MARINE CLIMATE CHANGE IMPACTS PARTNERSHIP: SCIENCE REVIEW

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Impacts of climate change on human health

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EXECUTIVE SUMMARY

A growing body of evidence, including a combination of anecdotal reports as well as peer-reviewed scientific datasets indicate that climate change-mediated health risks from the marine system may now be occurring in the UK. A key challenge is disentangling the role of natural variability in contributing to these risks. Evidence, in this regard, includes the observation that pathogenic vibrios are now being routinely isolated from the UK shellfish produce and waters, and that recent anomalous and extreme 'once in a century' precipitation patterns have decreased the microbiological quality of shellfish harvesting waters through CSO discharges. Projections for future health risks associated with the marine environment are difficult to accurately assess because they are complex, multifactorial and frequently based on incomplete or short-term datasets. For example, the transmission of many climate change-mediated diseases are determined by a range of factors, including social, demographic, economic and ecological conditions, and intrinsic human immunity (Semenza and Menne, 2009). However, increased confidence regarding GCM projection data, coupled to the integration of relevant epidemiological and environmental datasets will provide useful baseline data to assess future health risks.

1. WHAT IS ALREADY HAPPENING?

The marine environment contains a myriad of microbial agents that have been linked to human diseases. Fluctuations in the marine environment linked to climate change, such as alterations in temperature, salinity, rainfall and mixing events may have huge ramifications in terms of infectious disease. For example, recent change in sea temperature is considered one of the most pervasive and severe impacts in coastal ecosystems worldwide (Halpern *et al*., 2008), particularly in light of recent observations demonstrating recent warming in over 70% of the world's coastlines (Lima and Wethey, 2012). In the United Kingdom, three main groups of pathogenic agents have been identified that are likely to be sensitive to climatic conditions, and as such are the focus of this summary:

Algal toxins

A number of algal species, found naturally in UK waters, produce toxins that are pathogenic to humans. Filter feeding bivalve shellfish are capable of concentrating toxin-producing algae from the water column, leading to a direct route of human exposure. A perceived increase of harmful algal blooms has been globally registered with important ecological and economic consequences due to their effects on coastal marine resources (Miraglia *et al*., 2009). Overall, the number of reported cases of algal biotoxin ingestion are low in the UK, but are likely under reported due to disparate reported data regarding epidemiology in the UK (Hinder *et al*., 2011). The surveillance system in place in the UK plays an important role in reducing the human health impact of these toxins, although outbreaks of shellfish poisoning still occur regularly, and closures of aquaculture sites and shellfisheries occur each year. The toxin syndrome DSP (diuretic shellfish poisoning) is considered the most important toxin group in the UK, with 19 reported incidents from 1999-2009 (Hinder *et al*., 2011). Some dinoflagellates peak occurrences are now being found up to a month earlier in the season than their typical seasonal peak, extending the seasonality of ingestion cases. The first signs of climatic warming and an apparent increase in more warm water species, such as *Protoceratium reticulatum* in UK waters (a producer of YTX toxins), may be evidence of an expansion of the biogeographical ranges of warmer water species into higher latitudes. *Dinophysis* blooms in late 1980s and *Chrysochromulina* blooms in Northern Europe in 1988 were linked to changes in oceanographic circulation. Overall, however, algal blooms have reduced along the Eastern coast of the UK. Data published in 2012 using the continuous plankton recorder samples have shown dinoflagellates, including both HAB taxa (for example, *Prorocentrum* spp.) and non-HAB taxa (for example, *Ceratium furca*), have declined in abundance, particularly since 2006 in the North Atlantic and North Sea. In contrast, diatom abundance has not shown this decline with some common diatoms, including both HAB (for example, *Pseudonitzschia* spp.) and non-HAB (for example, *Thalassiosira* spp.) taxa, increasing in abundance (Hinder *et al*., 2012).

