MCCIP ARC Science Review 2010-11
The potential impacts of climate change on estuarine and coastal pollution

DAVID SHEAHAN[1], JACKIE MAUD[2], ANDREW WITHER[3] AND COLIN MOFFAT[4]

[1]Cefas, Pakefield Road, Lowestoft, NR33 0HT.

[2]Environment Agency - Research and Innovation, Red Kite House, Howbery Park, Wallingford, Oxon, OX10 8BD.

[3]Environment Agency, c/o Joseph Proudman Building, 6 Brownlow St. Liverpool L3 5DA

[4]Marine Scotland-Science, Marine Laboratory, 375 Victoria Road, Aberdeen, AB11 9D.

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EXECUTIVE SUMMARY

Climate change may result in a number of changes to physical and chemical processes in River Basins that ultimately result in increased pollution of transitional and coastal waters. The changes that occur will affect summer periods during which drought conditions, particularly in the South East of the UK are likely to result in the reduced dilution of chemicals present in sewage and other effluent discharges. More stormy conditions will affect summer and winter periods contributing to rapid runoff of chemicals from agricultural and urban areas and overflows from combined sewers. The predicted trend to drier summers, but more extreme rainfall events, will exacerbate the complementary problems of microbial delivery from livestock farming and sewage overflows (CSOs) producing intermittent and short term non-compliance in bathing and shellfish harvesting waters. Increased temperature and, in the longer term, decreased pH will affect the availability for accumulation by marine organisms of chemicals present in sediments and the water and will modify toxicity, in some cases reducing it (e.g. by increasing degradation) but in other cases increasing it (e.g. by enhancing uptake).

Most research effort so far has focused on modelling river water quality and climate change impacts, but the concepts and results can be extrapolated to estuaries and coastal waters. This work highlights such effects as:

- Water quality will be affected by changes in flow regime.
- Lower minimum flows imply higher concentrations downstream of point discharges.
- Increased storm events, especially in summer, could cause more frequent incidences of combined sewer overflows (CSOs) discharging highly polluted waters into waterbodies.
- More intense rainfall and flooding could result in increased suspended solids, sediment yields and associated contaminant metal fluxes.
- Invasive species - can alter the structure and function of ecosystems and this pressure may act in combination with the stress of contaminant exposure and altered physical parameters.

Many of the changes described above may result in deterioration of estuarine and coastal waters over a period of decades but in the shorter term breaches of current and emerging legislation are more likely to result. Climate change will therefore present a number of challenges to the Environment Agency and other organisations that have a broad range of duties to monitor, protect and improve estuaries and coastal waters. Increase in chemical and microbial pollution of coastal waters has the potential to impact on ecological quality, health, economic resource utilisation and compliance with EU Directives.

It is apparent that whilst many of the climate change influences on coastal waters have been hypothesised and prioritised and some patterns are emerging, existing evidence to support or refute these theories is still patchy. The current state of knowledge specifically on marine pollution is limited and the knowledge gaps are numerous and extensive.

FULL REVIEW

1. What is already happening?

Some of the main issues are in respect of estuarine and very coastal waters:

(i) Increased flooding causing increased storm sewage discharges, runoff from industrial sites and urban areas and agricultural land with chemical inputs from these areas increased to rivers and estuaries – *contributing to deoxygenation and increased chemical and microbial contamination.*

(ii) Increased temperatures, longer periods of drought, reduced water flow, increased salinity and decreased pH – *contributing to higher relative concentrations of treated sewage effluent – deoxygenation and microbial contamination, and change in chemical behaviour*.

(iii) Conditions may become more favourable for Invasive species to establish - *structure and function of ecosystems may be changed and this pressure may act in combination with the stress of contaminant exposure and altered physical parameters.*

Flooding effects have been particularly marked in Northern England and the South West. Estuaries and coastal areas in the South East are likely to be at highest risk from conditions that arise under low summer flows. A reduction in snowfall in Scotland is likely to increase the number and magnitude of flood peaks in rivers where snow has historically been a significant water store.

Flooding is also likely to increase soil and sediment erosion, leading to the re-mobilisation of metals and persistent organic compounds (Dennis *et al.*, 2003; Whitehead *et al.*, 2008) and micronutrients such as manganese, which at higher concentrations can be toxic (Environment Agency, 2003). As a result of flooding in 2000, large-scale remobilisation of metal-rich mine waste occurred in the headwaters of the River Swale, a tributary of the Yorkshire Ouse. Over the last 20 years increased flooding in this catchment (Longfield and Macklin, 1999) has resulted in much higher rates of metal cycling and redistribution. Floodplain sediments contaminated by mine waste are therefore a predominant supplier of sediment-associated metals in many UK and other similarly historically contaminated river basins.

