Proforma for the UK Climate Change Risk Assessment (CCRA) Submission of Evidence

*(Please note that the text boxes expand)

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3.Please tick below which of the following points your evidence relates to (if submitting more than one piece of evidence, please tick all that apply across all pieces of evidence- you do not need to submit a separate proforma for each publication).

Issues

1. ☒How risks or opportunities may have changed in the light of improved methods of assessment and new knowledge since 2012.
2. ☒The quantified effects of current and planned policies and other action in the overall assessment of risk.
3. ☒How climate change overseas could impact on the UK.
4. ☒What the net effect of different risks acting together could be, either due to concurrent timing, acting on the same location or the same receptor.
5. ☒How climate change interacts with other socio-economic factors to affect the level of risk or opportunity. Part of the analysis needs to address how important climate change is as a driver of change compared to other drivers.
6. ☒A quantitative assessment of the magnitude of impact and the urgency of action needed for different threats and opportunities.
7. ☒A quantitative assessment of the uncertainties, limitations and confidence in the underlying evidence and analysis for different risks.

Chapters

1. ☒ **Characterising the future** (update on climate science, setting out socio-economic scenarios, approach to analysis and understanding risk)
2. ☒ **The rural economy and natural environment** (risks/opportunities associated with land use in rural areas- agriculture, forestry and semi-natural habitats including marine habitats)
3. ☒ **Infrastructure** (risks/opportunities associated with transport, water, waste, ICT, and energy. Includes risks from flooding, storms, water scarcity, ground conditions and heat/cold)
4. ☒ **People and the built environment** (risks/opportunities directly affecting people and/or buildings, including through impacts from heat and cold, flood risk, water availability and quality, effects of climate change on wellbeing, risks/adaptation through blue and green infrastructure)
5. ☒ **Business and industry** (risks/opportunities to the private sector including finance, insurance, flood risk to

businesses, supply chains)

6. ☒ **Global security** (risks/opportunities associated with food security, conflict, or migration that could affect the UK)
7. ☒ **Cross-cutting issues** (chapter bringing together themes from across the report that have been considered separately in each chapter. This includes interdependencies, social vulnerability, and a focussed look on the level of resilience to a small number of plausible extreme events with multiple knock-on impacts such as a major drought, flood, heatwave or cold snap).

4.Please provide title/s, main author, year of publication and a brief summary of content for all evidence you are submitting. Please include a brief explanation of how it relates to the points ticked above.

i. Batstone, C., M. Lawless, et al. (2013). "A UK best-practice approach for extreme sea-level analysis along complex topographic coastlines." Ocean Engineering 71(0): 28-39.

Summary: The impacts of storm surges represent increasing risk to the world's coastlines. Coastal planners require accurate estimates of flood risk in order to provide suitable defensive measures. Therefore a reliable methodology is required for the estimation of extreme sea-level probabilities at high spatial resolution along coastlines.

This paper describes a new method for estimating these probabilities, with application to the UK coastline. The method provides interpolated sea levels around complex coastlines at high resolution and uses skew surge, which reliably discerns atmospheric impacts on sea level.

The method has been applied to the UK coastline to provide a database of extreme sea-level probabilities for the Environment Agency for England and Wales and the Scottish Environment Protection Agency. The database will be used to inform coastal defence strategy, flood mapping and forecasting and to support policy, implementation and operational decision-making.

Links to issues and chapters: This paper provides an improved methodology and knowledge base to better understand extreme sea levels due to storm surges around UK coasts, compared to the available knowledge in 2012. It also provides further information on the uncertainties and confidence on the information available. This paper will help inform Chapter 1 'Characterising the future' of sea level extreme events due to storm surges in the UK as it provides an improved methodology for estimating risk. It also links with Chapter 3 ' Infrastructure', Chapter 4 ' People and the built environment' and Chapter 5 ' Business and Industry' as the impacts of extreme flooding due to extreme sea levels affects people, industry and businesses located in coastal regions and therefore better understanding and probability of future event occurrence will improve adaptation and preparedness.

ii. Blanchard, J. L., S. Jennings, et al. (2012). "Potential consequences of climate change for primary production and fish production in large marine ecosystems." Philosophical Transactions of the Royal Society B: Biological Sciences **367**(1605): 2979-2989.

Summary: Existing methods to predict the effects of climate change on the biomass and production of marine communities model the interactions and dynamics of individual species. This is a very challenging approach when interactions and distributions are changing and little is known about the ecological mechanisms driving the responses of many species. An informative parallel approach is to develop size-based methods. These capture the properties of food webs that describe energy flux and production at a particular size, independent of species' ecology.

This paper couples a physical–biogeochemical model with a dynamic, size-based food web model to predict the future effects of climate change on fish biomass and production in 11 large regional shelf seas, with and without fishing effects.

Changes in potential fish production are shown to most strongly mirror changes in phytoplankton production. The authors project declines of 30–60% in potential fish production across some important areas of tropical shelf and upwelling seas, most notably in the eastern Indo-Pacific, the northern Humboldt and the North Canary Current.

Conversely, in some areas of the high latitude shelf seas, the production of pelagic predators was projected to increase by 28–89%.

Links to issues and chapters: This paper provides an improved methodology and knowledge base to better understand how climate change will impact primary production and ultimately fish stocks. Furthermore because it takes a regional approach to examining the shelf-seas this paper also provides information on how climate change overseas (or outside UK coastal waters) will impact the UK (specifically economies and business reliant on fishing) Consequently this paper will link to Chapter 1, 'Characterising the future', Chapter 2 'The rural economy and natural environment', Chapter 5 'Business and Industry' and Chapter 6, 'Global Security'.

iii. Esteves, L. S., J. M. Brown, et al. (2012). "Quantifying thresholds for significant dune erosion along the Sefton Coast, Northwest England." Geomorphology 143–144(0): 52-61.

Summary: This paper investigates the combinations of water levels and waves that cause significant erosion of a dune system over the period 1996-2008. Field and model hindcast data are used to establish a critical dune erosion threshold for the Sefton Coast (NW England). Evidence suggests that erosion is more likely to occur when wave heights are > 2.6 m, peak water level is > 10.2 m Chart Datum (CD) at Liverpool and when consecutive tidal cycles provide 10 h or more of water levels above 9.4 m CD. However, lower water levels and wave heights, and shorter events of sustained water levels, can cause significant erosion in the summer. While the return period for events giving rise to the most severe erosion in the winter is > 50 years, significant erosion in the summer can be caused by events with return periods < 1 year. It is suggested that this may be attributable to a known reduction in the mean dune toe elevation c. 30 cm.

Although the study shows it might be possible to characterise objectively storm events based on oceanographic conditions, the resultant morphological change at the coast is demonstrated to depend on the time and duration of events, and on other variables, which are not so easy to quantify. Improved monitoring pre- and post-storm of changes in beach/dune morphology is required to develop reliable proxies that can be used to establish early warning systems to mitigate the impacts of erosion and flooding in the future.

Links to issues and chapters: This paper provides an improved methodology, understanding of the magnitude of the impact and an examination of the drivers contributing to erosion sensitive coastal features such as dunes. Understanding the erosion of such coastal features is important as it has implications for the UK's natural flood defences. Consequently this information links in with Chapters 2, 3, 4, and 6.

iv. Grinsted, A., J. C. Moore, et al. (2012). "Homogeneous record of Atlantic hurricane surge threat since 1923." Proceedings of the National Academy of Sciences **109**(48): 19601-19605.

Summary: Detection and attribution of past changes in cyclone activity are hampered by biased cyclone records due to changes in observational capabilities. Here we construct an independent record of Atlantic tropical cyclone activity on the basis of storm surge statistics from tide gauges. We demonstrate that the major events in our surge index record can be attributed to landfalling tropical cyclones; these events also correspond with the most economically damaging Atlantic cyclones. We find that warm years in general were more active in all cyclone size ranges than cold years. The largest cyclones are most affected by warmer conditions and we detect a statistically significant trend in the frequency of large surge events (roughly corresponding to tropical storm size) since 1923. In particular, we estimate that Katrina-magnitude events have been twice as frequent in warm years compared with cold years ($P < 0.02$).

Links to issues and chapters: This paper provides improved understanding of the links between cyclone activity and storm surges, which have wider socio-economic impacts on coastal regions. Furthermore it provides information on the impacts of climate change overseas, in particular in regions where the UK has overseas territories, for which it is responsible. Consequently the findings of this paper link with Chapters 2, 4, 5 and 6.

v. Hartman, S. E., R. S. Lampitt, et al. (2012). "The Porcupine Abyssal Plain fixed-point sustained observatory (PAP-SO):

variations and trends from the Northeast Atlantic fixed-point time-series." ICES Journal of Marine Science: Journal du Conseil **69**(5): 776-783.

Summary: The Porcupine Abyssal Plain sustained observatory (PAP-SO) in the Northeast Atlantic (49°N 16.5°W; 4800 m) is the longest running open-ocean multidisciplinary observatory in the oceans around Europe. The site has produced high-resolution datasets integrating environmental and ecologically relevant variables from the surface to the seabed for >20 years. Since 2002, a full-depth mooring has been in place with autonomous sensors measuring temperature, salinity, chlorophyll-a fluorescence, nitrate, and pCO2. These complement on-going mesopelagic and seabed observations on downward particle flux and benthic ecosystem structure and function. With national and European funding, the observatory infrastructure has been advanced steadily, with the latest development in 2010 involving collaboration between the UK's Meteorological Office and Natural Environment Research Council. This resulted in the first simultaneous atmospheric and ocean datasets at the site. All PAP-SO datasets are open access in near real time through websites and as quality-controlled datasets for a range of remote users using ftp sites and uploaded daily to MyOcean and the global telecommunications system for use in modelling activities. The combined datasets capture short-term variation (daily–seasonal), longer term trends (climate-driven), and episodic events (e.g. spring-bloom events), and the data contribute to the Europe-wide move towards good environmental status of our seas, driven by the EU's Marine Strategy Framework Directive

Links to issues and chapters: This paper provides improved methods and data availability to assess the risks of climate change. Furthermore, because multiple oceanographic parameters are recorded together at the same site it helps to better assess the net effects of climate change on marine parameters. The data presented in this paper is used to feed into policy such as MSFD. Therefore the paper helps to quantify the effects of current policy. The information also feeds into Chapter 3.

vi. Henson, S., R. Lampitt, et al. (2012). "Variability in phytoplankton community structure in response to the North Atlantic Oscillation and implications for organic carbon flux." Limnology and Oceanography 57(6): 1591-1601.

