%
When I have problems, I try to solve them on my own	32.5	47.6	16.4	3.1	0.3
If the government spent less time trying to fix everybody's problems we'd all be better off	19.0	28.1	34.6	12.5	5.8
People should be allowed to make as much money as they can for themselves, even if others are not able to	10.7	29.7	34.1	17.2	8.3
Pro-environmentalism	%	%	%	%	%
I think of myself as someone who is concerned about the environment	20.4	45.0	26.8	5.2	2.6
I consider myself to be environmentally conscious	18.8	47.3	27.0	5.2	1.7
Being environmentally- friendly is an important part of who I am	18.8	35.7	34.2	7.3	4.0
I would be embarrassed to be seen as having an environmentally-friendly lifestyle	2.9	7.1	20.1	34.3	35.5

Q21. Which source of information do you trust the most to give correct information about ocean acidification? Please select one.

	Frequency	Percent
Scientists	395	41.6
Television programmes (documentaries)	117	12.3
Environmental groups	111	11.7
Non-governmental organisations	99	10.4
Internet	65	6.8
TV news	62	6.5
Family and friends	30	3.2
Newspapers	28	2.9
Government	23	2.4
Social media	14	1.5
Industry and business	6	.6
Total	950	100

Q22. Which one of these sources of information would you most likely get your information about ocean acidification? Please select one.

	Frequency	Percent
Scientists	209	22.0
Internet	208	21.9
Television programmes (documentaries)	170	17.9
TV news	105	11.1
Environmental groups	84	8.8
Non-governmental organisations	58	6.1
Newspapers	55	5.8
Social media	23	2.4
Family and friends	17	1.8
Government	12	1.3
Industry and business	9	.9
Total	950	100

Q23. Please rank these information sources from most trusted to least trusted. Drag and drop the items into the desired order (1 Most Trusted – 10 Least Trusted).
% of responses displayed.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Scientists	46.4	15.6	11.0	6.4	4.7	3.7	3.7	2.6	3.1	1.8	1.1
Environmental groups	10.7	20.0	15.1	12.7	8.6	8.3	6.9	5.0	5.3	3.2	4.3
Non-governmental organisations	9.0	17.0	15.3	13.2	11.4	8.9	6.2	6.8	5.0	3.7	3.4
Television programmes (documentaries)	8.5	15.5	16.5	16.9	10.3	9.6	8.0	5.5	4.0	2.7	2.6
Internet	6.8	6.6	8.4	9.5	12.3	10.9	13.7	9.7	8.4	9.7	4.2
Family and friends	6.2	4.1	4.8	6.9	9.6	10.0	9.5	13.5	11.4	13.2	10.8
TV news	4.8	8.2	9.7	12.4	13.3	13.6	12.3	9.3	7.2	6.8	2.5
Newspapers	2.8	3.7	5.2	6.1	9.6	11.6	12.1	13.8	14.6	11.7	8.8
Government	2.4	3.9	6.2	6.0	7.2	9.0	9.4	11.2	12.4	13.0	19.3
Social media	1.4	2.9	3.7	2.4	5.0	6.7	9.0	11.1	14.5	16.0	27.3
Industry and business	1.0	2.6	4.2	7.5	8.0	7.8	9.4	11.7	14.1	18.7	15.7

Q24. On a scale of 1 to 10 how positive or negative do you feel about ocean acidification?
% of responses displayed.

	1	2	3	4	5	6	7	8	9	10	Total
Affect	5.4	13.0	4.0	13.9	36.7	11.1	7.4	4.6	2.0	1.9	100

Q25. When you think about ocean acidification how strongly, if at all, do you feel each of the following emotions? Please rate each emotion on a scale of 1 to 10 where 1 means you have not felt it all and 10 means you have felt it extremely.
% of responses displayed.

	1	2	3	4	5	6	7	8	9	10
Contempt	22.1	5.8	8.4	10.5	26.0	10.5	7.4	5.1	2.3	2.0
Guilt	19.3	6.5	10.3	9.8	20.2	11.1	10.7	6.0	3.9	2.1
Hopelessness	14.9	4.7	7.7	8.3	23.0	13.7	11.5	9.3	4.3	2.6
Indifference	23.3	8.4	12.4	8.4	21.4	9.5	7.7	3.7	2.4	2.6
Fear	14.8	4.9	8.2	7.5	20.3	15.2	12.3	8.4	4.7	3.6
Shame	17.8	6.1	9.0	7.7	21.6	12.4	9.9	7.5	4.1	4.0
Regret	14.8	4.6	6.2	6.7	21.9	12.9	14.9	8.3	5.5	4.0
Outrage	15.6	4.0	8.4	7.4	21.0	12.6	12.3	9.5	5.2	4.0
Hope	11.3	5.4	6.7	11.1	25.4	13.6	12.1	6.4	3.8	4.2
Anger	16.1	4.8	7.8	6.9	21.3	12.8	12.1	9.2	4.2	4.7
Worry	10.5	2.7	6.3	6.5	20.2	14.9	16.7	10.7	6.4	5.1
Disgust	16.3	4.2	5.8	8.4	19.9	15.0	11.4	8.2	5.5	5.3
Disappointment	11.9	3.1	6.5	5.4	21.2	13.6	14.0	12.8	5.7	5.8
Sympathy	10.3	2.8	5.0	4.7	21.1	15.1	17.1	10.9	6.5	6.2
Sadness	10.6	3.2	5.4	6.0	17.1	14.2	14.9	12.1	8.2	8.3