Remobilisation of sediments also has the potential to cause deoxygenation in the water column which has been demonstrated experimentally for sediments from various UK river systems (Neal *et al.*, 2006). This potential increase in chemical load and physical effects in estuarine and coastal waters will add further stress to exposed organisms.

Change in physical factors such as temperature may also affect toxicity and fate of chemicals. For some chemicals such as the insecticide DDT, increased temperatures can increase toxicity (Buckman *et al.*, 2007) but for other chemicals a decrease in temperature results in increased toxicity e.g. pyrethroid insecticides (Weston *et al.*, 2009). The increase/decrease of toxicity with increase/decrease in temperature depends upon the balance between chemical degradation and uptake and excretion and whether more toxic metabolites of a parent chemical result from metabolism by an organism.

Ammonia is a good example of a chemical whose behaviour and potential impact may be different under climate change. Ammonia is present in equilibrium between free ammonia (NH_3) and the ammonium ion (NH_4^+). Under all normal conditions the bulk of the ammonia encountered in estuaries will be as the ammonium ion. Although both forms of ammonia may have adverse impacts, it is the un-ionised 'free' ammonia which exerts the main toxic impact to fish and other marine organisms. Higher pH (e.g. less acidic) and temperature and lower salinity all increase the proportion of unionised ammonia. Total ammonia concentrations in estuaries may increase during low flow conditions as dilution is reduced, and loads invariably rise significantly during intense rainfall events through discharge of storm sewage and increases from diffuse sources. However the build up of ammonia may be counteracted to some extent by nitrification processes giving rise to increased nitrate concentrations as ammonia is oxidised to nitrate. The impact of climate change on ammonia toxicity remains a big unknown. The likely increase in temperature is pulling in one direction, whilst possible decreases in pH (more acidic conditions) and increased salinity pull in the other. As the relative rates of these changes are difficult to predict we are entering a period of great uncertainty. The issue of ammonia toxicity has been covered in more detail in *MCCIP ARC Pollution Supplementary Review 2010-11* (Wither, 2010). Increased storm events producing combined sewer overflows and reduced water flow during periods of drought will also result in higher concentrations of other chemical contaminants e.g. priority pollutants (Gasperi *et al.*, 2008).

Although chemical contaminants in storm overflows are of concern, the human pathogens present in combined sewer overflows (CSOs) discharges have implications for disease transmission and ill health through consumption of shellfish (Lee *et al.*, 2003) and use of recreational waters (WHO, 2003). Studies of shellfish held in the vicinity of storm overflows immediately following CSO events have been shown to have faecal coliform bacteria and *Escherichia coli* flesh concentrations that exceed European shellfish hygiene requirements (Kay *et al.*, 2008). There is also economic impact from the pollution loading where bathing water quality is reduced which restricts the attractiveness of coastal resorts to visitors (Georgiou and Brouwer, 2010). The issue of microbial contamination has been covered in more detail in the *MCCIP ARC Science Review 2010-11 Microbial Pollution of Bathing and Shellfish Waters* (Wither *et al.*, 2010).

As our climate warms there is the likelihood of a reduction in snow accumulation in Scotland. Despite limited snow monitoring in Scotland, anecdotal evidence and long term temperature changes point to widespread reduction in snowfall. A reduction in snowfall is likely to increase the number and magnitude of flood peaks in rivers where snow has historically been a significant water store e.g. Mar Lodge area on the River Dee (SEPA, 2009a). The impact of this on contaminants remains unclear other than it will influence the flow regime and perhaps exacerbate other aspects of flow which will be influenced by greater precipitation. The polybrominated diphenyl ether congener pattern in trout from Lochnagar, a loch influenced by snow accumulation, is quite distinct with BDE99 dominating the profile (Webster *et al.*, 2008). The reason for this is unclear, but illustrates a possible impact at altitude which may be altered if the conditions change and this may be translocated to estuarine and coastal environments. It is interesting to note that in a study by the Food Standards Agency, the dioxin concentrations in red deer liver from animals from the north of Scotland, including relatively close to Lochnagar, were above the 6 pg WHO-TEQ/g fat (Food Standards Agency, 2006; units are picograms of World Health Organization Toxin Equivalent per gram of fat. The use of WHO-TEQ allows concentrations of the less toxic compounds to be expressed as an overall equivalent concentration of the most toxic dioxin, 2,3,7,8-TCDD). The most likely source of such contaminants is precipitation, some of which will be snow. This may be indicative of the presence of dioxins which may be released into the aquatic environment or may be more accessible if they enter the Scottish aquatic environment through rainfall rather than snow.

