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Climate Change Impacts on Harmful Algal Blooms (HABs)

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EXECUTIVE SUMMARY

A range of different harmful algal blooms (HABs) are routinely observed in UK waters. A strong regional distribution can be observed in the distribution of these HAB genera, with shellfish toxin producing genera and their impacts being more regularly detected along the Irish South and West coasts and in Scotland. Analysis of phytoplankton time series data from the continuous plankton recorder (CPR) has shown the dynamics of this community to be sensitive to changes in the physical conditions in the water column, with a number of changes identified over the last four decades. These include an extension of the growing period and increase in phytoplankton biomass (associated with warmer sea surface temperatures) as well as a change in the timing of dinoflagellate blooms. In particular the distribution of a selected number of HAB genera in the NE Atlantic has been observed to have changed over this time. In some regions of the North Sea these changes appear to be associated with climatic oscillations e.g. changes in the NAO index.

Analysis of data from a number of coastal monitoring sites over the last two decades have also highlighted a number of changes. Large blooms of the dinoflagellate *Karenia mikimotoi*, which is associated with fish kills, have been observed in northern waters off Ireland and Scotland. These blooms are thought to develop in the more offshore regions and predictions of climate change that indicate any increase in the duration of stratification of the water column in the future could influence the development of these blooms.

Climate change may also influence the toxicity of some HAB species via processes such as pH, nutrient availability, temperature and irradiance (cloud cover). In Scottish waters the incidence of intoxication of blue mussels (*Mytilus edulis*) with paralytic shellfish poisoning toxins (PSP toxins), primarily due to *Alexandruim spp*, have decreased since the 1990s, with no closures of shellfish harvesting areas enforced in two of the last five years. Recent research described the dinoflagellate responsible for producing the azaspiracid (AZA), *Azadinium spinosum*, from specimens collected from Scottish waters This toxin has been responsible for extensive closures of Irish shellfish harvesting areas over the last eight years.

Increases in sea temperature have the potential to allow harmful species currently not detected in UK watersd to become established as part of the phytoplankton community should they be introduced via shipping activity, drifting debris or natural range expansion.

There is a high natural variability associated with HAB events, particularly with respect to local hydrographic conditions, therefore any changes in temperature, salinity, water column stability or precipitation have the potential to impact the dynamics of HABs in UK waters through direct or indirect effects. Changes in UK waters may also be driven by offshore influences. Changes in the circulation of the subpolar gyre influence the ecosystem structure on the eastern margin of the North Atlantic and hence the Northern North Sea.

The influence of some climate change impacts such as ocean acidification remains unknown.

FULL REVIEW

Background

Algal blooms are a natural part of the seasonal phytoplankton cycle in UK waters. Some blooms can have a negative impact on the ecosystem or the local economy. These algal blooms have been given the name Harmful Algal Blooms (HABs). For example the dinoflagellate *Karenia mikimotoi*, forms high biomass blooms which can generate mortalities of farmed fish due to clogging of gills, deoxygenation and ichtyotoxin production. These blooms can also impact the benthos through the anoxic conditions that occur during bloom decay. Other HAB genera may be harmful at much lower densities. These include the shellfish toxin producers which are routinely detected in Irish and Scottish waters, and to a lesser extent in Northern Ireland, England and Wales. Examples of these low biomass HABs include species from the dinoflagellate genera *Alexandrium,* associated with the production of paralytic shellfish poisoning (PSP) toxins and *Dinophysis*, associated with the production of lipophillic shellfish toxins (LSTs). The toxins responsible for diarrhetic shellfish poisoning (DSP) are included in the LST grouping. Species from the diatom genus *Pseudo-nitzschia* are associated with the production of domoic acid (DA), the toxin responsible for amnesic shellfish poisoning (ASP). Even at low cell densities, the accumulation of toxins from these HAB genera in shellfish flesh may pose a risk to humans if these shellfish are consumed. Closures of shellfish harvesting areas are enforced under EU legislation (EC/853/2004, EC/2074/2005 and EC/1664/2006) when shellfish toxicity exceeds defined concentrations with a resulting economic impact on the shellfish farmers. Finally, the haptophyte *Phaeocystis* is also considered a HAB species, as bloom decay results in unsightly foam on beaches.