Summary: The North Atlantic Oscillation (NAO) is a major mode of variability in the North Atlantic, dominating atmospheric and oceanic conditions. This paper examines the phytoplankton community-structure response to the NAO using the Continuous Plankton Recorder data set. Diatoms dominate the phytoplankton community in positive NAO periods, whereas in negative NAO periods, dinoflagellates outcompete diatoms. The implications for interannual variability in deep ocean carbon flux are examined using data from the Porcupine Abyssal Plain time-series station. Contrary to expectations, carbon flux to 3000 m is enhanced when diatoms are outcompeted by other phytoplankton functional types. Additionally, highest carbon fluxes were not associated with an increase in biomineral content, which implies that ballasting is not playing a dominant role in controlling the flux of material to the deep ocean in this region. In transition zones between gyre systems, phytoplankton populations can change in response to forcing induced by opposing NAO phases.

Links to issues and chapters: This paper provides new knowledge on how changing plankton communities change in response to the North Atlantic Oscillation, which in turn affects carbon supply to the sea flood and thus the benthic communities living there. Consequently it also links into the net effects of the drivers of change in carbon flux. Overall this paper links with Chapters 2 and 3.

vii. Jevrejeva, S., J. C. Moore, et al. (2012). "Sea level projections to AD2500 with a new generation of climate change scenarios." Global and Planetary Change **80–81**(0): 14-20.

Summary: Sea level rise over the coming centuries is perhaps the most damaging side of rising temperature. The economic costs and social consequences of coastal flooding and forced migration will probably be one of the dominant impacts of global warming. To date, however, few studies on infrastructure and socio-economic planning include provision for multi-century and multi-metre rises in mean sea level. Here we use a physically plausible sea level model constrained by observations, and forced with four new Representative Concentration Pathways (RCP) radiative forcing scenarios to project median sea level rises of 0.57 for the lowest forcing and 1.10 m for the highest forcing by 2100 which rise to 1.84 and 5.49 m respectively by 2500. Sea level will continue to rise for several centuries even after stabilisation of radiative forcing with most of the rise after 2100 due to the long response time of sea level. The rate of sea level rise would be positive for centuries, requiring 200–400 years to drop to the 1.8 mm/yr 20th century average, except for the RCP3PD which would rely on geoengineering.

Links to issues and chapters: This paper provides *new knowledge* on how sea level is predicted to change in the future and what the long-term consequences for sea level rise are if emissions stabilised today. It also highlights the fact that there are many *socioeconomic effects* such as coastal flooding and forced migration which will be affected by long term sea level rise. It also highlights the *uncertainties and limitations* in the underlying evidence for the risks of sea level rise. This links with *Chapters 2, 4, 5, 6 and 7*.

viii. McCarthy, G., E. Frajka-Williams, et al. (2012). "Observed interannual variability of the Atlantic meridional overturning circulation at 26.5°N." Geophysical Research Letters **39**(19): L19609.

Summary: The Atlantic meridional overturning circulation (MOC) plays a critical role in the climate system and is responsible for much of the heat transported by the ocean. A mooring array, nominally at 26°N between the Bahamas and the Canary Islands, deployed in Apr 2004 provides continuous measurements of the strength and variability of this circulation. With seven full years of measurements, this paper examines the interannual variability of the MOC. While earlier results highlighted substantial seasonal and shorter timescale variability, there had not been significant interannual variability. The results of this paper show a 30% decline, which persisted from early 2009 to mid-2010. The authors show that the cause of the decline was not only an anomalous wind-driven event from Dec 2009–Mar 2010 but also a strengthening of the geostrophic flow. In particular, the southward flow in the top 1100 m intensified, while the deep southward return transport—particularly in the deepest layer from 3000–5000 m—weakened. This rebalancing of the transport from the deep overturning to the upper gyre has implications for the heat transported by the Atlantic.

Links to issues and chapters: This paper provides *new knowledge* on how ocean circulation and heat distribution is changing in the Atlantic. This information will help to *better quantify* how the ocean circulation may respond to climate change and will impact the *confidence and uncertainties* in the underlying evidence for the implications of changes in ocean circulation. Ocean circulation impacts global climate therefore the data in this paper does not fit into one single chapter but has implications for all chapters. It could be seen as best fitting into *Chapters 2 and 8*.

ix. Merino, G., M. Barange, et al. (2012). "Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate?" Global Environmental Change **22**(4): 795-806.

Summary: Expansion in the world's human population and economic development will increase future demand for fish products. As global fisheries yield is constrained by ecosystems productivity and management effectiveness, per capita fish consumption can only be maintained or increased if aquaculture makes an increasing contribution to the volume and stability of global fish supplies. This paper uses predictions of changes in global and regional climate (according to IPCC emissions scenario A1B), marine ecosystem and fisheries production estimates, human population size estimates, fishmeal and oil price estimations, and projections of the technological development in aquaculture feed technology, to investigate the feasibility of sustaining current and increased per capita fish consumption rates in 2050. The paper concludes that meeting current and larger consumption rates is feasible, despite a growing population and the impacts of climate change on potential fisheries production, but only if fish resources are managed sustainably and the animal feeds industry reduces its reliance on wild fish. Ineffective fisheries management and rising fishmeal prices driven by greater demand could, however, compromise future aquaculture production and the availability of fish products.

Links to issues and chapters: Changing ecosystem productivity due to climate change will likely impact fisheries yield. This paper highlights the *opportunities* for better fisheries management in order to continue meeting demand for fish consumption. The paper also shows the *net effects of different risks* (management climate change) on fisheries production. It therefore fits with *Chapters 2, 3, 5, 6 and 7.*

x. Pickering, M. D., N. C. Wells, et al. (2012). "The impact of future sea-level rise on the European Shelf tides." Continental Shelf Research 35(0): 1-15.

Summary: This paper investigates the effect of future sea-level rise (SLR) on the tides of the northwest European Continental Shelf. The tidal amplitude responds to SLR in a spatially non-uniform manner, with substantial amplitude increases and decreases for both 2m SLR and 10 m SLR scenarios. With 2m SLR the spring tidal range increases up to 35 cm at Cuxhaven and decreases up to −49 cm at St. Malo. Additionally the changes in the shallow water tides are larger than expected. With SLR the depth, wave speed and wave length (tidal resonance characteristics) are increased causing changes in near resonant areas. This paper highlights the importance of considering the modification of the tides by future SLR. These substantial future changes in the tides could have wide reaching implications; including for example, correctly calculating design level requirements for flood defences, the availability of tidal renewable energy and dredging requirements.

Links to issues and chapters: This paper improves our knowledge for the future, of how climate change will impact tides across the European Shelf. The finding suggesting the modification of tides by SLR, will have implications for risks to the natural coastal environment (*Chapter 3*), infrastructure (*Chapter 4*), people and the built environment (*Chapter 5*), business and industry (*Chapter 6*) and Global security (*Chapter 7*), in particular potential migration of populations from coastal areas.

xi. Srokosz, M., M. Baringer, et al. (2012). "Past, Present, and Future Changes in the Atlantic Meridional Overturning Circulation." Bulletin of the American Meteorological Society **93**(11): 1663-1676.

Summary: Observations and numerical modeling experiments provide evidence for links between variability in the Atlantic meridional overturning circulation (AMOC) and global climate patterns. Reduction in the strength of the overturning circulation is thought to have played a key role in rapid climate change in the past and may have the potential to significantly influence climate change in the future, as noted in the last two Intergovernmental Panel on Climate Change (IPCC) assessment reports. Both IPCC reports also highlighted the significant uncertainties that exist regarding the future behaviour of the AMOC under global warming. Model results suggest that changes in the AMOC can impact surface air temperature, precipitation patterns, and sea level, particularly in areas bordering the North Atlantic, thus affecting human populations. Here, the current understanding of past, present, and future changes in the AMOC and the effects of such changes on climate are reviewed. The focus is on observations of the AMOC, how the AMOC influences climate, and in what way the AMOC is likely to change over the next few decades and the twenty-first century. The potential for decadal prediction of the AMOC is also discussed. Finally, the outstanding challenges and possible future directions for AMOC research are outlined.

Links to issues and chapters: This paper provides a review of the current understanding of past present and future changes of the Atlantic Meridonal Overturning Circulation. As such it contributes to *Chapter 2*, and *improves knowledge* of the risks of climate change. The implications for changes in AMOC are far reaching, spanning nearly all of the chapters. As such this information should certainly feed into *Chapter 8, cross-cutting issues*.

xii. Statham, P. J. (2012). "Nutrients in estuaries — An overview and the potential impacts of climate change." Science of The Total Environment **434**(0): 213-227.