Pathogenic vibrios

There is increasing concern regarding the poleward spread of bacterial waterborne infectious diseases, mediated by anthropogenic warming of the marine environment. One such pathogen group, non-cholera vibrios, are a globally significant yet poorly understood cause of morbidity and mortality. Approximately a dozen *Vibrio* species are known to cause disease in humans (Austin, 2005), and infection is usually initiated from exposure to seawater or consumption of raw or undercooked seafood (Dechet *et al*., 2008).

Several key datasets have emerged since the 2010 MCCIP report that provide new information in this area. In the UK, there have been very few domestically-acquired cases reported in the last 20 years, however, the fact that vibriosis is a largely under-reported clinical condition probably masks the true extent of disease in the UK. Recent data have shown a clear increase in vibriosis in Northern Europe, with outbreaks typically linked to warm weather episodes (Baker-Austin *et al*., 2012). Furthermore, recent work by Cefas has identified pandemic (O3:K6) *V. parahaemolyticus* recently in UK shellfish and water samples (Powell *et al*,. 2013), although no clinical cases linked to these strains has yet been reported in the UK. Several other studies have demonstrated the presence of pandemic strains in marine water samples in Europe, as well as clinical cases, most instances to date have been reported in Southern Europe (Martinez-Urtaza *et al*., 2005; Quilici *et al*. 2005; Ottaviani *et al*., 2010). With the exception of a single clinical case of pandemic *V. parahaemolyticus* in Norway in 2002, and believed to be domestically acquired (Ellingsen *et al*., 2008), we believe that these bacterial strains represent the most northerly identified pandemic strains isolated directly from the environment. This work follows on from previous studies in the UK (Wagley *et al*., 2008) that did not detect pandemic strains in UK shellfisheries products, suggestive that the emergence of these strains may be a recent phenomenon. For example, a clinical wound infection linked to recreational contact with seawater was recently reported in UK waters (Reilly *et al*., 2011). Both of these reports are noteworthy as surface seawater temperatures in the UK have been comparatively low in recent years. For example, the UK mean temperature for summer of 2012 was 13.9 °C, which is 0.4 °C below recent average temperatures. Other than 2011, the summer of 2012 was the coolest summer since 1998 (Met Office, 2012). Recent analysis of the long-term plankton datasets in the North Sea have shown a clear transition during the 1980s, with the bacterial community becoming dominated by vibrios in the last 2 decades (Vezzulli *et al*., 2012). These data are striking as the transition appears to correspond closely with the temporal warming trends observed in the area, and further corroborate the emergence of marine-borne vibriosis in Northern Europe (Baker-Austin *et al*., 2012).

Combined sewer overflows (CSOs)

Historically, the principal sources of microbiological contamination of UK coastal waters have been continuous sewage discharges. With the investment in sewerage infrastructure over the past decades, contamination due to intermittent discharges such as combined sewer overflows (CSOs) is becoming relatively more important (Lee *et al*., 2003; UKMMAS 2010; Crowther *et al.,* 2011). The Marine Conservation Society estimates that there will be about 31,000 CSOs impacting UK coastal waters (MCS, 2011). Several pathogens of human health relevance are found in these discharges, namely norovirus, hepatitis A, *E. coli* and *Salmonella* species (Lee *et al*., 2003). The fact that the vast majority of shellfish harvesting sites in England and Wales and Northern Ireland are category B (Acornley *et al*., 2010) underlines the long-term issue of microbial pollution of the marine environment. Indeed, the vast majority of outbreaks of shellfish-related illness reported annually in the UK occur in officially approved areas (generally class B), where shellfish are depurated in approved plants in compliance with the legislation (Cefas, 2011). Estimating the precise role of CSOs in this context is, however, complex because spill volumes and frequencies are influenced by population, land use and technological changes. Modelled estimates of CSO impacts on shellfish water quality in catchments subject to significant sewerage infrastructure improvement suggest that, during extreme rainfall, CSOs may contribute more than 50% of the total flux of faecal indicator bacteria (faecal coliforms, enterococci) to nearshore waters (Crowther *et al*., 2011).

