MARINE CLIMATE CHANGE IMPACTS PARTNERSHIP: SCIENCE REVIEW

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Impacts of climate change on pollution (estuarine and coastal)

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EXECUTIVE SUMMARY

Climate change may alter physical and chemical processes increasing pollution of transitional and coastal waters. Drought conditions, particularly in the south-east of the UK will reduce surface runoff but also dilution of continuous discharges. Drier summers, but more extreme rainfall events, will exacerbate microbial delivery from livestock farming and combined 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 water and sediment contaminant bioaccumulation and toxicity to marine organisms, in some cases increased degradation and metabolism may reduce toxicity but in other cases increased stress may increase vulnerability.

It is uncertain if water quality change will affect resilient estuarine species or change ecosystem function. Climate change presents challenges to Competent Monitoring Authorities (CMAs) as chemical and microbial pollution of coastal waters has the potential to impact on ecological quality, health, economic resource utilisation and compliance with EU Directives.

To address gaps in knowledge model predictions can provide a context within which the magnitude of change in environmental impact from current activities or events, e.g. dredge disposal, storm overflows, thermal inputs can be evaluated and remediation planned for.

FULL REVIEW

1. WHAT IS ALREADY HAPPENING?

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

(i) Increases in storm sewer overflows following high rainfall - may contribute to deoxygenation and increased chemical and microbial pollution.

(ii) Increased surface runoff following high rainfall – may contribute to release to the marine environment of contaminants from land.

(iii) 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 pollution, and change in chemical behaviour.

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

Under the UKCP09 high emission scenario for the 2050s there is a predicted 50% probability of there being a 10-20% increase in winter precipitation across most of the UK. But 20-30% less precipitation is predicted in the south and south-west during the summer and therefore estuaries and coasts in these areas are likely to be at highest risk from conditions that arise under low summer flows. The climate projections for the high emission scenario are chosen here as the currently observed acceleration in emissions is tracking high-end emissions scenarios (Allison *et al*., 2009).

As our climate warms there is the likelihood of a reduction in snow accumulation in Scotland. Despite limited snow monitoring in Scotland, 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). It is unclear the reason for this, 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). 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.

Increased flooding can increase soil and sediment erosion, leading to the remobilisation of metals and persistent organic compounds (Dennis *et al.*, 2003; Whitehead *et al.*, 2008) and micronutrients such as manganese, which at higher concentrations are 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.

Any increased storminess will also increase the probability of contaminant remobilisation from sediments particularly on exposed coasts. Rising sea level in isolation is unlikely to increase total mobilisation of sediment, but may well mobilise new sources of sediment hitherto above the level of tidal influence with unpredictable consequences.

Sediment contaminants may also be released from terrestrial sources as a result of coastal erosion although under UKCP09, sea-level rise and storm surges that may contribute to increased coastal erosion are generally predicted to be less significant than was the case for UKCP02. However, recently reported data provide an example where coastal erosion has contributed to contaminant input to the marine environment. In May 2008 a coastal landslide deposited landfill debris onto the shore near Lyme Regis, UK. Six months later, the sampling and analysis of intertidal sediments and biota from the area showed elevated metal concentrations near the landslip zone and in several cases these exceeded Threshold Effects or Probable Effects Levels for six metals (As, Cu, Hg, Ni, Pb, Zn) and there were several instances of increased accumulation in marine molluscs (Pope *et al.*, 2011).

Remobilisation of sediments regardless of the presence of contaminants 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) and marine areas such as sea lochs e.g. Loch Creran (Almroth-Rosell *et al.*, 2012). This potential increase in chemical load and physical effects in estuarine and coastal waters will add further stress to exposed organisms.

Increased storm events producing combined sewer overflows can also lead to the greater mobilisation of some contaminants e.g. those associated with particulates but dissolved substances dependent on their source may be reduced in concentration compared to low flow conditions (e.g. see Neal *et al.*, 2000). The situation may be more complicated as the highest concentrations of some pollutants occur in the early part of a storm event the so called 'first flush' (e.g. Lee *et al.*, 2002) and so organisms are exposed to a pulsed exposure of pollutants. Conversely under reduced water flow during periods of drought, organisms in receiving waters will be exposed to relatively higher concentrations of chemical contaminants, e.g. priority pollutants from continuous point or diffuse inputs (Gasperi *et al.*, 2008).