Summary: The fate and cycling of macronutrients introduced into estuaries depend upon a range of interlinked processes. Hydrodynamics and morphology in combination with freshwater inflow control the freshwater flushing time, and the timescale for biogeochemical processes to operate that include microbial activity, particle-dissolved phase interactions, and benthic exchanges. In some systems atmospheric inputs and exchanges with coastal waters can also be important. Climate change will affect nutrient inputs and behaviour through modifications to temperature, wind patterns, the hydrological cycle, and sea level rise. Resulting impacts include: 1) inundation of freshwater systems 2) changes in stratification, flushing times and phytoplankton productivity 3) increased coastal storm activity 4) changes in species and ecosystem function. A combination of continuing high inputs of nutrients through human activity and climate change is anticipated to lead to enhanced eutrophication in the future. The most obvious impacts of increasing global temperature will be in sub-arctic systems where permafrost zones will be reduced in combination with enhanced inputs from glacial systems.

Links to issues and chapters: This paper provides a review of the impacts of climate change on nutrients in estuaries. As such it helps to formulate *new knowledge* and look at the net effects of climate change and nutrient inputs in estuaries on the *marine and estuarine habitats*. Consequently this paper links with *Chapters 2 and 3*.

xiii. Wood, J. (2013). "Blue technologies: Innovation hotspots for the European marine sector. ." (In: McDonough, Niall, (ed.) Navigating the Future IV. Brussels, European Marine Board, 122-133, 203pp. (European Marine Board Position Paper, 20).)

Summary: The Marine Board Navigating the Future series provides regular pan-European summaries of the current status of marine research, priority recommendations and future scientific challenges in the context of European societal needs. Navigating the Future is a blueprint to guide both the research and the science policy agendas at European and national level. Since 2001 when the first Navigating the Future position paper was published, the series has been widely recognized, both by researchers and science policymakers, as providing critical periodic foresight and recommendations on emerging marine science topics and needs, and associated societal challenges and opportunities. Navigating the Future IV is designed to inform the Commission calls under the forthcoming Horizon 2020 programme. The paper is organized around the framework of key societal challenges in the areas of climate, human health, food security, energy and safe and sustainable use of marine space. NFIV also addresses strategic and enabling issues such as European Ocean Observing System (EOOS), training, the science-policy interface and ocean literacy.

Links to issues and chapters: This report provides contextual links to the *opportunities and risks* that climate change will bring to the marine sector. It also provides an overview of the *policies* and *other activities* from industrial and technological innovation that will impact on the marine environment with socioeconomic feedbacks. Consequently this report will provide information for *Chapters 2, 3, 4, 5, 6, and 7.*

xiv. CARAMANNA, G., WEI, Y., MAROTO-VALER, M. M., NATHANAIL, P. & STEVEN, M. 2013. Laboratory experiments and field study for the detection and monitoring of potential seepage from CO2 storage sites. Applied Geochemistry, 30, 105-113.

Summary: Potential CO2 seepages from geological storage sites or from the injection rig may affect the surrounding environment. To develop reliable detection techniques for such seepages a laboratory rig was designed that is composed of three vertical Plexiglas columns. The columns can be filled with sediments and water; CO2 can be injected from the bottom. Two columns are used to simulate the impact of CO2 on soils; while the third one, which is larger in size, simulates CO2 seepage in aquatic environments. The main results of the laboratory experiments indicate that increased levels of CO2 generate a quick drop in pH. Once the seepage is stopped, a partial recovery towards the initial values of pH is recorded. The outcomes of the laboratory experiments on the aquatic seepage are compared with observations from a submarine natural emission of CO2. In this natural underwater seepage multi-parametric probes and laboratory analysis were used to analyze the composition and the chemical effects of the emitted gas; basic acoustic techniques were tested as tools for the prompt detection of CO2 bubbles in water.

xv. CARAMANNA, G., WEI, Y., MAROTO-VALER, M. M., NATHANAIL, P. & STEVEN, M. 2012. Design and use of a laboratory rig for the study of the chemical-physical effects on aquatic environments of potential seepage from CO2 storage sites. Greenhouse Gases: Science and Technology, 2, 136-143.

Summary: In sub-seabed storage, CO2 is injected under the seafloor in geological structures that are able to trap and retain it. Even if the overall procedure is considered safe, the effects of potential seepage must be addressed in order to develop a reliable risk assessment of the process. This study focuses on the effects of CO2 seepage on the chemistry of sediments and on the overlying water column in shallow-water environments. The results highlight a fast response of the system when injected with CO2 with a sharp reduction of the pH values of the interstitial water inside the sediments; once the injection stops, a recovery toward the initial values is recorded. The water above the sediment is also affected by the presence of CO2; in this case the gas-water interaction is controlled by the water movements induced by the rising bubble column.

xvi. CARAMANNA, G., VOLTATTORNI, N. & MAROTO-VALER, M. M. 2011. Is Panarea Island (Italy) a valid and cost-effective natural laboratory for the development of detection and monitoring techniques for submarine CO2 seepage? Greenhouse Gases: Science and Technology, 1, 200-210.

Summary: Developing reliable detection and monitoring techniques for underwater CO2 seepage and its effects on the marine environment is important for a wide range of topics; for example: volcanic surveillance, risk assessment of potential leakages from sub-seabed CO2 storage sites, and to forecast the effects of ocean acidification. A novel approach is to use areas where natural release of CO2 is present as 'field-laboratories' for validation of CO2 monitoring techniques and procedures. One such area was identified close to the volcanic island of Panarea (Italy). From these first results, the submarine degassing area of Panarea can be realistically considered a natural laboratory where it is possible to test and validate detection methods for the prompt identification of potential seepage from sub-seabed CO2 storage areas. The particularly favorable environment permits the use of simplified logistics, thus reducing the costs of the research to almost negligible values if compared with any high-seas operation.

xvii. ESPA, S., CARAMANNA, G. & BOUCHÉ, V. 2010. Field study and laboratory experiments of bubble plumes in shallow seas as analogues of sub-seabed CO2 leakages. Applied Geochemistry, 25, 696-704.

Summary: To understand the effects of increased levels of CO2 on the marine realm, it is possible to study areas where, for natural reasons, there are emissions of CO2 from the seabed. One of these areas is located east of Panarea Island (Aeolian Islands – Southern Tyrrhenian Sea – Italy). Here, the volcanic activity that characterizes the Aeolian archipelago causes a continuous release of CO2 (up to 98% of the total gas) from several vents on the seafloor in shallow water. This area was studied by means of surface techniques and direct SCUBA diving surveys; the data presented refers to a field campaign performed in 2008. Furthermore, some laboratory experiments in a two-layer stratified fluid were conducted to understand the main features of the physical interaction of a gas plume with the surrounding environment. Both field and laboratory experiments show that there is a development of a pseudo-convective cell around the rising plume with the formation of vortices that act as a physical barrier thus reducing the interaction between the plume and the surrounding water.

xviii. CARAMANNA, G. & HENNIGE, S. 2014. Potential impact of CO2 emissions on the seafloor. Advances in Enviornomental Research. Hauppauge, New York: NOVA Science Publishers.

Summary: Carbon Capture and Storage (CCS) aims to capture CO2 from fossil-fuel sources, transport and store it in suitable geological formations where it will be confined for extremely prolonged times. This is considered a feasible way of mitigating global warming. For the UK and large parts of Europe, the North Sea is potentially the most suitable location for CCS projects required to achieve planned targets in the reduction of CO2 emission. The risk of CO2 seepage must be addressed considering potential consequences on the marine environment. CO2 emissions may affect the seafloor with physical (e.g. sediments displacement), chemical (e.g. acidification) and biological (e.g. toxicity) effects. Laboratory experiments and the study of natural submarine CO2 vents are contributing to the development of a solid body of knowledge on these effects. This chapter reviews the physical, chemical and biological implications of sub-seabed storage of CO2, and the consequences of potential seep events.

Links to issues and chapters (for references xiv – xviii): These papers listed above provide evidence and new knowledge related to Chapter 3 – in particular related to marine habitats and the impacts of CO2 on the marine environment.

xix. BAUDRON, A. R., NEEDLE, C. L., RIJNSDORP, A. D. & TARA MARSHALL, C. 2014. Warming temperatures and smaller body sizes: synchronous changes in growth of North Sea fishes. Global Change Biology, 20, 1023-1031.

Summary: In this study the authors show that over a 40-year period six of eight commercial fish species in the North Sea examined underwent concomitant reductions in asymptotic body size with the synchronous component of the total variability coinciding with a 1–2 °C increase in water temperature. Smaller body sizes decreased the yield-per-recruit of these stocks by an average of 23%. Although it is not possible to ascribe these phenotypic changes unequivocally to temperature, four aspects support this interpretation: (i) the synchronous trend was detected across species varying in their life history and life style; (ii) the decrease coincided with the period of increasing temperature; (iii) the direction of the phenotypic change is consistent with physiological knowledge; and (iv) no cross-species synchrony was detected in other species-specific factors potentially impacting growth. These findings support a recent model-derived prediction that fish size will shrink in response to climate-induced changes in temperature and oxygen: the smaller body sizes being projected for the future are already detectable in the North Sea. This study is the first to provide empirical support for this prediction at the ecosystem scale for marine fish species.

Links to issues and chapters The loss of yield associated with the decrease in body size of commercial fish species could, ultimately, jeopardise the economic efficiency of the North Sea fisheries, thus potentially threatening the UK fishing industry. This relates to Chapter 6 on the risks for the industry. This loss of yield is also likely to diminish the production of the North Sea fisheries. In addition the decline in fish body size could decrease the productivity of the North Sea fisheries since smaller fish produce fewer, smaller eggs, which are less likely to survive. This issue relates to Chapter 7 on food security.

xx. RIUS, M., CLUSELLA-TRULLAS, S., MCQUAID, C. D., NAVARRO, R. A., GRIFFITHS, C. L., MATTHEE, C. A., VON DER HEYDEN, S. & TURON, X. 2014. Range expansions across ecoregions: interactions of climate change, physiology and genetic diversity. Global Ecology and Biogeography, 23, 76-88.