Additional screening equipment and storage capacity in CSOs have been effective in minimising impacts on coastal water quality. The construction of large storage tanks to accommodate increasing flows and reducing discharges is, however, unlikely to be sustainable from a technical and operational viewpoint (Myerscough and Digman, 2008). Although it is well known that extreme rainfall events are frequently linked to CSO discharge events, it is difficult to ascertain, both regionally and nationally, the role of climate change in terms of associated pathogen loads entering surface waters and impacting shellfisheries.

2. WHAT COULD HAPPEN?

Based on expert opinion, and published scientific reports the impacts of climate change on HABs, vibrios and CSOs can be summarised as follows:

Harmful algal biotoxins

Projections of future algal blooms in the North Sea indicate that their growth periods may become more extended, which, in turn, may have implications for the harvest of shellfish (Peperzak, 2003). Global changes in ocean circulation have been linked to climatic variations, such as temperature increase. This could potentially enhance/change phytoplankton assemblages within a UK marine context. Changes in mean UK sea surface temperatures (SST) alone may also be significant. For example shifts in diatoms to dinoflagellates in the North Atlantic, and North Sea may be likely. As most HABs are flagellate species this could represent a significant transition in community composition. Finally, cold water algal species may be displaced by warmer water species, changing the community composition of toxin-producing algae. Finally, changes in precipitation patterns, predicted in a range of climate change models may also impact HABs. For example, increased precipitation may lead to run-off from agricultural systems with consequent nutrient enrichment of aquatic and marine environments, potentially leading to increased growth of HABs. The precise role of climate change in terms of HABs risk occurrence is not clearly defined, so not only temperature but also other parameters, such as irradiation, precipitation, mixing events, currents, etc (Hinder *et al.*, 2012) should be the focus of long-term studies.

Vibrios

Most *Vibrio* species of human health relevance grow preferentially in warm (>15 ºC), moderate/low salinity (<25 ppt NaCl) seawater and a warming and lower saline marine environment is likely to significantly increase the abundance and seasonal distribution and subsequent clinical risk associated with this group of pathogens. Recent projections for surface seawater temperature change indicate significant warming of the vast majority of UK waters by the middle and end of this century (2070-2098), particularly during summer and autumn months (UK Climate Projections, 2009). As part of these projections, it is likely that the sea surface temperatures of large regions of the UK coastline may exceed the 18 ºC isotherm implicated in at risk periods seen in Northern Europe, particularly for *Vibrio* wound infections (Baker-Austin *et al.*, 2012). Again, the role of both natural variability and anthropogenic factors leading to a greater number of extreme warm weather episodes as recently experienced in Northern Europe (e.g. 2003, 2006 and 2010) is likely to play a role in increasing clinical cases, particularly localised wound-associated infections. In addition, numerous vibrios of human health relevance grow preferentially in low salinity waters, thus increased freshening salinity conditions caused by higher rainfall patterns may increase clinical risk by extending the geographical area over which these pathogens may occur in the UK. Unfortunately, no projections of *Vibrio* risk, based on climate modelling data, have been produced for the UK. Extrapolations from areas that have undergone recent rapid warming, such as the Baltic Sea and North Sea area (Baker-Austin *et al.*, 2012) or have experienced anomalous weather conditions prior to *Vibrio* outbreaks such as Chile, Alaska, and Northern Spain (Martinez-Urtaza *et al.*, 2008, 2010, 2012) may be a useful portent for future risk in the UK.

Recent studies have indicated that long-distance movements of water may represent an effective vehicle for disease emergence associated with vibrios (Martinez-Urtaza *et al.*, 2012; Baker-Austin *et al.*, 2010). Thus climate change-mediated changes in ocean currents should be considered as a possible risk factor. Data showing large-scale water movements, and particularly warm-water movements from areas where these pathogens are endemic may therefore be useful for informing future risk. As with recent work in the USA utilising long-term epidemiological datasets (Dechet *et al.*, 2008), and based on dedicated surveillance networks, focusing on the epidemiology of vibriosis will be necessary to adequately assess the climate change-mediated impacts of these pathogens in the UK and across Europe as a whole. A recent publication led by the European Centre for Disease Control (ECDC) has placed non-cholera vibrios as the leading group of pathogenic agents sensitive to climate change, highlighting the growing regional interest in vibriosis (Lindren *et al.*, 2012).