SEPA (2009b) have recently reported on trends in organic carbon in Scottish rivers and lochs. The data shows that the concentration of organic carbon in many Scottish rivers has approximately doubled over the last 20 years, with soils being the most likely source. Most of the sites with increasing TOC were in the east of Scotland, but this actually reflects the distribution of sites sampled. Loss of soil organic matter reduces soil properties including the ability to retain pollutants and nutrients resulting in increases in pollutant content in run-off. The implications of this for contaminant and nutrient redistribution, specifically to estuarine and coastal locations, are unclear.

Climate change also has the potential to impact upon UK compliance with emerging regulatory frameworks such as the Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD). The WFD provides a regulatory framework for River Basins including estuaries and coastal waters. A series of objectives are set under the Directive to ensure that good ecological status is achieved by 2015. Status is assessed on the basis of various chemical, physical, and ecological parameters all of which may be influenced by climate change, leading to a failure to achieve environmental objectives. The MSFD will regulate the marine environment from coastal waters outwards and aims to achieve good environmental status by 2020. The Environment Agency undertook a scoping study of climate change influences on environmental standards (Environment Agency, 2003) which showed that many complex interactions could occur between climate change factors, chemicals and receptors.

Climate Change Research

It is important to understand the potential impacts of climate change on water quality, but predicting this is particularly difficult in estuarine and coastal areas because of the wide range in natural variability in hydrology, chemistry and ecology. To assist with the understanding of climate change processes and their interactions on water quality, and to enable better prediction the Environment Agency has been increasingly using mathematical models. A science project was undertaken to review the potential impacts of climate change on surface water quality, which although focused on five UK freshwater river systems, is applicable to estuarine and coastal systems (Environment Agency, 2008). This research used SIMCAT (the Environment Agency's water quality model) and complementary modelling work with the INCA (Integrated Catchment) model to run four UKCIP02 climate change scenarios for the 2010s, 2020s and 2050s, to simulate flow, phosphorus, nitrate, ammonia, sediments and ecology. The results demonstrated that water quality impacts are different depending on geographic location and water body location within the catchment, but suggested that the changes predicted from the modelling were not large. Further work is planned on this topic in light of publication of the new UKCP09 climate change scenarios.

Conclusions from this study suggest that:

- Water quality will be affected by changes in flow regime.
- Lower minimum flows imply higher concentrations downstream of point discharges.

- Increased storm events, especially in summer, could cause more frequent incidences of CSOs discharging highly polluted waters into waterbodies.
- More intense rainfall and flooding could result in increased suspended solids, sediment yields and associated contaminant metal fluxes

There are other marine pollution issues related to climate change that are highlighted as high-risk issues for further investigation. These include the potential for increased dilution of chemicals following intense rainfall, which may fail to pick up breaches of Environmental Quality Standards (EQSs); the probability of a concentrated first pulse of pollution during a rainfall event following an extended dry period and related specifically to agricultural land, the possibility of increased slurry runoff from dry, fissured ground, again following a period of dry weather. These are all work areas that require further investigation to determine the potential for significant environmental impacts.

As the climate changes and the waters of the North-East Atlantic generally warm, there has been an increase in warm-water fish species (e.g. red mullet, john dory, triggerfish) in UK waters during recent decades, while many coldwater species have experienced declines. (Pinnegar *et al.*, MCCIP 2008). New species may also become established in estuaries and coastal areas as a consequence of human activities such as navigation (Ruiz *et al.*, 2000) and aquaculture. Invasive species can alter the structure and function of ecosystems (MacDougal and Turkington, 2005) and this pressure may act in combination with the stress of contaminant exposure and altered physical parameters associated with climate change e.g. invasive macroalgae colonising a bivalve native to the Mediterranean induce biological stress and oxidative damage (Box *et al.*, 2009).