Summary: Climate change is expected to drive range shifts among a wide array of organisms. Non-indigenous species (NIS) provide a unique opportunity to observe the establishment of range boundaries in a way that cannot be directly seen for native species. Recent studies have indicated that climate change facilitates biological invasions at local scales. However, the generality of these effects is unclear, as there is a dearth of comparative studies that assess how rapid environmental change affects species ranges across taxa and biogeographic provinces. This study provides empirical evidence that NIS, regardless of their thermal tolerance, range size and genetic variability, are expanding their ranges and increasing in abundance. This trend is uncorrelated with levels of human-mediated NIS transport but concurrent with changes in seawater temperature, which suggests that climate change fosters the spread and abundance of NIS across multiple spatial scales.

Links to issues and chapters: This paper provides further evidence on known climate impacts and the risks associated with climate change.

xxi. MCCIP 2013. Marine Climate Change Impacts Report Card 2013. Marine Climate Change Impacts Partnership.

Summary: The 2013 MCCIP Report Card provides the very latest updates on our understanding of how climate change is affecting UK seas. There are 4 key messages communicated in the report card. 1) Temperature records continue to show an overall upward trend despite short-term variability. 2) The seven lowest Arctic sea-ice extents in the satellite era were recorded between 2007 and 2013. 3) Changes to primary production are expected throughout the UK, with southern regions (e.g. Celtic Sea, English Channel) becoming up to 10% more productive and northern regions (e.g. central and northern North Sea) up to 20% less productive; with clear implications for fisheries. 4) There continue to be some challenges in identifying impacts of climate change. These are due to difficulties distinguishing between short-term variability and long-term trends, and between climate drivers and other pressures.

Links to issues and chapters: This report summarises what is happening currently in the marine environment in terms of climate change and also what could happen in the future. It also addresses knowledge gaps and the socioeconomic impacts of climate change in the marine environment and the confidence associated with the data. This links with many of the issues being addressed by the CCRA and in particular links with Chapters 2, 3, 6 and 7.

xxii. DJ, M., C, M., K, C., AF, Z. & S, H. 2007. CO2-induced acidification affects hatching success in Calanus finmarchicus. Marine Ecology Progress Series, 350, 91-97.

xxiii. MAYOR, D. J., EVERETT, N. R. & COOK, K. B. 2012. End of century ocean warming and acidification effects on reproductive success in a temperate marine copepod. Journal of Plankton Research, 34, 258-262.

xxiv. MAYOR, D., SOMMER, U., THORNTON, B., DAVIDSON, R. L. & VIANT, M. R. in prep. The metabolomic response of marine copepods to environmental warming, ocean acidification and food deprivation. Functional ecology.

Summary and links to issues and chapters: Copepods are microscopic crustaceans that form the link between phytoplankton and fish. These studies examined how these organisms are affected by more acidic and/or warmer seawater. Our observational and analytical data demonstrate that Calanus finmarchicus and Calanus helgolandicus, two of the most important copepods in the North Atlantic and North Sea, appear to be relatively robust to the predicted end-of-century climate change scenarios. Our most recent study (Mayor et al., in prep) demonstrates that marine 'omega-3 fatty acids', which come from different types of phytoplankton, are central to how these animals deal with food deprivation, a major indirect effect of environmental warming. Changes in the supply of these fatty acids due to the direct effects of climate change on the composition of phytoplankton communities could have major implications for how well these animals can cope with climate-driven stress. These papers link with Chapter 3 - Risks of climate change to the marine environment**;** the additive and interactive effects of warming and ocean acidification.

xxv. GIERING, S. L. C., SANDERS, R., LAMPITT, R. S., ANDERSON, T. R., TAMBURINI, C., BOUTRIF, M., ZUBKOV, M. V., MARSAY, C. M., HENSON, S. A., SAW, K., COOK, K. & MAYOR, D. J. 2014. Reconciliation of the carbon budget in the ocean/'s twilight zone. Nature, 507, 480-483.

Summary and links to issues and chapters: Oceanic carbon sequestration via biological activity is thought to keep atmospheric CO2 approximately 200ppm lower that it would otherwise be. This study demonstrates that the storage of carbon in the deep ocean is, in part, determined by a synergy between bacteria and zooplankton. We know very little about this newly described relationship and hence we cannot yet predict how it will change in response to stressors such as global warming, ocean acidification and increased hypoxia. This needs to be a major priority research area in the near future. This paper links with **Chapter 3 identifying the risks of climate change to the marine environment**; predicting how climate change will affect oceanic carbon sequestration.

xxvi. ANDERSON, T. R., HESSEN, D. O., MITRA, A., MAYOR, D. J. & YOOL, A. 2013. Sensitivity of secondary production and export flux to choice of trophic transfer formulation in marine ecosystem models. Journal of Marine Systems, 125, 41-53.

Summary and links to issues and chapters: Global biogeochemical models are used to predict primary production and carbon export into the deep sea, processes that are central to global climate regulation. This study demonstrates that the predictions of such models vary considerably, depending on the underpinning assumptions about the physiology of zooplankton. We need to have a more detailed understanding of organismal physiology and how it is affected by environmental change before the risks of global biogeochemical response to climate change can be fully appreciated. This paper links with **Chapter 3 - Risks of climate change to the marine environment**; predicting how climate change will affect oceanic carbon sequestration.

xxvii. MAYOR, D. J., THORNTON, B., HAY, S., ZUUR, A. F., NICOL, G. W., MCWILLIAM, J. M. & WITTE, U. F. M. 2012. Resource quality affects carbon cycling in deep-sea sediments. ISME J, 6, 1740-1748.

xxviii. MAYOR, D. J., THORNTON, B. & ZUUR, A. F. 2012. Resource Quantity Affects Benthic Microbial Community Structure and Growth Efficiency in a Temperate Intertidal Mudflat. PLoS ONE, 7, e38582.

Summary and Links to issues and chapters: Marine sediments store billions of tonnes of organic carbon each year and return key nutrients to the overlying waters, fuelling primary productivity. These studies demonstrate that the capacity of marine sediments to achieve these two important functions is strongly influenced by the quantity and biochemical composition (quality) of the organic matter they receive. Climate-driven changes in phytoplankton communities, and hence the quantity and quality of organic matter that is exported to the underlying sediments, will therefore affect rates of carbon storage and nutrient recycling at the seafloor. This links to **Chapter 3 - Risks of climate change to the marine environment**; understanding how climate change will affect carbon sequestration and nutrient regeneration in marine sediments.

xxix. RHEIN, M., S. R. RINTOUL, S. AOKI, E. CAMPOS, D. CHAMBERS, R. A. FEELY, S. GULEV, G. C. JOHNSON, S. A. JOSEY, A. KOSTIANOY, C. MAURITZEN, D. ROEMMICH, L. D. TALLEY AND F. WANG 2013. Chapter 3 Observations: Ocean. In: 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 (ed.) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA. : Cambridge University Press.

Summary and links to issues and chapters: Relates directly to the last issue identified: 'A quantitative assessment of the uncertainties, limitations and confidence in the underlying evidence and analysis for different risks.' Specifically this chapter of the latest IPCC report, for which I was one of the Lead Authors, provides a quantitative assessment of the evidence for climate change from ocean observations (in particular ocean warming, changing salinity and rising sea level). See report for details.

xxx. HENSON, S., COLE, H., BEAULIEU, C. & YOOL, A. 2013. The impact of global warming on seasonality of ocean primary production. Biogeosciences, 10, 4357-4369.

Summary: The seasonal cycle (i.e. phenology) of oceanic primary production (PP) is expected to change in response to climate warming. This paper uses the output from 6 global biogeochemical models to examine the response in the seasonal amplitude of PP and timing of peak PP to the IPCC AR5 warming scenario. The paper also investigates whether trends in PP phenology may be more rapidly detectable than trends in annual mean PP. The results indicate a transformation of currently strongly seasonal (bloom forming) regions, typically found at high latitudes, into weakly seasonal (non-bloom) regions, characteristic of contemporary subtropical conditions.

xxxi. BEAULIEU, C., HENSON, S. A., SARMIENTO, J. L., DUNNE, J. P., DONEY, S. C., RYKACZEWSKI, R. R. & BOPP, L. 2013. Factors challenging our ability to detect long-term trends in ocean chlorophyll. Biogeosciences, 10, 2711-2724.

Summary: Global climate change is expected to affect the ocean's biological productivity. The most comprehensive information available about the global distribution of contemporary ocean primary productivity is derived from satellite data. Large spatial patchiness and interannual to multidecadal variability in chlorophyll a concentration challenges efforts to distinguish a global, secular trend given satellite records which are limited in duration and continuity. This paper, demonstrates that there are a few regions with statistically significant trends over the ten years of SeaWiFS data, but at a global scale the trend is not large enough to be distinguished from noise. The authors quantify the degree to which red noise (autocorrelation) especially challenges trend detection in these observational time series. They further demonstrate how discontinuities in the time series at various points would affect our ability to detect trends in ocean chlorophyll a. We highlight the importance of maintaining continuous, climate-quality satellite data records for climate-change detection and attribution studies.

xxxii. HENSON, S. A., SARMIENTO, J. L., DUNNE, J. P., BOPP, L., LIMA, I., DONEY, S. C., JOHN, J. & BEAULIEU, C. 2010. Detection of anthropogenic climate change in satellite records of ocean chlorophyll and productivity. Biogeosciences, 7, 621-640.