Q26. Please select one of the following options. As a whole, does ocean acidification make you feel…

Very bad	Bad	Neutral	Good	Very good
10.0%	44.5%	40.2%	3.5%	1.9%

Q27. To what extent do you agree with the following statements about ocean acidification?

	Strongly Disagree	Tend to Disagree	Neither Agree nor Disagree	Tend to Agree	Strongly Agree	Total
	Percent	Percent	Percent	Percent	Percent	Frequency
My local area is likely to be affected by ocean acidification	14.3	26.2	34.6	18.9	6.1	954
Ocean acidification will mostly affect areas that are far from here	9.1	22.5	36.5	25.7	6.2	953
Ocean acidification will mostly affect people in developing countries	8.3	20.6	42.0	22.6	6.6	953
Ocean acidification is likely to have a big impact on people like me.	7.8	21.4	50.0	16.7	4.1	952

Q28. When, if at all, do you think Britain will start feeling the effects of ocean acidification?

	Frequency	Percent
We are already feeling the effects	243	25.5
In the next 10 years	171	17.9
In the next 20 years	140	14.7
In the next 50 years	62	6.5
In the next 100 years	18	1.9
Beyond the next 100 years	15	1.6
Never	17	1.8
Don't know	267	28.0
No opinion	21	2.2
Total	954	100

Q29. To what extent do you agree or disagree with the following statements?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
I believe that ocean acidification is happening too fast to adapt	6.7%	20.4%	53.1%	17.8%	2.0%
I am concerned that ocean acidification will pose a serious personal risk	7.5%	19.7%	46.6%	19.8%	6.3%
I think that ocean acidification is a serious risk for tourism and leisure	9.4%	35.2%	43.5%	9.7%	2.1%
I am worried that there will be an impact on food availability	11.1%	38.7%	37.0%	10.7%	2.5%
I think that ocean acidification will affect the reproduction and physiology of organisms	22.5%	44.1%	29.1%	3.6%	.8%
I don't think that we know enough about the long-term effects of ocean acidification	27.5%	38.6%	25.7%	6.7%	1.6%

Q30. From what you know or have heard about ocean acidification, on balance, which of these statements, if any, most closely reflects your own opinion?

	Frequency	Percent
The benefits of ocean acidification far outweigh the risks	32	3.4
The benefits of ocean acidification slightly outweigh the risks	51	5.3
The benefits and risks of ocean acidification are about the same	91	9.5
The risks of ocean acidification slightly outweigh the benefits	143	15.0
The risks of ocean acidification far outweigh the benefits	323	33.9
None of these	42	4.4
Don't know	272	28.5
Total	954	100

Q31. On the whole, how acceptable or unacceptable is ocean acidification to you?

	Frequency	Percent
Extremely acceptable	14	1.5
Very acceptable	20	2.1
Fairly acceptable	49	5.1
Slightly acceptable	43	4.5
Neither acceptable nor unacceptable	255	26.8
Slightly unacceptable	109	11.4
Fairly unacceptable	192	20.1
Very unacceptable	179	18.8
Extremely unacceptable	92	9.7
Total	953	100

Q32. How would you assess the benefits, if any, of ocean acidification for…

	Very high benefits	High benefits	Some benefits	Low benefits	No benefits	No opinion/ Don't know
Yourself	1.8%	4.4%	11.2%	15.5%	41.8%	25.3%
British Society as a whole	2.8%	5.7%	12.4%	17.1%	36.6%	25.4%
The environment	3.4%	6.5%	11.9%	12.6%	43.6%	22.0%

Q33. How would you assess the risks, if any, of ocean acidification for…

	Very high risks	High risks	Some risks	Low risks	No risks	No opinion/Don't know
Yourself	5.6%	10.3%	32.5%	20.7%	8.2%	22.8%
British Society as a whole	7.7%	18.9%	36.8%	12.1%	2.1%	22.5%
The environment	22.3%	26.3%	23.7%	6.6%	1.6%	19.6%

Q34. Please indicate to what extent you agree or disagree about the following statements about the ocean.