Data from a number of different coastal monitoring programmes in the UK and Ireland as well as from the Continuous Plankton Recorder (CPR) operated by the Sir Alister Hardy Foundation of Ocean Science (SAHFOS) have identified regional variations, interannual variability and changes over time within the distribution of selected HAB species around the UK and Irish coast.

1. What is already happening?

Long term decadal time series are required to examine the relationship between climate and HABs in UK and Irish Waters. The longest time series currently available in the UK is that from the CPR operated by SAHFOS. Analysis of this time series has highlighted the sensitivity of the plankton community in the North Sea to climatic and physical influences. It has identified two anomalies in the phytoplankton community in the North Sea over the last forty years (Edwards et al. 2002). The first, termed the ‘cold boreal anomaly’ was observed at the end of the 1970s, associated with a temperature and salinity minima. It is believed to be associated with a pulse of water from the east Greenland Sea entering the sub polar gyre and its subsequent circulation around the North Atlantic (Edwards et al. 2002). Analysis of North Sea phytoplankton CPR data from this period associates this anomaly with low phytoplankton biomass assessed by the phytoplankton colour index (PCI) and certain key species observed only in low abundance (Edwards et al. 2002). This time series also identifies a 'warm temperate' event associated with high salinities and temperatures in the late 1980s. Marked synchronous changes in the duration of the phytoplankton growing season were observed in both the North Sea and Baltic from the CPR and other time series (Edwards et al. 2002, Alheit et al. 2005, Edwards et al. 2006, Wiltshire et al. 2008). This event has been termed a regime shift due to its synchronous impact within the N.E. Atlantic area and has been associated with a positive phase of the North Atlantic Oscillation associated with warming sea surface temperatures (Edwards et al. 2002). A study of individual phytoplankton groups have shown increased temperatures to influence the phenology of dinoflagellates, which have been observed to bloom earlier in the North Sea (Edwards and Richardson 2004). A review of HAB data from the CPR shows the distribution of HABs in the North Sea to have altered since the 1960s in response to climatic oscillations with a general decrease in abundance observed along the east coast of the UK (Regions 1 and 2) (Edwards et al. 2006). The geographic regions mentioned throughout this chapter are those as shown as the regional section in the main card.

A number of coastal monitoring programmes have been in operation around the UK coast and Irish coasts since the mid 1990s. These time series reveal a strong regional distribution for some shellfish toxin producing genera as well as providing observations of HAB events. These data highlight the probability that any climatic influence on the development and/or distribution of HABs will be likely to have a regional impact. It should be noted that Region 8 is infrequently monitored aside from satellite imaging and CPR sampling.

Shellfish toxin producing HABs

Paralytic shellfish poisoning toxins

A distinct regional distribution can be observed in the distribution of the PSP causative organism *Alexandrium,* with shellfish toxin accumulation being more prevalent in Scottish waters (Regions 1, 6 and 7) than elsewhere in Britain and Ireland. Recent investigations into the diversity of *Alexandrium* has confirmed the widespread presence of the potent PSP toxin producing *Alexandrium tamarense* (Group I) strain and provided the first records of the distribution of the non toxin producing *A. tamarense* (Group III) strain these regions (Collins *et al*. 2009, Brown *et al*. in press). PSP toxicity in Regions 3 and 4 and in Irish waters has been associated with *A. minutum* (Percy 2006, Touzet *et al*. 2008) with high biomass *Alexandrium* blooms identified as *A. minutum* as well as *A. tamarense* (Group III) strain (Ni Rathaille 2007). PSP events along the south and western coasts of Ireland have been restricted to a single area where a cyst bed of *Alexandrium* is present. The extension of toxicity outside this area has not been observed.

A decrease in PSP toxicity in Scottish shellfish has been observed over the period since monitoring began in 1990 (Bresnan *et al*. 2008a), with closures of *Mytilus edulis* harvesting areas being enforced as a result of elevated concentrations of PSP toxins in shellfish flesh in only three of the last five years.