Summary: This paper compares recent trends in satellite ocean colour data to longer-term time series from three biogeochemical models (GFDL, IPSL and NCAR). The authors find that detection of climate change-driven trends in the satellite data is confounded by the relatively short time series and large interannual and decadal variability in productivity. Thus, recent observed changes in chlorophyll, primary production and the size of the oligotrophic gyres cannot be unequivocally attributed to the impact of global climate change. Instead, the analyses suggest that a time series of ~40 years length is needed to distinguish a global warming trend from natural variability. In some regions, notably equatorial regions, detection times are predicted to be shorter (~20–30 years). Analysis of modelled chlorophyll and primary production from 2001–2100 suggests that, on average, the climate change-driven trend will not be unambiguously separable from decadal variability until ~2055. Because the magnitude of natural variability in chlorophyll and primary production is larger than, or similar to, the global warming trend, a consistent, decades-long data record must be established if the impact of climate change on ocean productivity is to be definitively detected.

Links to issues and chapters: The above papers listed (xxx - xxxiii) link with Chapter 2 - characterising the future, updating how climate change will impact marine productivity and our ability to discern long term climate trends from decadal variability in oceanic ecosystems. They also link with Chapter 3 - the rural economy and the natural environment in particular relating to marine habitats and how the planktonic ecosystems may change as a result of climate.

xxxiii. JONES, D. O. B., YOOL, A., WEI, C.-L., HENSON, S. A., RUHL, H. A., WATSON, R. A. & GEHLEN, M. 2013. Global reductions in seafloor biomass in response to climate change. Global Change Biology

Summary: Seafloor organisms are vital for healthy marine ecosystems, contributing to elemental cycling, benthic remineralization, and ultimately sequestration of carbon. Deep-sea life is primarily reliant on the export flux of particulate organic carbon from the surface ocean for food, but most ocean biogeochemistry models predict global decreases in export flux resulting from 21st century anthropogenically induced warming. This paper shows that decadal-to-century scale changes in carbon export associated with climate change lead to an estimated 5.2% decrease in future (2091–2100) global open ocean benthic biomass under RCP8.5 (reduction of 5.2 Mt C) compared with contemporary conditions (2006–2015). The polar oceans and some upwelling areas may experience increases in benthic biomass, but most other regions show decreases, with up to 38% reductions in parts of the northeast Atlantic. Our analysis projects a future ocean with smaller sized infaunal benthos, potentially reducing energy transfer rates though benthic multicellular food webs. More than 80% of potential deep-water biodiversity hotspots known around the world, including canyons, seamounts, and cold-water coral reefs, are projected to experience negative changes in biomass. These major reductions in biomass may lead to widespread change in benthic ecosystems and the functions and services they provide.

Links to Chapters and issues: This paper links to Chapter 2 - characterising the future and Chapter 3 - the rural economy and natural environment through its discussion of the marine benthic habitat and the impacts of climate change in the future on benthic habitats and ecosystems.

xxxiv. PORZIO, L., BUIA, M. C. & HALL-SPENCER, J. M. 2011. Effects of ocean acidification on macroalgal communities. Journal of Experimental Marine Biology and Ecology, 400, 278-287.

xxxv. BEARE, D., MCQUATTERS-GOLLOP, A., VAN DER HAMMEN, T., MACHIELS, M., TEOH, S. J. & HALL-SPENCER, J. M. 2013. Long-Term Trends in Calcifying Plankton and pH in the North Sea. PLoS ONE, 8, e61175.

Summary: Relationships between six calcifying plankton groups and pH are explored in a highly biologically productive and data-rich area of the central North Sea using time-series datasets. The long-term trends show that abundances of foraminiferans, coccolithophores, and echinoderm larvae have risen over the last few decades while the abundances of bivalves and pteropods have declined. Despite good coverage of pH data for the study area there is uncertainty over the quality of this historical dataset; pH appears to have been declining since the mid 1990s but there was no statistical connection between the abundance of the calcifying plankton and the pH trends. If there are any effects of pH on calcifying plankton in the North Sea they appear to be masked by the combined effects of other climatic (e.g. temperature), chemical (nutrient concentrations) and biotic (predation) drivers. Certain calcified plankton have proliferated in the central North Sea, and are tolerant of changes in pH that have occurred since the 1950s but bivalve larvae and pteropods have declined. An improved monitoring programme is required as ocean acidification may be occurring at a rate that will exceed the environmental niches of numerous planktonic taxa, testing their capacities for acclimation and genetic adaptation.

xxxvi. HALL-SPENCER, J. M., RODOLFO-METALPA, R., MARTIN, S., RANSOME, E., FINE, M., TURNER, S. M., ROWLEY, S. J., TEDESCO, D. & BUIA, M.-C. 2008. Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. Nature, 454, 96-99.

Summary: The atmospheric partial pressure of carbon dioxide (pCO2) will almost certainly be double that of pre-industrial levels by 2100 and will be considerably higher than at any time during the past few million years. The oceans are a principal sink for anthropogenic CO2 where it is estimated to have caused a 30% increase in the concentration of H+ in ocean surface waters since the early 1900s and may lead to a drop in seawater pH of up to 0.5 units by 2100. Our understanding of how increased ocean acidity may affect marine ecosystems is at present very limited as almost all studies have been in vitro, short-term, rapid perturbation experiments on isolated elements of the ecosystem. This paper shows the effects of acidification on benthic ecosystems at shallow coastal sites where volcanic CO2 vents lower the pH of the water column. Sea-grass production was highest in an area at mean pH 7.6 (1,827 muatm pCO2) where coralline algal biomass was significantly reduced and gastropod shells were dissolving due to periods of carbonate sub-saturation. The species populating the vent sites comprise a suite of organisms that are resilient to naturally high concentrations of pCO2 and indicate that ocean acidification may benefit highly invasive non-native algal species. Our results provide the first in situ insights into how shallow water marine communities might change when susceptible organisms are removed owing to ocean acidification.

xxxvii. JOHNSON, V. R., RUSSELL, B. D., FABRICIUS, K. E., BROWNLEE, C. & HALL-SPENCER, J. M. 2012. Temperate and tropical brown macroalgae thrive, despite decalcification, along natural CO2 gradients. Global Change Biology, 18, 2792-2803.

Summary: Predicting the impacts of ocean acidification on coastal ecosystems requires an understanding of the effects on macroalgae and their grazers, as these underpin the ecology of rocky shores. Whilst calcified coralline algae (Rhodophyta) appear to be especially vulnerable to ocean acidification, there is a lack of information concerning calcified brown algae (Phaeophyta), which are not obligate calcifiers but are still important producers of calcium carbonate and organic matter in shallow coastal waters. This paper compares ecological shifts in subtidal rocky shore systems along CO2 gradients created by volcanic seeps in the Mediterranean and Papua New Guinea, focussing on abundant macroalgae and grazing sea urchins. This is the first study to provide a comparison of ecological changes along CO2 gradients between temperate and tropical rocky shores. The similarities we found in the responses of Padina spp. and sea urchin abundance at several vent systems increases confidence in predictions of the ecological impacts of ocean acidification over a large geographical range.

xxxviii. KERFAHI, D., HALL-SPENCER, J., TRIPATHI, B., MILAZZO, M., LEE, J. & ADAMS, J. 2014. Shallow Water Marine Sediment Bacterial Community Shifts Along a Natural CO2 Gradient in the Mediterranean Sea Off Vulcano, Italy. Microbial Ecology, 67, 819-828.

Summary: The effects of increasing atmospheric CO2 on ocean ecosystems are a major environmental concern, as rapid shoaling of the carbonate saturation horizon is exposing vast areas of marine sediments to corrosive waters worldwide. Natural CO2 gradients off Vulcano, Italy, have revealed profound ecosystem changes along rocky shore habitats as carbonate saturation levels decrease, but no investigations have yet been made of the sedimentary habitat. The results of the experiments discussed in this paper support the view that globally increased ocean pCO2 will be associated with changes in sediment bacterial community composition but that most of these organisms are resilient. However, further work is required to assess whether these results apply to other types of coastal sediments and whether the changes in relative abundance of bacterial taxa that we observed can significantly alter the biogeochemical functions of marine sediments.

xxxix. MILAZZO, M., RODOLFO-METALPA, R., CHAN, V. B. S., FINE, M., ALESSI, C., THIYAGARAJAN, V., HALL-SPENCER, J. M. & CHEMELLO, R. 2014. Ocean acidification impairs vermetid reef recruitment. Sci. Rep., 4.

Summary: Vermetids form reefs in sub-tropical and warm-temperate waters that protect coasts from erosion, regulate sediment transport and accumulation, serve as carbon sinks and provide habitat for other species. The gastropods that form these reefs brood encapsulated larvae; they are threatened by rapid environmental changes since their ability to disperse is very limited. The authors used transplant experiments along a natural CO2 gradient to assess ocean acidification effects on the reef-building gastropod Dendropoma petraeum. They found that although D. petraeum were able to reproduce and brood at elevated levels of CO2, recruitment success was adversely affected. Long-term exposure to acidified conditions predicted for the year 2100 and beyond caused shell dissolution and a significant increase in shell Mg content. Unless CO2 emissions are reduced and conservation measures taken, the results suggest these reefs are in danger of extinction within this century, with significant ecological and socioeconomic ramifications for coastal systems.

xl. PORZIO, L., BUIA, M. C. & HALL-SPENCER, J. M. 2011. Effects of ocean acidification on macroalgal communities. Journal of Experimental Marine Biology and Ecology, 400, 278-287.