CSOs

The number of households in England is projected to grow to 27.5 million in 2033 (Office for National Statistics, 2010). This population growth will have significant impacts on the capacity of the existing sewerage systems which are already under pressure from extreme rainfall events. Modelled estimates of climate change impacts on CSO spill frequency and volumes in seven catchments representative of the range of hydrological conditions found in the UK indicate that, on average, spill volumes may increase 11% by 2020 under a medium emissions scenario (90%ile projection) (S. Wade, pers. comm. 2010). This is of concern during the summer months, when there is a significant reduction in flows and spills would have greater impact due to reduction in dilution (S. Wade, pers. comm. 2010). A separate assessment on the change in sewer flooding that may result from climate change, increased drained area and new population and housing growth up to 2040 predicts significant increase in sewer flooding (median increase in volume=51%) after allowing for existing network capacity (Mott MacDonald, 2011). Interestingly, together the three factors produce a greater effect than that provided by the sum of the individual changes (Mott MacDonald, 2011). No geographic trends or trends linking the change in flooding to the population of the catchments were found in this study.

Work carried out by the Environment Agency indicates that there will be a significant impact on average river flows across the UK; by 2050, river flows during the winter across England and Wales may increase by 10–15% with lower flows in most rivers from April–December and flows in the late summer and early autumn could decrease by over 50% and by as much as 80% in some catchments (Environment Agency, 2008). However, it is not known exactly the extent to which these changes will impact upon the quality of the coastal waters in any given location, year or season.

It is expected that climate change impacts would result in more failures to comply with the microbiological standards of the Bathing Water and Shellfish Water Directives and worse classifications under the Shellfish Hygiene and therefore increase the health risk associated with recreational water use and shellfish consumption. It is anticipated that further progress in improving the quality of shellfish and bathing waters in the UK will require the implementation of measures to reduce runoff from agricultural land together with further reduction in the spill frequency of CSOs, although in some areas additional improvements for continuous sewage discharges may also be required (UKMMAS, 2010). The economic regulator Ofwat has agreed with water companies an investment of more than £1 Billion between 2010–2015 to limit pollution from CSOs; in Scotland, the Water Industry Commission intends to spend over £200 Million during this period (Water UK, 2009).

Current generalised climate modelling (GCM) predictions do not provide highly accurate regional resolution to predict medium or long-term term effects of rainfall, and hence CSO impacts in the UK. Where data are available, there is a strong regional variation in both intensity and seasonality with SE England predicted to experience more seasonal variation with potentially reduced event occurrence in the summer, whereas western areas are likely to experience a large increase in winter storm intensity and less reduction in the summer. The human health impacts linked to this are complex. For example, milder, wetter winters may actually reduce the impact of norovirus due to inactivation of virus particles in the environment, which are temperature and UV sensitive.

It is not economically feasible to construct sewerage infrastructure with capacity to cope with most extreme weather events (CIWEM, 2004). Therefore, impacts from CSO discharges should be appraised in the context of the sewerage system they form a part of, i.e. the total system should be considered so that the required environmental quality can be achieved in the most efficient and cost-effective way (CIWEM, 2004). Site-specific solutions to these impacts may involve reduction of domestic and industrial sewage production, reduction of the demand for additional capacity by eliminating surface water drainage from CSOs, diversion of surface water drainage away from the sewerage system or decentralisation of sewage treatment infrastructure. In many areas, perhaps an effective way of minimising CSO impacts would be to reduce the amount of inflow/infiltration which in some sewerage systems represents a major contributor to the flow.