Although chemical contaminants in storm overflows are of concern, the human pathogens present in combined sewer overflow (CSO) discharges have implications for disease transmission and ill health through consumption of shellfish (Lee *et al.*, 2003) and use of recreational waters (WHO, 2003). The dominance of storm events in the export of pathogens (and many other contaminants is now well established, Kay *et al.*, 2008a). 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.*, 2008b). 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). Any increased frequency in periods of more intense rainfall is expected to increase the export of microbial pathogens to surface waters. The impact of rainfall is demonstrated by the increased numbers of 'failing' bathing waters during the wet summers of 2011 and 2012 (Defra, 2012).

Change in physical factors such as temperature, and chemical factors such as dissolved oxygen, salinity and pH may also affect toxicity, mobility and fate of chemicals. For example ammonia is present in the aquatic environment in equilibrium between free ammonia (NH_3) and the ammonium ion (NH_4^+). Under all normal conditions the bulk of the ammonium encountered in estuaries will be as the ammonium ion (Clegg and Whitfield, 1995). Although both forms of ammonia may have adverse impacts, it is the unionised 'free' ammonia which exerts the main toxic impact to fish and other marine organisms (Eddy 2004). Higher pH (e.g. less acidic conditions) and temperature (an increase of 10°C has been shown to increase toxicity by a factor of four to some species (Kir *et al.*, 2004) 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.

Conversely for other chemicals a decrease in temperature can result 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.

The modulation of levels of dissolved organic carbon present in the aquatic systems, some as a direct result of climate change, may directly affect the bioavailability and toxicity of certain contaminants. Loss of soil organic matter reduces soil properties including the ability to retain pollutants and nutrients resulting in increases in pollutant load in run-off. The concentration of organic carbon in many Scottish rivers has approximately doubled over recent years, with soils being the most likely source (SEPA, 2009b). Most of the sites with increasing TOC were in the east of Scotland, but this reflects the distribution of sites sampled. However, no trend has been observed overall in the concentration of suspended solids in Scottish rivers (SEPA, 2011a). Increase in rainfall and extreme weather events might be expected to lead to increased suspended solid concentrations, but could have been counteracted by changes in water course management. In most regions of Scotland, winter flows and the frequency of high flow events have increased over the last decades (SEPA, 2011b). Thus, while total solid concentrations have not significantly increased, the data suggest an increase in the loading as flows have increased. The implications of this for contaminant and nutrient redistribution, specifically to estuarine and coastal locations, are unclear.

Potential changes in chemical and physical conditions under climate change also have 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 and, if that is not possible, it allows interim targets to be set for 2015 and 2021 with full compliance by 2027. 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 UK environmental agencies use many chemical standards, derived both internally and externally, to help protect the environment. Some of these standards could potentially be adversely influenced by climate change (during either the standard derivation or the compliance monitoring phases). The results of a scoping study conducted by the Environment Agency (2003) suggest that the way in which chemical standards are currently set in the EU is already likely to take into account the range of climate changes predicted (at least under UKCIP02 scenarios). However, a case study for EQS compliance monitoring in rivers shows that many more samples may need to be taken to maintain current levels of confidence that chemical standards are not breached.

More recently, much effort has taken place on harmonising European methods to support research on emerging pollutants in view of potential climate change (Schwesig *et al*., 2011). The NORMAN (Network of Reference Laboratories for Monitoring and Bio-monitoring of Emerging Pollutants) is an EU initiative (funded from 2005, but self-sustaining from 2009) that recognises the increasing impact of climate change on the distribution, transformation and toxicity of environmental pollutants. The ultimate aim of NORMAN is the development of a framework for analytical method validation to enable reliable monitoring and bio-monitoring of emerging pollutants.

Climate change research

The potential influence of climate change upon chemical pollutants has been considered in a number of reviews. Noyes *et al.* (2009) considered interactions of chemicals with biota and the influence of increasing temperature, changing precipitation patterns and salinity. Climate change induced-toxicological effects include increased uptake by biota, increased elimination, remobilisation of bioaccumulated POPs, increased toxicity, increased metabolism and potential increased detoxification (synthetic pyrethroid pesticides) or more toxic metabolites (organophosphate pesticides), increased salinity and associated increased bioavailability of pesticides/POPs (i.e. the half-life of malathion is known to increase with increasing salinity, (Song and Brown, 1998)). The review also reports that solvent switching and solvent depletion processes involve the partitioning of POPs from water to phytoplankton and zooplankton, followed by bioaccumulation and biomagification up the food chain (Braune *et al*., 2005). It is concluded that effects on toxicants are very likely to be non-linear and predicting thresholds and tipping-points are likely to be an important focus of future research.