Lipophilic shellfish toxins

The dinoflagellate genus *Dinophysis* also shows a non homogeneous regional distribution around Britain and Ireland. *Dinophysis* species generated DSP closures of shellfish harvesting areas have to be routinely enforced along the south and west coast of Ireland, west coast of Scotland, Orkney and Shetland Isles (Regions 1, 5, 6, 7). Closures for DSP are less frequently enforced in Regions (2, 3 and 4). There is a striking relationship between the occurrence of DSP in shellfish and water column stratification around Britain and Ireland, with DSP toxicity seldom recorded in tidally mixed waters. Analysis of monitoring and CPR data has revealed considerable decadal variation in the distribution of *Dinophysis* in Regions 1, with a decrease in abundance in this area since the 1970s (Edwards *et al*. 2006). Other LSTs, e.g. Pectenotoxins (PTX) and Yessotoxins (YTX) have also been detected in Scottish shellfish (Regions 1,5,6 and7) (Stobo *et al*. 2008) but closures of shellfish harvesting areas have yet to be enforced due to high concentrations of these toxins.

The shellfish toxin Azaspiracid (AZA) which has caused widespread shellfish closures in Irish waters since its detection in the mid 1990's has also been detected in Scottish shellfish from Regions 1,5,6 and 7 (Stobo *et al.* 2008). A newly described dinoflagellate species, *Azadinium spinosum,* was isolated and identified from Region 1 (Tillman *et al.* 2009). This species has been shown to produce Azaspiracid and is potentially a causative organism of the toxicity in shellfish.

Amnesic shellfish poisoning toxins

The diatom genus *Pseudo-nitzschia* is associated with the production of domoic acid (DA), the toxin responsible for ASP. This diatom is a widespread component of the Scottish phytoplankton community in Regions 1, 6 and 7 (Fehling *et al.* 2006, Brown and Bresnan 2008 and Bresnan et al 2008b). *P. australis* and *P. seriata* have been confirmed as DA producers from cell isolates generated from region 6, with the level of toxicity being related to environmental factors such as the form of nutrient limitation and available irradiance (Fehling *et al.* 2004, 2005). Similar observations of *P. australis* in south western Irish coastal locations have resulted in ASP in farmed shellfish.

Fish killing HAB species

The dinoflagellate *K. mikimotoi* is a typical component of the summer phytoplankton community in UK and Irish waters usually at low densities at coastal monitoring sites. However, offshore high biomass blooms of *K. mikimotoi* are common in the English Channel associated with thermal fronts (Pingree *et al.* 1975, Holligan *et al.* 1984, Kelly Gerreyn *et al.* 2004). In more northern latitudes relatively few early records of *K. mikimotoi* attaining bloom densities exist. A bloom of *K. mikimotoi* in the Clyde Sea area did result in fish kills in 1980 (Jones *et al.* 1982, Roberts *et al.* 1983, Potts and Edwards 1987) and a sizeable population was observed on the southern Malin Shelf in summer 1996 (Gowen et al 1998). *K. mikimotoi* assumed reduced significance in Scottish waters for nearly two decades. However, in the last decade reported bloom incidences have been more frequent with events of red tide proportions being observed in 1999 in Orkney and in 2003 in the Orkney and Shetland Islands. In 2006 an extensive and protracted bloom of *K. mikimotoi* occurred over much of the Scottish west coast and Islands (Davidson *et al.* 2009). This bloom follows a similar incident in Western Irish waters during 2005, which resulted in extensive marine mortalities of benthic and pelagic organisms (Silke et al 2005). Most recently a further *K. mikimotoi* bloom occurred on the Ayrshire coast in 2009. The increased frequency of these incidents suggests that *K. mikimotoi* may be becoming a regular threat to aquaculture in Britain and Ireland.

While incidences are rare in UK waters diatom species, particularly belonging to the genus *Chaetoceros*, may cause inappetence and mortalities of farmed fish. Examples of diatom induced mortalities include those generated by blooms of *C. wighami* and *C. debile* in Loch Torridon in 1988 and 1998 (Bruno *et al.* 1989, Treasurer *et al.* 2003).