3. KNOWLEDGE GAPS

a. *Epidemiology and clinical reporting*: Joined-up datasets regarding clinical cases linked to the marine environment are lacking. These include active and passive systems of reporting for vibriosis, HABs ingestion and faecal-associated pathogens from CSO discharges. A single system of reporting and notification, using detailed epidemiology (e.g. tracing back shellfish-associated ingestion cases) would undoubtedly improve the situation in the UK. This is likely to encompass numerous agencies and stakeholders, such as Public Health England, Environment Agency, Cefas, etc.

b. *Modelling and forecasting*: Many of the climatic events prior to, and during, clinical infections and extreme weather events such as heatwaves and extreme rainfall events are predictable. However, current climate models are based on a spatial-temporal scale that is too coarse to resolve processes relevant to urban drainage modelling and CSO impacts. Greater research emphasis on the role of these impacts, coupled to epidemiological and baseline environmental data gathering during these events is essential for risk assessment purposes. Further work is also required to understand the relative impact of climate change in relation to other pressures such as changes in land uses and management.

c. *Environmental monitoring*: Greater research emphasis on the occurrence of specific pathogenic agents and toxins in the environment is urgently required. This includes vibrios, faecal pathogens, HABs, toxins, and algae in both overlying water and in commercially relevant shellfish species. In addition, there is very limited information on flow volumes and bacterial concentration levels in CSO discharges. Post-project monitoring and assessment in the context of CSO improvement schemes are also required to provide the evidence required to identify solutions that are resilient to climate change impacts in the long-term.

4. SOCIO-ECONOMIC IMPACTS

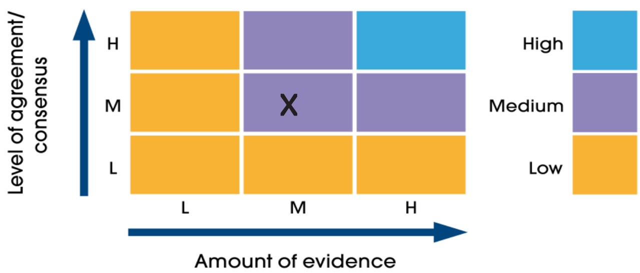
• Transient closures of shellfish harvesting beds due to CSO discharges. Increasing CSO discharges may have a significant increase in closure of commercial harvesting beds in shellfish production areas and potentially beaches following pollution events.

• Transient closures of shellfish harvesting beds due to *Vibrio* outbreaks and HABs toxin occurance.

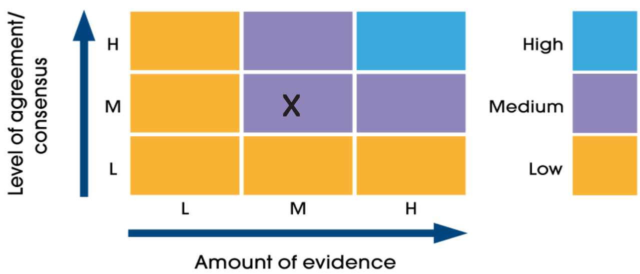
• Increased clinical costs and healthcare burden associated with the treatment of *Vibrio* infections and HABs ingestion cases.

5. CONFIDENCE ASSESSMENT

What is already happening?



What could happen?



A moderate level of confidence on both axes. This is based on the fact that although there is now a mounting body of evidence for an increase in risk in some areas (e.g. the apparent regime shift in HABs species in UK waters during the 1980s coinciding with warming trends, similar data for vibrios using similar datasets etc.) linking these changes with reported illnesses is problematical because of gaps in epidemiology and clinical reporting. Also, precise mechanistic data regarding climate forcing and its impacts on human health are frequently lacking in the UK. An example of this is to what degree climate change-mediated extreme weather events have increased the pathogen loads in shellfish harvesting areas and to what degree this has impacted human health. With data augmenting these knowledge gaps, a greater level of confidence could be attained. More data on *Vibrio* abundance in both water and shellfish samples, as well as published reports on retrospective abundance/

outbreaks has been obtained since 2010, which has increased the confidence of data gathering in this area. Averaging all available information suggests a moderate classification on both axes for this group of human health risks.

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