2. What could happen in the future?

I. Increased storm surges, with seabed disturbance - *potential for contaminant remobilisation from marine sediments and flooding and remobilisation of contaminants from land-based sources.*

II. Higher temperatures - *increased uptake/stress/toxicity in some cases increased degradation? Increased release of contaminants from sediments?*

III. Seawater is becoming more acidic (lower pH) from absorption of carbon dioxide due to increased atmospheric concentrations causes reduced calcification in many species. Already shown in tropics, though some species increase their calcification – therefore a mixed picture – *under acidic conditions metals can become more bio-available leading to accumulation by marine organisms.*

The effects of climate change are not limited to the potential for increasing concentrations of contaminants as chemical speciation may be influenced by changes in seawater acidity and temperature. Seawater acidification specifically may increase the organic and inorganic speciation of metals and as a result their bioavailability in marine environments. Greater bioavailability of dissolved iron for example may increase primary productivity whereas increase in dissolved copper may result in increased toxicity (Millero *et al.*, 2009). Both types of change may represent a serious potential risk to water quality and ecosystem health. Acidification may also reduce an organism’s tolerances to a number of other environmental factors including pollutants (Widdicombe and Spicer, 2008). However, increasing temperatures may also enhance biodegradation of contaminants and therefore reduce pollution impacts. Therefore acidification and warming effects must be considered in combination and should be a future adaptation research area.

An Environment Agency science project is currently underway to translate the UKCP09 climate projections into policy and practice and will provide an initial assessment of the implications for the Environment Agency. Water quality, diffuse pollution and water temperature are some of the specific indicators that will be analysed. This project is due to deliver July 2010 and it is expected that outputs will be produced at a regional scale (according to UKCP09 land 25km grid squares, administration and river basin districts and also the UKCP09 marine regions).

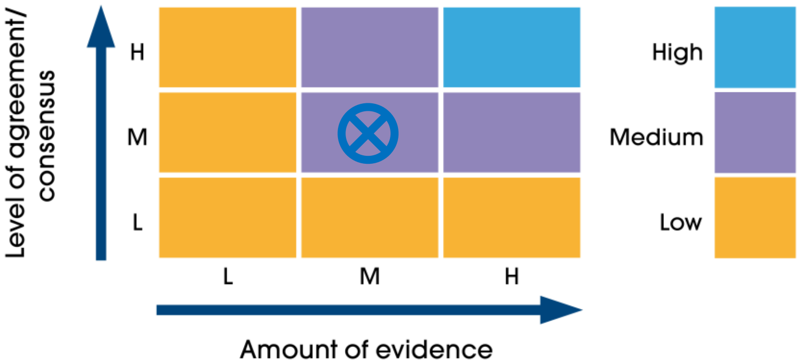
As climate changes and the waters of the North East Atlantic continue to warm, there will be further impacts on the distribution of marine species. Recent warming is exceeding the ability of local species to adapt and is consequently leading to major changes in the structure, function and services of these ecosystems. Clearly, over time there have been changes in species distributions as a result of natural climatic variations. However, in considering changes in the distribution and condition of species that would not have occurred in the absence of direct or indirect human impacts, chemical pollution has to be taken into consideration as an additional factor imposing stress to biota (ICES, 2007). The ICES Working Group on Biological Effects of Contaminants (WGBEC) are of the view that current evidence provides a clear link between pollution and climate change, with increasing temperature, decreasing pH or UV radiation possibly acting as additional or synergistic stressors. In addition, an altered composition in primary production (as shown in the Baltic) might influence food availability with more serious pollutant effects. Climate related changes in fish communities might also result in a modified transfer of contaminants within the food web (ICES 2007).

Another major area of change with respect to contaminant exposure, distribution and effects will relate to shifts in land use and agricultural distribution/practices. This, to respond to climate change, will bring about changes in chemical treatments and hence in pesticide distributions.

Chlorobiphenyl distributions in shallower offshore areas are dominated by atmospheric inputs (Webster *et al.*, 2007). If climate change alters the prevailing atmospheric transport systems then this could influence contaminant and nutrient deposition, although the impact of such changes is unknown.