Harmful microflagellate blooms in UK and Irish waters are also rare. The best documented events relate to an unidentified species known as 'Flagellate X' (possibly *Heterosigma akashiwo*) which bloomed in Loch Striven in 1979 (Tett 1980) and in 1982 in Loch Fyne (Gowen *et al.* 1982). Both events were associated with mortalities of farmed salmon. 'Flagellate X' has also been implicated in farmed fish mortalities on the west coast of Ireland (Doyle *et al.* 1984).

2. What could happen in the future?

Sea level rise

Increasing sea levels have the potential to result in localised increased coastline length as well as regional probability of more retention zones with the potential to favour the growth of HABs.

Sea surface temperature

Many HAB species are flagellates, life forms that are favoured by increased temperatures though direct influences on enzymatic rate processes and indirectly through increased stability of the water column. Increased temperatures may facilitate the introduction or natural range expansion of HAB species from more southerly areas. Examples of these are *Gymnodinium catenatum*, a PSP toxin producer frequently observed in Spanish waters and *Ostreopsis*, a toxin-producing benthic dinoflagellate which is now known to have a European distribution outside of the Mediterranean. However difficulties in predicting rates of range expansion and long distance dispersal events make it difficult to anticipate when or if, these species will appear in UK waters. Nevertheless, instances of the growth of *Coolia monotis*, *Prorocentrum lima* and toxic *Amphidinium* species may be expected to increase. Predicted temperature increases are highest in Regions 2, 3 and 4 which may present these areas with a different sensitivity towards this effect.

Stratification

Increases in the duration of stratification has the potential to impact on the abundance of HABs in UK waters. The predicted earlier stratification date increases the duration of time over a year where stratified conditions favour dinoflagellate growth. This is particularly apparent from the predictions in Region 8, an area where offshore high biomass *K. mikimotoi* blooms have been hypothesized to initiate and impact coastal areas in Region 6, 7 and 1. The extension of stratification, and hence the bloom season, into what is traditionally regarded as the autumn months can potentially impact the influence of HABs on the aquaculture industry.

The impact of climate change on algal toxicity

It is known that environmental parameters such as temperature, pH, light, nutrient supply and water movement/turbulence can affect algal bloom dynamics and their toxicity. Climate change is expected to impact on these environmental parameters so it must therefore be assumed that the toxicity of harmful algal blooms will also be modulated (in addition to changes in species composition, timing and spatial extent of blooms as discussed above). Recent examples of environmental parameters modulating algal growth and toxicity have been published for cyanobacterial blooms in freshwater reservoirs (Naselli-Flores *et al*., 2007; Davis *et al*., 2009), and it is likely that similar responses can be found in marine toxic algae. The impacts of climate change enhancing the potential for toxic algal blooms in river systems through modulating of environmental parameters such as flow rates and nutrient concentrations has also been highlighted.

Ocean acidification and multiple pressures

The influence of increasing ocean acidification on the phytoplankton community (including HABs) has yet to be fully investigated. Increased CO_2 concentrations will influence the abundance of pH sensitive species; however, impacts from ocean acidification may also be less obvious. A lower pH has the potential to influence the speciation of nutrients (e.g. nitrogen, phosphate and silica) important for phytoplankton growth (Turley *et al*. 2009). In addition some phytoplankton groups with a low affinity for CO_2 could be favoured by increasing concentrations of CO_2 (Rost *et al*. 2008), thereby altering diversity within the phytoplankton community.

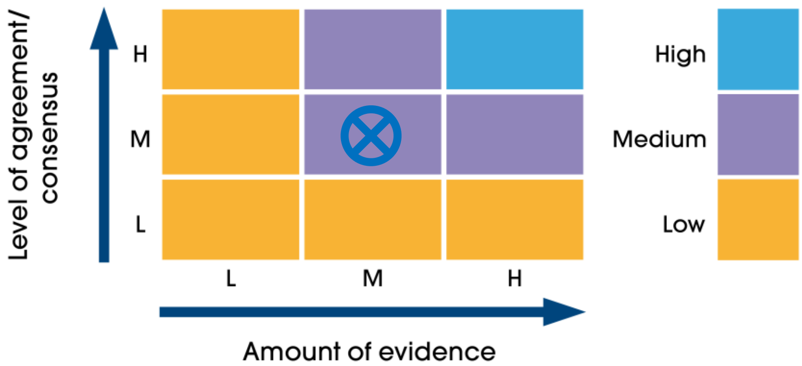
One other relevant factor is that of multiple pressures. Jackson (2008) discussed the impacts that multiple changes and pressures brought to bear on the marine environment, of which climate change is one, will lead to shifts in microbially dominated ecosystems with boom and bust cycles of dinoflagellate blooms, some of which may produce toxins.