Summary: There are high levels of uncertainty about how coastal ecosystems will be affected by rapid ocean acidification caused by anthropogenic CO2, due to a lack of data. The few experiments to date have been short-term (< 1 year) and reveal mixed responses depending on the species examined and the culture conditions used. It is difficult to carry out long-term manipulations of CO2 levels, therefore areas with naturally high CO2 levels are being used to help understand which species, habitats and processes are resilient to the effects of ocean acidification, and which are adversely affected. This paper describes the effects of increasing CO2 levels on macroalgal communities along a pH gradient caused by volcanic vents. The data show that many macroalgal species are tolerant of long-term elevations in CO2 levels but that macroalgal habitats are altered significantly as pH drops, contributing to a scant but growing body of evidence concerning the long-term effects of CO2 emissions in vegetated marine systems.

xli. RODOLFO-METALPA, R., HOULBREQUE, F., TAMBUTTE, E., BOISSON, F., BAGGINI, C., PATTI, F. P., JEFFREE, R., FINE, M., FOGGO, A., GATTUSO, J. P. & HALL-SPENCER, J. M. 2011. Coral and mollusc resistance to ocean acidification adversely affected by warming. Nature Clim. Change, 1, 308-312.

Summary: Increasing atmospheric carbon dioxide (CO2) concentrations are expected to decrease surface ocean pH by 0.3–0.5 units by 2100, lowering the carbonate ion concentration of surface waters. This rapid acidification is predicted to dramatically decrease calcification in many marine organisms. Reduced skeletal growth under increased CO2 levels has already been shown for corals, molluscs and many other marine organisms. The impact of acidification on the ability of individual species to calcify has remained elusive, however, as measuring net calcification fails to disentangle the relative contributions of gross calcification and dissolution rates on growth. This paper shows that tissues and external organic layers play a major role in protecting shells and skeletons from corrosive seawater, limiting dissolution and allowing organisms to calcify. The combined field and laboratory results demonstrate that the adverse effects of global warming are exacerbated when high temperatures coincide with acidification.

xlii. RUSSELL, B. D., CONNELL, S. D., UTHICKE, S., MUEHLLEHNER, N., FABRICIUS, K. E. & HALL-SPENCER, J. M. 2013. Future seagrass beds: Can increased productivity lead to increased carbon storage? Marine Pollution Bulletin, 73, 463-469.

Summary: While carbon capture and storage (CCS) is increasingly recognised as technologically possible, recent evidence from deep-sea CCS activities suggests that leakage from reservoirs may result in highly CO2 impacted biological communities. In contrast, shallow marine waters have higher primary productivity which may partially mitigate this leakage. We used natural CO2 seeps in shallow marine waters to assess if increased benthic primary productivity could capture and store CO2 leakage in areas targeted for CCS. We found that the productivity of seagrass communities (in situ, using natural CO2 seeps) and two individual species (ex situ, Cymodocea serrulata and Halophila ovalis) increased with CO2 concentration, but only species with dense belowground biomass increased in abundance (e.g. C. serrulata). Importantly, the ratio of below:above ground biomass of seagrass communities increased fivefold, making seagrass good candidates to partially mitigate CO2 leakage from sub-seabed reservoirs, since they form carbon sinks that can be buried for millennia.

xliii. TITTENSOR, D. P., BACO, A. R., HALL-SPENCER, J. M., ORR, J. C. & ROGERS, A. D. 2010. Seamounts as refugia from ocean acidification for cold-water stony corals. Marine Ecology, 31, 212-225.

Summary: Cold-water stony corals create habitat for a diverse range of deep-water species but are thought to be threatened by ocean acidification due to oceanic uptake of anthropogenic CO2. Knowledge of the severity of this threat is hampered by our limited understanding of the distribution and habitat requirements of these corals. Here we estimate the global acidification threat to these organisms using a global database of cold-water stony coral records and a species distribution modelling approach. We parameterised the models using present-day environmental data, and then replaced these data with future projections of ocean chemistry from the year 2099. We found suitable coral habitat to be very heterogeneously distributed, being concentrated in the northern North Atlantic and around New Zealand. Projected changes in ocean chemistry induced a pronounced reduction in habitat suitability in the North Atlantic, and a low-to-moderate impact elsewhere under both the IPCC IS92a and S650 scenarios. Seamount summits are impacted by these changes, but consistently provide more suitable habitat than the surrounding seafloor, with around 98% of seamount summits having higher suitability in both future scenarios; this is because they lie in shallower waters with a higher aragonite saturation state. These results suggest that anthropogenic-induced changes in ocean chemistry are likely to severely impact cold-water stony coral habitat in the deep-sea of the North Atlantic, and that impacts will be less severe elsewhere. We predict that coral communities on the summits and upper slopes of seamounts will be less susceptible to ocean acidification during this century than those on the surrounding seafloor, and thus that seamounts may serve as temporary refugia.

Links to issues and Chapters: The papers listed above (xxxiv - xliii) links with Chapters 2 - Characterising the future, updating climate science in terms of ocean acidification effects currently being measured and their impacts into the future. This also links with Chapter 3 - The rural economy and natural environment looking at the effects of ocean acidification on marine habits and ecosystems such as corals and phytoplankton.

xliv. HOLT, J., BUTENSCHÖN, M., WAKELIN, S. L., ARTIOLI, Y. & ALLEN, J. I. 2012. Oceanic controls on the primary production of the northwest European continental shelf: model experiments under recent past conditions and a potential future scenario. Biogeosciences, 9, 97-117.

Summary: This paper demonstrates that changes in oceanic nutrients are a first order factor in determining changes in the primary production of the northwest European continental shelf on time scales of 5–10 yr. The authors present a series of coupled hydrodynamic ecosystem modelling simulations, which show a substantial reduction in surface nutrients in the open-ocean regions of the model domain, comparing future and present day time-slices. The reduction in primary production by the reduced nutrient transport is mitigated by on-shelf processes relating to temperature, stratification (length of growing season) and recycling. Regions less exposed to ocean-shelf exchange in this model (Celtic Sea, Irish Sea, English Channel, and Southern North Sea) show a modest increase in primary production (of 5–10%) compared with a decrease of 0–20% in the outer shelf, Central and Northern North Sea.

Links to chapters and issues: This paper highlights new mechanisms of how changes in ocean conditions can potentially impact primary production in NW European Seas. It links with Chapter 2 - characterising the future, providing an update on how future climate will impact primary production in the ocean due to changes in nutrient inputs and ocean stratification. It also links with Chapter 3 - the rural economy and natural environment, specifically marine habitats and the physical conditions of the habitats in the upper ocean.

xlv. HOLT, J., HUGHES, S., HOPKINS, J., WAKELIN, S. L., PENNY HOLLIDAY, N., DYE, S., GONZÁLEZ-POLA, C., HJØLLO, S. S., MORK, K. A., NOLAN, G., PROCTOR, R., READ, J., SHAMMON, T., SHERWIN, T., SMYTH, T., TATTERSALL, G., WARD, B. & WILTSHIRE, K. H. 2012. Multi-decadal variability and trends in the temperature of the northwest European continental shelf: A model-data synthesis. Progress in Oceanography, 106, 96-117.

Summary: This paper examines the trends and variability in temperature of the northwest European shelf seas over the period 1960–2004 using four approaches: a regional model simulation (using the Proudman Oceanographic Laboratory Coastal Ocean Modelling System; POLCOMS), in situ multi-annual timeseries observations, satellite remote sensed (AVHRR) sea surface temperature (SST), and an analysis of data held in an international database at the International Council for the Exploration of the Sea (ICES). The authors find that all data sources give a consistent picture, with both trends and variability being intensified on-shelf and north of ~48°N. The model is seen to have good skill in reproducing both the trends and variability, but tends to underestimate the trends. The modelled variability is overestimated in some coastal and open ocean regions and underestimated elsewhere, while the phase of this variability is generally well represented. Generally the model performance is better on-shelf than in the open ocean.

Links to chapters and issues: This paper provides a new analysis of sustained observations and model simulations showing how the temperature of the NW European Seas has varies over the past 50 years. In particular this links to Chapter 2 - Characterising the future, updating the climate science.

xlvi. HOLLOWED, A. B., BARANGE, M., BEAMISH, R. J., BRANDER, K., COCHRANE, K., DRINKWATER, K., FOREMAN, M. G. G., HARE, J. A., HOLT, J., ITO, S.-I., KIM, S., KING, J. R., LOENG, H., MACKENZIE, B. R., MUETER, F. J., OKEY, T. A., PECK, M. A., RADCHENKO, V. I., RICE, J. C., SCHIRRIPA, M. J., YATSU, A. & YAMANAKA, Y. 2013. Projected impacts of climate change on marine fish and fisheries. ICES Journal of Marine Science: Journal du Conseil.

Summary: This paper reviews current literature on the projected effects of climate change on marine fish and shellfish, their fisheries, and fishery-dependent communities throughout the northern hemisphere. The review addresses the following issues: (i) expected impacts on ecosystem productivity and habitat quantity and quality; (ii) impacts of changes in production and habitat on marine fish and shellfish species including effects on the community species composition, spatial distributions, interactions, and vital rates of fish and shellfish; (iii) impacts on fisheries and their associated communities; (iv) implications for food security and associated changes; and (v) uncertainty and modelling skill assessment. Climate change will impact fish and shellfish, their fisheries, and fishery-dependent communities through a complex suite of linked processes. Integrated interdisciplinary research teams are forming in many regions to project these complex responses. National and international marine research organizations serve a key role in the coordination and integration of research to accelerate the production of projections of the effects of climate change on marine ecosystems and to move towards a future where relative impacts by region could be compared on a hemispheric or global level. Eight research foci were identified that will improve the projections of climate impacts on fish, fisheries, and fishery-dependent communities.