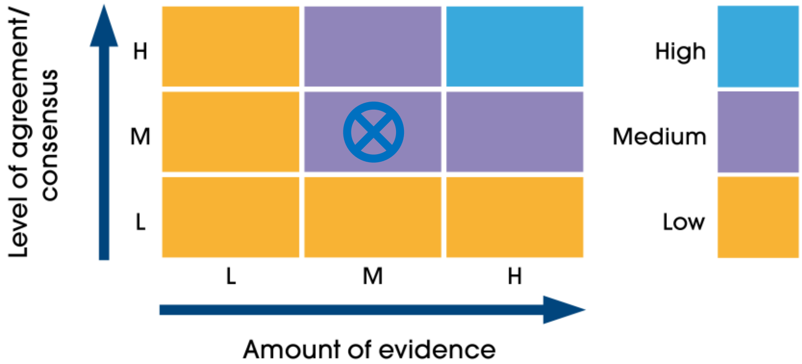
3. Confidence in the science

What is already happening: ***Medium***



In some areas, for example our current understanding of the inputs, behaviour and impact of ammonium, is reasonably good and would warrant a higher value for evidence and consensus. This is also the case for microbial contamination for which our knowledge of inputs and behaviour in the environment is better understood. But in other cases there is greater uncertainty e.g. for the distribution of priority pollutants and other chemicals from CSO inputs and the potential for toxicity enhancement through increased temperatures and reducing pH.

What could happen: ***Medium***



Predictions for the future are limited in a number of areas by available research. More specific issues are developed in this report card than were presented previously.

4. Knowledge gaps

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

Relating specifically to climate change and coastal pollution a number of knowledge gaps are apparent, many of which are cross-cutting to the different functions of the Environment Agency but also engage other organisations that contribute to improved understanding of marine processes. These include but are not limited to the following areas of research:

- Projected changes in the statistical distribution of river flows
- Estimates of the probabilities of changes in water quality and the probabilities of failing water quality standards including accurate and integrated, process-based prediction models for microbial pollutants in coastal catchments and near-shore receiving waters
- The joint probability of intense rainfall during or after a long period of dry weather and low river flow
- The possibility for higher effluent concentrations due to water re-use
- The possible changes to mixing and circulation of discharges from outfalls
- The potential for hypoxic episodes in coastal waters causing fish kills
- Increased distribution of contaminants due to increased sediment disturbance
- A better understanding of the effects of salinity, temperature and pH change upon chemical contaminants and their potential impact on marine organisms.
- In addition to the issue of coastal pollution per se, there is the wider aspect of the combined impacts of climatic variability and other stressors, such as chemical and microbiological pollutants, and the impact this may have on species distribution. In this context:
    - More research is required to evaluate the interactions between climate change and contaminants to better understand and predict how on-

going and future climate changes may interact with anthropogenic impacts, including chemical and microbiological pollution.

- o Experimental studies and modelling efforts are needed to test various scenarios concerning transport, transfer and cycling of chemical pollutants and to assess the counteracting effects on important species including the impact on their well-being/fitness, and the potential effects on populations/ecosystems.

5. Socio-economic impacts

The potentially increased concentration of contaminants (such as ammonia, various organic chemicals and metals derived from CSO discharges) resulting from storm water inputs or due to reduced water flows may impact adversely on both commercial and recreational fisheries within estuaries.

Estuaries and other Transitional and Coastal waters are important nursery grounds for commercially important species, e.g. Bass, and unfavourable conditions through chemical intoxication could threaten commercial coastal fisheries and recreational sea angling.

Although shellfish have a greater tolerance to some contaminants they are inherently immobile and unable to avoid acute exposure. In addition the greater potential frequency of contamination of shellfisheries with sewage effluents, in particular the microbiological contamination, will mean that greater time and effort will have to be given to depuration of shellfish intended for consumption.

Salmonids are an important species with the recreational fishery also having a high social and commercial value (this issue is important because increased contamination of surface waters and their deoxygenation can influence fish avoidance well below lethal concentrations and may severely impact salmon runs in vulnerable rivers).

- There are over 12,000 full or part time fisherman in the commercial sector.
- The value of fish landed by UK vessels is £630m per annum of which about 20% -28% comes from the inshore fishery.
- The Scottish salmon farming industry is worth in excess £380m per annum.
- Although the landings of fin-fish have shown a steady decline over many years landings of key shellfish species (Nephrops, scallops and crabs) continue to rise.
- Cultivated shellfish total value for 2006 ~£23m to the UK economy (Shellfish Association, 2009).
- By comparison wild shellfish from near-shore intertidal and subtidal beds (cockles, mussels and oysters) have a relatively modest commercial value (although still >£6m per annum). The social value of these fisheries is much higher with many local communities having a long established affinity with fishing. The condition of many of these fisheries (Wash, South Wales, Morecambe Bay) is poor and although ammonia and other contaminants have not been identified as a key issue, any chemical stressors present could inhibit recovery (Shellfish Association, 2009).

The value of recreational sea angling is now approaching that of the commercial sector; a 2004 report estimated that recreational sea angling in the UK was worth £1,000m annually (PMSU, 2004).

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