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
	Percent	Percent	Percent	Percent	Percent
The ocean is the best place for what I like to do	9.1	16.7	39.8	23.3	11.1
I feel the ocean is a part of me	10.1	19.6	37.3	20.9	12.2
Visiting the ocean says a lot about who I am	11.6	21.1	41.4	16.9	9.0
I identify very strongly with the ocean	11.8	26.1	35.5	18.2	8.5
I am very attached to the ocean	14.3	28.0	35.1	14.7	8.0
I get more satisfaction out of visiting the ocean more than any other place	14.4	24.9	35.1	17.7	7.9
The ocean is very special to me	15.8	29.7	36.3	12.5	5.8
No other place can compare to the ocean	23.4	33.0	29.5	9.6	4.5

Q35. How concerned, if at all, are you about climate change (sometimes referred to as global warming)?

	Very concerned	Fairly concerned	Not very concerned	Not at all concerned	Don't know	No opinion	Total
Frequency	207	433	170	80	28	27	945
Percent	21.9	45.8	18.0	8.5	3.0	2.9	100

Q36. As far as you know, do you personally think the world's climate is changing, or not?

	Frequency	Percent
Yes	788	82.9
No	163	17.1
Total	951	100

Q37. Thinking about the causes of climate change, which, if any, of the following best describes your opinion?

	Frequency	Percent
Climate change is entirely caused by natural processes	66	6.9
Climate change is mainly caused by natural processes	115	12.1
Climate change is partly caused by natural processes and partly caused by human activity	403	42.2
Climate change is mainly caused by human activity	284	29.8
Climate change is entirely caused by human activity	49	5.1
There is no such thing as climate change	37	3.9
Total	954	100

Q38. Which of the following groups, if any, do you trust to give you correct information on climate change?

	Frequency	Percent
Independent scientists (such as University Research centres)	597	62.6
Environmental groups	321	33.7
Government scientists	158	16.6
None of these	130	13.6
Friends and family	81	8.5
The media	65	6.8
The government	55	5.8
Business and industry	44	4.6
Other	30	3.1

Q39. To what extent do you agree or disagree with the following statements?

	Strongly Agree	Tend to Agree	Neither Agree nor Disagree	Tend to Disagree	Strongly Disagree
There is very little I can personally do to help address climate change	8.9%	25.8%	34.8%	25.3%	5.1%
Climate change will mostly affect developing countries	12.4%	24.4%	40.1%	16.7%	6.4%
We can trust scientists to tell us the truth about climate change	13.1%	49.2%	26.8%	7.7%	3.3%
Climate change will have consequences for me or my family	13.1%	43.4%	34.3%	6.1%	3.0%
Climate change is likely to be a serious problem for Great Britain	16.5%	37.0%	36.9%	7.0%	2.5%

Q40. How high or low a priority should it be for the UK government to take action on climate change?

	Frequency	Percent
Very low priority	37	3.9
Fairly low priority	101	10.6
Medium priority	316	33.2
Fairly high priority	314	33.0
Very high priority	184	19.3
Total	952	100

Q41. On a scale of -5 to 5 how positive or negative do you feel about climate change?

	-5	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**Total**
Affect	10.6	9.0	14.3	13.6	7.5	30.3	4.5	3.1	3.2	1.7	2.1	100.0

APPENDIX H: KNOWLEDGE SCALE DEVELOPMENT

Statements included in the survey to measure knowledge of OA were a combination of scientifically accurate and widely agreed upon statements, not scientifically correct statements and statements which were uncertain. To determine what category these statements fell into two experts also completed the knowledge section of the survey individually and talked through any contentious statements. The knowledge items included possible causes, impacts, interactions and responses to OA and each of these sub-sections formed a scale to assess each knowledge component. The scoring system was based on Tobler et al. (2012) where participants responses were scored 1 for a correct response and 0 for a wrong or don't know response. Areas of uncertainty were harder to score as some of the statements could be quite complex or become accurate in future. Other issues with this scoring system were that participants may have scored highly despite having low levels of knowledge by simply guessing correctly with others who may actually know more choosing not to answer and therefore scoring less.

The items were transformed into dichotomous variables and scored appropriately with each participant given an overall total for each section as shown below. For example Strongly Agree & Agree, and Disagree & Strongly Disagree were combined with either a 0 or 1 allocated depending on whether the statement was scientifically sound or not. Neither Agree nor Disagree scored 0 in all cases.