Links to chapters and issues: This paper provides a new summary of our knowledge on effects of climate change on living marine resources, in particular Chapters 2 and 3 focussing on how climate is changing and affecting marine habitats related to fish populations. This also links to Chapter 7 - Global Security, in particular food security from fisheries.

xlvii. BARANGE, M., MERINO, G., BLANCHARD, J. L., SCHOLTENS, J., HARLE, J., ALLISON, E. H., ALLEN, J. I., HOLT, J. & JENNINGS, S. 2014. Impacts of climate change on marine ecosystem production in societies dependent on fisheries. Nature Clim. Change, 4, 211-216.

Summary: Growing human populations and changing dietary preferences are increasing global demands for fish, adding pressure to concerns over fisheries sustainability. This paper develops and links models of physical, biological and human responses to climate change in 67 marine national exclusive economic zones, which yield approximately 60% of global fish catches, to project climate change yield impacts in countries with different dependencies on marine fisheries. Predicted changes in fish production indicate increased productivity at high latitudes and decreased productivity at low/mid latitudes, with considerable regional variations. With few exceptions, increases and decreases in fish production potential by 2050 are estimated to be <10% (mean +3.4%) from present yields. Despite projected human population increases and assuming that per capita fish consumption rates will be maintained, ongoing technological development in the aquaculture industry suggests that projected global fish demands in 2050 could be met, thus challenging existing predictions of inevitable shortfalls in fish supply by the mid-twenty-first century. This conclusion, however, is contingent on successful implementation of strategies for sustainable harvesting and effective distribution of wild fish products from nations and regions with a surplus to those with a deficit. Changes in management effectiveness and trade practices5 will remain the main influence on realized gains or losses in global fish production.

Links to chapters and issues: This paper presents an exploration of the impacts of climate change on fish production on a global scale. This links particularly with Chapters 2, 3, 6 and 7. Future climate change will likely affect marine fisheries with impacts for global food security. However, this paper suggests if fisheries are properly managed that shortfalls in fish supply for global populations could be minimised.

xlviii. BROWN, J., WOLF, J. & SOUZA, A. 2012. Past to future extreme events in Liverpool Bay: model projections from 1960–2100. Climatic Change, 111, 365-391.

Summary: Knowledge of the likely future wind, wave and surge climate in Liverpool Bay is of importance for coastal flood defence management. This paper examines a 140-year time series (1960–2100) of wind and wave model projections at the WaveNet buoy location in Liverpool Bay and also of surge model projection at two ports in Liverpool Bay, namely Liverpool and Heysham. Analysis of significant changes in the statistics over time shows that there is little change in extreme wave and surge conditions in Liverpool Bay. Although there is a slight increase in the severity of the most extreme events, the frequency of extreme wind and wave events is slightly reduced, while the frequency of extreme surge events slightly increases over the 140-year period. From the model projections, we find that the trends in the local wind are directly reflected in the wave field within Liverpool Bay. The trends in the skew surge projections deviate slightly from those in the wind patterns.

Links to Chapters and Issues: This paper investigates the trends in the 140 year UKCP09 wind, wave and surge data for Liverpool Bay. This links to Chapter 2 characterising the future of wind, wave and surge data for the Liverpool Bay area. This also has links to Chapter 5 and 6, which focus on people and the built environment, and the risks to industry and businesses, which could be impacted by coastal flooding in the future.

xlix. QUANTE, M. In progress. North Sea Region Climate Change Assessment.

Summary: The North Sea Region Climate Change Risk Assessment (NOSCCA) report on climate change in the North Sea will be made public in late 2014. This will cover many of the Chapters and Issues of the climate change risk assessment. In particular this report will focus on 1) Past and current climate change in the region, 2) Climate change projections, 3) Impacts of current and future climate change on ecosystems and 4) Climate impacts on socio-economy related to the North Sea Region.

l. HARLE, J., POPOVA, K., YOOL, A. & HOLT, J. In prep. The provenance of water of the northwest European continental

shelf and its susceptibility to future changes in oceanic conditions: implications for shelf sea ecosystems'. Geophysical Research Letters.

Summary: This paper explores where the water on the Northwest European shelf originates under present and potential future conditions over multi-annual timescale. It identifies how changes to the distribution of this location and the prevalent water column characteristics, arising from climate change impacts on ocean circulation patterns and stratification, may change the nutrient concentration transported on-shelf. This also has potential implications for the transport of non-indigenous species of marine organisms on-shelf.

li. YOOL, A., POPOVA, E. E., COWARD, A. C., BERNIE, D. & ANDERSON, T. R. 2013. Climate change and ocean acidification impacts on lower trophic levels and the export of organic carbon to the deep ocean. Biogeosciences Discuss., 10, 3455-3522.

Summary: Most future projections forecast significant and ongoing climate change during the 21st century, but with the severity of impacts dependent on efforts to restrain or reorganise human activity to limit carbon dioxide (CO2) emissions. A major sink for atmospheric CO2, and a key source of biological resources, the World Ocean is widely anticipated to undergo profound physical and – via ocean acidification – chemical changes as direct and indirect results of these emissions. Given strong biophysical coupling, the marine biota is also expected to experience strong changes in response to this anthropogenic forcing. This paper examines the large-scale response of ocean biogeochemistry to climate and acidification impacts during the 21st century for Representative Concentration Pathways (RCPs) 2.6 and 8.5 using an intermediate complexity global ecosystem model, Medusa–2.0. The primary impact of future change lies in stratification-led declines in the availability of key nutrients in surface waters, which in turn leads to a global decrease (1990s vs. 2090s) in ocean productivity (−6.3%). This impact has knock-on consequences for the abundances of the low trophic level biogeochemical actors modelled by Medusa–2.0 (−5.8%), and these would be expected to similarly impact higher trophic level elements such as fisheries. Related impacts are found in the flux of organic material to seafloor communities (−40.7% at 1000 m), and in the volume of ocean suboxic zones (+12.5%). For all processes, there is geographical variability in change, and changes are much more pronounced under RCP 8.5 than the RCP 2.6 scenario.

Links to chapters and issues: Projections of impacts of ocean acidification to the end of the century from a global model. This links to Chapter 2 - characterising the future of climate change in the oceans and the resultant impacts; Chapter 3 in particular marine habitats, including both pelagic and benthic habitats; and Chapter 7 on Global security, in particular food security from fisheries which will be impacted by changes in the plankton communities in the pelagic and benthic ocean habitats.

5. If you are not sending a standalone copy of your evidence, please provide web links in the box below.

i. http://www.sciencedirect.com/science/article/pii/S0029801813000838
ii. http://rstb.royalsocietypublishing.org/content/367/1605/2979#aff-6
iii. http://www.sciencedirect.com/science/article/pii/S0169555X11001085
iv. http://www.pnas.org/content/early/2012/10/10/1209542109.abstract
v. http://icesjms.oxfordjournals.org/content/69/5/776.abstract
vi. http://www.aslo.org/lo/toc/vol_57/issue_6/1591.html
vii. http://www.sciencedirect.com/science/article/pii/S0921818111001469
viii. http://onlinelibrary.wiley.com/doi/10.1029/2012GL052933/abstract
ix. http://www.sciencedirect.com/science/article/pii/S0959378012000271
x. http://www.sciencedirect.com/science/article/pii/S0278434311003578
xi. http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-11-00151.1
xii. http://www.sciencedirect.com/science/article/pii/S0048969711011715
xiv. http://www.sciencedirect.com/science/article/pii/S0883292712002715
xv. http://onlinelibrary.wiley.com/doi/10.1002/ghg.1277/abstract
xvi. http://onlinelibrary.wiley.com/doi/10.1002/ghg.28/abstract
xvii. http://www.sciencedirect.com/science/article/pii/S088329271000051X
xix. http://onlinelibrary.wiley.com/store/10.1111/gcb.12514/asset/gcb12514.pdf?v=1&t=hue8bc1d&s=1e41a2ba2ce4bcb60fd1af40b22d0660b19e43ce
xx. http://onlinelibrary.wiley.com/doi/10.1111/geb.12105/abstract
xxii. http://www.int-res.com/abstracts/meps/v350/p91-97/
xxiii. http://plankt.oxfordjournals.org/content/34/3/258.abstract
xxiv. In prep not yet published
xxv. http://www.nature.com/nature/journal/v507/n7493/full/nature13123.html
xxvi. http://www.sciencedirect.com/science/article/pii/S0924796312001790
xxvii. http://www.nature.com/ismej/journal/v6/n9/full/ismej201214a.html
xxviii. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0038582
xxx. http://www.biogeosciences.net/10/4357/2013/bg-10-4357-2013.html
xxxi. http://www.biogeosciences.net/10/2711/2013/bg-10-2711-2013.html
xxxii. http://www.biogeosciences.net/7/621/2010/bg-7-621-2010.html
xxxiii. http://onlinelibrary.wiley.com/doi/10.1111/gcb.12480/abstract
xxxv. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0061175
xxxvi. http://www.nature.com/nature/journal/v454/n7200/full/nature07051.html
xxxvii. http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2012.02716.x/abstract

xxxviii. http://link.springer.com/article/10.1007%2Fs00248-014-0368-7#

xxxix. http://www.nature.com/srep/2014/140228/srep04189/full/srep04189.html

xl. http://www.sciencedirect.com/science/article/pii/S0022098111000591

xli. http://www.nature.com/nclimate/journal/v1/n6/full/nclimate1200.html

xlii. http://www.sciencedirect.com/science/article/pii/S0025326X13000465

xliii. http://onlinelibrary.wiley.com/doi/10.1111/j.1439-0485.2010.00393.x/abstract

xliv. http://www.biogeosciences.net/9/97/2012/bg-9-97-2012.html

xlv. http://www.sciencedirect.com/science/article/pii/S0079661112000894

xlvi. http://icesjms.oxfordjournals.org/content/early/2013/07/05/icesjms.fst081.abstract

xlvii. http://www.nature.com/nclimate/journal/v4/n3/full/nclimate2119.html

xlviii. http://www.hzg.de/institute/coastal_research/projects/noscaa/034620/index_0034620.html

xlix. In progress

l. In Progress

li. http://www.biogeosciences.net/10/5831/2013/bg-10-5831-2013.html

6.If the evidence being submitted is not from a peer-reviewed journal, please state briefly how it has been independently reviewed.