Changes in offshore circulation

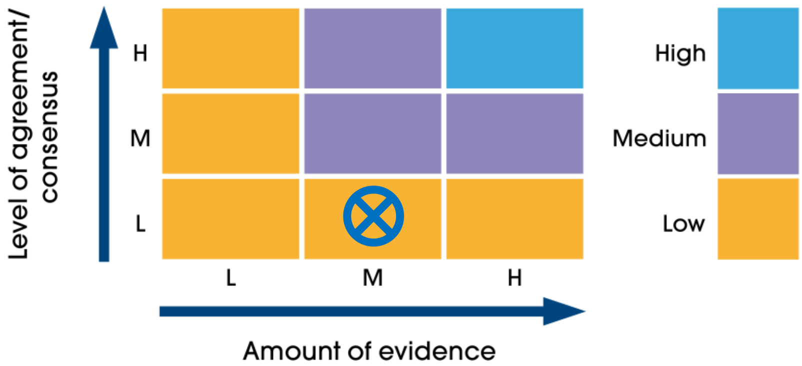
Changes in offshore circulation can influence the abundance and diversity of phytoplankton in UK waters. Impacts from this have already been identified in Region 1 where influx of polar water into the North Sea in the late 1970s resulted in a decrease in phytoplankton abundance, with one species *Ceratium macroceros* being lost from the North Sea dinoflagellate community (Edwards *et al*. 2002). Changes in the circulation of the subpolar gyre may influence variability in ecosystem structure on the eastern margin of the North Atlantic (Hatún *et al*. 2009) and should be considered when interpreting longer term phytoplankton time series data as well as making predictions for the future. Whitehead *et al*., (2009) and the studies into the impact of regional climate change on HABs in the northeast Atlantic concluded that HABs in Norwegian coastal waters and the Skagerrak are particularly sensitive to climate induced changes in temperature, salinity, and the North Atlantic Oscillation (NAO) (Edwards *et al*., 2006). McDermott and Raine (2006) give indications of which species, or more accurately which groups of species, from the genus of large dinoflagellates *Ceratium* could be used as evidence of such changes.

3. Confidence in the science

What is already happening: Medium



What could happen: Low



Coastal monitoring data since the 1990s has shown a high degree of variability in the incidence of HABs around the UK coast. The impact from some HAB genera (e.g. *Alexandrium*) appears to be decreasing. There is the possibility that species predominance may change in the future and thus it is likely that while there may be an increase in events in some areas, others will experience a decrease.

4. Knowledge gaps

The top priority knowledge gaps that need to be addressed in the short term to provide better advice to be given to policy makers are:

1. The majority of HAB monitoring is performed in coastal areas. The role of advection from the offshore in seeding blooms in coastal areas requires further attention.
2. Limited work has been performed in modelling different HAB species in UK waters. It is therefore difficult to predict the response of different HAB groups and genera to the influences of climate change.
3. The impact of increasing ocean acidification on UK HAB species has yet to be investigated.
4. Ichtyotoxic species such as *Karenia mikimotoi* have yet to be investigated to a level that would allow a proper evaluation of their impacts on the marine ecosystem (including critical life phases of exploited species).

5. Socio-economic impacts

Increased HAB events may have a direct detrimental effect on ecosystems and they can often have a direct commercial impact on aquaculture industry as both shellfish and fish farms can be affected by HABs. Predictions of future food consumption indicate that these two sources will be of much greater importance in the future.

Predicted strengthening of shellfish toxin regulatory levels will have a large impact on shellfish harvesting activities.

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