Causes	**Agree**	**Disagree**	**Don't Know**
Overfishing	0	1	0
Pollution from chemical & industrial waste	0	1	0
Increase in seawater temperatures from climate change	0	1	0
Climate change altering wind patterns and ocean circulation (upwelling)	1	0	0
Carbon dioxide leaks from CCS (local, dependent on technology)	1	0	0
Pollution from ships etc	0	1	0
Carbon dioxide in the atmosphere from humans	1	0	0
Natural cycles of change in ocean chemistry	0	1	0
Acid rain	0	1	0
Litter	0	1	0
Naturally-occurring carbon dioxide	0	1	0
Total Score	*3*	*8*	*0*
Consequences			
Damage to marine food chain	1	0	0
Reduced ability of ocean to absorb carbon dioxide	0	0	0
Increased ability of ocean to absorb carbon dioxide	0	1	0
Impact on food availability for people	1	0	0
Tourism and Leisure	1	0	0
Natural systems affected (weather & currents)	0	0	0

More favourable conditions for some tiny marine organisms	0	0	0
Less favourable conditions for some tiny marine organisms	1	0	0
More favourable conditions for some large marine organisms	0	1	0
Less favourable conditions for some large marine organisms	1	0	0
Availability of drinking water	0	1	0
Damage to coral reefs	1	0	0
Skin damage	0	1	0
Extinction of some organisms	1	0	0
Problem for people reliant on ocean for livelihoods	1	0	0
Total Score	*8*	*4*	*0*
Interactions			
Climate change	1	0	0
Temperature increases from global warming	1	0	0
River system run-off	0	1	0
Rate of carbon dioxide emissions	1	0	0
Temperature increases from natural changes	0	1	0
Rate of ice-melt	1	0	0
Ocean circulation	1	0	0
Total Score	*5*	*2*	*0*
Measures to reduce OA			
Switch to renewable and clean energy	1	0	0
Communication with policymakers	1	0	0
Recycling household waste	0	1	0
Introduce alkaline substances into the ocean to rebalance it	1	0	0
Creating more MPAs	0	1	0
Monitoring OA	1	0	0
Increasing public awareness of the risks of OA	1	0	0
Restricting fishing of affected organisms	0	1	0
Reduce carbon emissions	1	0	0
Planting more trees	0	1	0
Leaving the ocean alone to balance itself out over time	1	0	0
Reduction of chemical and industrial waste	0	1	0
Total Score	*7*	*5*	*0*
MAXIMUM TOTAL SCORE	*23*	*19*	*0*

Table 1. Scores assigned to knowledge scales

APPENDIX I: FACTOR ANALYSES FOR SCALE CONSTRUCTS

Factor Analysis – Pro-environmentalism scale

I think of myself as someone who is concerned about the environment	.907
I consider myself to be environmentally conscious	.885
Being environmentally- friendly is an important part of who I am	.872
I would be embarrassed to be seen as having an environmentally-friendly lifestyle	.410

Factor Analysis – Emotion scale

	Factor 1	Factor 2
Outrage	.874	
Disgust	.869	
Anger	.868	
Disappointment	.856	
Worry	.855	
Fear	.854	
Sadness	.840	
Shame	.822	
Regret	.792	
Guilt	.768	
Hopelessness	.753	
Sympathy	.731	
Contempt	.701	
Indifference		.903
Hope		.492

Factor Analysis – Values scale

	Factor 1	Factor 2
The world would be a better place if its wealth were divided equally among nations	.807	
In my ideal society, all basic needs such as food, housing, education and health care would be guaranteed by the government for everyone	.763	
Discrimination against minorities is still a very serious problem in our society	.733	
When I have problems, I try to solve them on my own		.701
If the government spent less time trying to fix everybody's problems we'd all be better off		.684
People should be allowed to make as much money as they can for themselves, even if others are not able to		.654

Factor Analysis – Benefits scale

	Factor 1
How would you assess the benefits, if any, of ocean acidification for...-British Society as a whole	.952
How would you assess the benefits, if any, of ocean acidification for...-Yourself	.940
How would you assess the benefits, if any, of ocean acidification for...-The environment	.924

Factor Analysis - Risks scale

	Factor 1
How would you assess the risks, if any, of ocean acidification for...-British Society as a whole	.959
How would you assess the risks, if any, of ocean acidification for...-Yourself	.936
How would you assess the risks, if any, of ocean acidification for...-The environment	.922

Factor Analysis – Place attachment scale

	Factor 1
I am very attached to the ocean	.890
I identify very strongly with the ocean	.888
The ocean is very special to me	.883
I feel the ocean is a part of me	.872
Visiting the ocean says a lot about who I am	.872
I get more satisfaction out of visiting the ocean more than any other place	.861
The ocean is the best place for what I like to do	.838
No other place can compare to the ocean	.707

Factor Analysis – Psychological distance scale

	Factor 1	Factor 2
Ocean acidification will mostly affect people in developing countries		.858
Ocean acidification will mostly affect areas that are far from here		.813
My local area is likely to be affected by ocean acidification	.857	
Ocean acidification is likely to have a big impact on people like me	.832	