xiii. http://www.marineboard.eu/images/publications/Navigating%20the%20Future%20IV-168.pdf – Reviewed by a scientific editorial board.

xviii. https://www.researchgate.net/publication/261588602_Potential_impact_of_CO2_emissions_on_the_seafloor – Reviewed by book editor

xxi. http://www.mccip.org.uk/annual-report-card/2013.aspx – The report is a summary of 33 individual, peer-reviewed reports commissioned by MCCIP. Links to the 33 individual reports can be found at the above web address.

xxix. http://www.climatechange2013.org/report/full-report/ - This is a report based on peer reviewed evidence which is independently reviewed by a panel of scientific editors prior to publication.

xxxiv. http://www.nap.edu/openbook.php?record_id=12904&page=59 – Reviewed by editors.

7.Please state how the research has been funded, e.g. through a Research Council or Government Department (we are interested in collecting this information to report back to the Research Councils and others on what impact their research has had).

i. Environment Agency for England and Wales under the Flood and Coastal Erosion Risk R&D Programme and the Scottish Environmental Protection Agency
ii. UK Natural Environment Research Council's Quantifying and Understanding the Earth System programme as part of the 'QUEST-Fish' project.
iii. Morphological Impacts and Coastal Risks Induced by Extreme Storm Events (MICORE) project funded by the European Community's Seventh Framework Programme (FP7/2007-2013)
iv. National Science Foundation of China Grant 1076125; by the Danish Strategic Research Council through its support of the Centre for Regional Change in the Earth System (CRES; www.cres-centre.dk) under Contract DSF-EnMi 09-066868; and by European Research Council Advanced Grant 246815, WATERundertheICE, and the Inge Lehmann Foundation
v. European Community's 7th Framework Programme FP7/2007-2013 under EuroSITES, grant agreement 202955, HERMIONE project, grant agreement 226354 (seeArticle II.30. of the grant agreement) and European Community's 7th Framework Programme (FP7/2007-2013).
vi. Natural Environment Research Council grant NE/G013055/1
vii. NSFC No. 41076125 and China's National Key Science Program for Global Change Research (No. 2010C8950504) and NERC consortium "Using Inter-glacials to assess future sea level scenarios" (NE/1008365/1).
viii. NSFC No. 41076125 and China's National Key Science Program for Global Change Research (No. 2010C8950504) and NERC consortium "Using Inter-glacials to assess future sea level scenarios" (NE/1008365/1).Natural Environment Research Council (NERC), National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), and European Community's 7th framework programme (FP7/2007–2013) under grant agreement No. GA212643 (THOR: "Thermohaline Overturning – at Risk", 2008–2012).
ix. Natural Environment Research Council (NERC, project NE/F001517)
x. Natural Environmental Research Council Advanced Fellowship (NE/F014821/1)
xi. UK RAPID and US AMOC programmes
xii. Not stated
xiii. European Science Foundation
xiv. Centre for Innovation in Carbon Capture and Storage (Engineering and Physical Sciences Research Council Grant EP/F012098/1)
xv. Centre for Innovation in Carbon Capture and Storage - Engineering and Physical Sciences Research Council grant EP/F012098/1
xvi. Centre for Innovation in Carbon Capture and Storage - Engineering and Physical Sciences Research Council grant EP/F012098/1
xvii. n/a
xviii. Centre for Innovation in Carbon Capture and Storage - Engineering and Physical Sciences Research Council grant EP/F012098/1
xix. Marine Scotland Science
xx. DST-NRF Centre of Excellence for Invasion Biology to C.L.G and M.R., the South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation to C.D.M, and the European Union Seventh Framework Programme (FP7/2007–2013) under grant agreement no. PIOF-GA-2009-254634 to M.R
xxi. Not stated
xxii. NERC

xxiii. NERC Grant (NE/G014744/1), Student Awards Agency for Scotland and Scottish Government

xxiv. Not yet published.

xxv. Oceans 2025 and EU FP7-ENV-2010 Collaborative Project 264933 BASIN Basin-Scale Analysis, Synthesis and Integration, ANR-POTES program (no. ANR-05-BLAN-0161-01) supported by the Agence Nationale de la Recherche (ANR, France), NERC (NE/G014744/1)

xxvi. Natural Environment Research Council. The work was part funded by the European Union Seventh Framework Programme EURO-BASIN ([FP7/2007-2013] [ENV.2010.2.2.1-1 ENV.2010.2.2.1-1 ENV.; grant agreement no. 264933].

xxvii. Leverhulme Trust (F/00152/T) and supported by NERC's Life Sciences Mass Spectrometry Facility (EK116-11-07), NERC (NE/G014744/1), Rural and Environment Science and Analytical Services Division (RESAS) of the Scottish Government

xxviii. Natural Environment Research Council (NE/G014744/1), Rural and Environment Science and Analytical Services Division of the Scottish Government

xxix. IPCC

xxx. NERC grant NE/G013055/1

xxxi. NERC grant NE/G013055/1 and NSF grant EF-0424599

xxxii. NASA grants NNG06GE77G and NNX07AL81G, Carbon Mitigation Initiative funded by BP Amoco, NSF grant EF-0424599, ANR-GlobPhy and FP7-MEECE projects

xxxiii. Natural Environment Research Council as part of the Marine Environmental Mapping Programme (MAREMAP), UK Natural Environment Research Council

xxxiv. n/a

xxxv. Not stated

xxxvi. Royal Society University Research Fellowship, Leverhulme Trust

xxxvii. University of Plymouth. Grant Number: 265103, Save Our Seas Foundation, Australian Institute of Marine Science, Australian Commonwealth, Department of Innovation, Industry, Science and Research, Australian Research Council

xxxviii. National Research Foundation (NRF) grant funded by the Korean government, Ministry of Education, Science and Technology (MEST) (NRF-2013-031400). This work was also partly supported by the Global Frontier Project, Centre of Integrated Smart Sensors funded by Ministry of Education Science and Technology, Korea (2012M3A6A6054201). Korean Government Scholarship Program, Ministry of Education, Science, and Technology, South Korea. EU FP7 project “Mediterranean Sea Acidification under a changing climate” (grant agreement no. 265103), with additional funding from Save Our Seas Foundation.

xxxix. EU-FP7 MedSeA project (grant agreement no. 265103) and to the MIUR-PRIN 2010–2011 (project no. 2010Z8HJ5M_010), with additional funding to M.M. from the Assemble project (EU-FP7) and to J.M.H.-S. from Save Our Seas Foundation

xl. Leverhulme Trust and EU FP7 EPOCA Grant 211380

xli. Prince Albert II of Monaco Foundation, the International Atomic Energy Agency, Save our Seas Foundation, an EU MARES studentship and the EU ‘Mediterranean Sea Acidification under a changing climate’ project (MedSeA; grant agreement 265103), European Project on Ocean Acidification (EPOCA; grant agreement 211384).

xlii. Australian Institute of Marine Science, and an International Science Linkages Grant of the Australian Commonwealth Department of Innovation, Industry, Science and Research, Australian Research Council grant, EU FP7 project MedSeA (Grant Agreement No. 265103), additional funding from Save Our Seas Foundation and support of COST action ES0906 “Seagrass productivity: from genes to ecosystem management”

xliii. European FP7 projects EPOCA (grant 211384) and KNOWSEAS (grant 226675), the Seventh Framework Programme (FP7/2007-2013) Coralfish project (grant agreement no. 213144) and the International Union for Conservation of Nature (IUCN) project Cold Water Coral Modeling and the Interactions of Ocean Acidification (Project No. 77059–000)

xliv.	NERC National Capability in Modelling Programme, EC FP7 Marine Ecosystem Evolution in a Changing Environment (MEECE No. 212085) Collaborative project.
xlv.	NERC National Capability in Modelling Programme, EC FP7 Marine Ecosystem Evolution in a Changing Environment (MEECE No. 212085) Collaborative project, FP7 MYOCEAN and NERC National Centre for Earth Observation.
xlvi.	n/a
xlvii.	Natural Environment Research Council's 'Quantifying and Understanding the Earth System' programme as part of the 'QUEST-Fish' project
xlviii.	Not stated
xlix.	In progress
l.	In progress
li.	NERC Regional Ocean Modelling (ROAM) Project (NE/H017372/1) of the UK Ocean Acidification research programme (UKOA). Part funded by EUFP7 Euro-Basin (FP7/2007-2013, ENV.2010.2.2.1-1, grant agreement umber 254933). Joint DECC/Defra Met. Office Hadley Centre Climate Programme (GA01101), EUFP7 COMBINE project (grant number 226520).

8.Please state whether you wish to review aspects of the report where your evidence is referenced (the ASC may ask you to review the use of the evidence in any case where we have done additional analysis).

☒Yes
☐No

9. If you want the information you submit to be kept confidential, please explain why in the box below.

Please complete this proforma and send it with copies of evidence (or web links) to ccra@theccc.gsi.gov.uk before midday on Wednesday 30th April 2014.