Hooper *et al.* (2013) discuss climate-induced toxicant sensitivities (CITS) and the complexity of interactions between climate change and the array of chemical stressors on biota, highlighting that climate change could also act at multiple trophic levels by multiple toxicological pathways. Amongst many, potential effects included ultra-violet-photo-activated toxicity of PAHs in sunnier environments, increased toxicity of pesticides with increasing salinity associated with changing pesticide usage and drier summers, and the relationship between warming, increased runoff, contaminants and hypoxia. The use of mechanistic toxicology to assess climate change risks is encouraged and adverse outcome pathways (AOPs) are specially highlighted. It is acknowledged that toxic mechanisms tend to be shared across chemical classes and also that biological acclimation mechanisms are generally shared across similar taxonomies. Environmental toxicologists and risk assessors are encouraged to recognise the potential of AOP constructs to facilitate the refocusing and prioritisation of regulatory efforts, research agendas and conservation planning.

There is also evidence to support a change of water-monitoring strategies to focus on analytical methods for biota determination (Carere *et al*., 2011). Climate changes have the potential to enhance the bioavailability of dangerous pollutants with bioaccumulative properties with an increasing risk of transfer in the food chain. Mercury is a key compound because it accumulates in organisms as methylmercury. Environmental factors such as temperature, pH, salinity and DO will all modify the transformation and bioavailability of mercury. The development of Biota standards under the EU Commission proposal (COM(2011)876) will help to address any changing trends in the accumulation of priority substances.

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).

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, 2007-2008). 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. Some authors consider invasive species as biological pollutants (Elliott, 2003) as a number of introductions have altered 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. The direct impacts of non-native species are considered in detail in the relevant 2013 MCCIP report (Cook *et al*., 2013).

It is important to understand how climate change may influence water quality, but predicting the effects of this is particularly difficult for estuarine and coastal areas because of the wide range in natural variability in hydrology, chemistry and ecology. Species in estuaries typically tolerate wide ranging conditions of temperature, salinity and other factors and are therefore resilient to much of the climate driven change and it is uncertain whether species level change will in any case affect functioning (e.g. Elliott and Quintino, 2007). The lower diversity of species present in estuaries may however mean that there is a limited pool of species from which to draw should extreme conditions result in the loss of only a few species (Elliott and Whitfield, 2011).

A number of projects are now underway that attempt to provide a better understanding of the interaction of climate change and the response of species and communities to that change: e.g. the EU project DEVOTES (http://www.devotes-project.eu/) aims to improve the understanding of human activities impacts (cumulative, synergistic, antagonistic) and variations due to climate change on marine biodiversity, using long-term series data (pelagic and benthic). A major aim of the programme is for monitoring and assessment strategies to identify good indicators for assessment at species, habitats and ecosystems level, for the status classification of marine waters.

The EU programme VECTORS (http://www.marine-vectors.eu/) is addressing invasives, outbreaks and changes in fisheries distribution and productivity - in a sea with changing pressures including marine renewables, climate change, ocean acidification, fisheries and shipping.

The EU project KNOWSEAS (http://www.knowseas.com/) aims to provide a comprehensive scientific knowledge base and practical guidance for the application of the Ecosystem Approach to the sustainable development of Europe's regional seas.

2. WHAT COULD HAPPEN?

(i) Reduced frequency of summer rainfall in UK western and northern areas could lead to improvements in seawater quality in associated bathing waters.

(ii) Higher temperatures- increased uptake/stress/toxicity in some cases increased degradation? *Increased release of contaminants from sediments? Slightly stronger and considerable longer stratification* (UKCP09).

(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 bioavailable leading to accumulation by marine organisms. Recent data indicate the potential for increased stress from reduced pH resulting in increased mortality and sublethal biological effects when in combination with elevated metal concentrations in sediments.*

(iv) Increased coastal erosion causing pollution to enter the marine environment; either new sources or legacy issues - *contaminated sediments and land, near coastal landfills.*

The impact of changed rainfall patterns will not impact all parts of the UK equally. In UK western and northern bathing water sites, the frequency of summer rainfall events is predicted to decrease under current climate change scenarios (Kay *et al.*, 2011). It is conceivable, therefore, that a 'health gain' attributable to sea bathing exposures will be observed as the current century unfolds. However, the precision of all such assessments is constrained by the paucity of data on usage rates and activity patterns at EU bathing sites. No parallel assessment of risk from shellfish harvesting waters has, to date, been undertaken which would need to consider the full annual pattern of rainfall-induced water quality impairment and, thus, consider the projected winter increase in storm events for most UK regions (see the 2013 MCCIP report on bathing and shellfish waters, Wither *et al.*, 2013).

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. In the longer term such pH changes have significant consequences for calcifying organisms due to decreases in specific mineral concentrations, however, 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. Climate change and ocean acidification interactions with aquatic toxicology are reviewed by Nikinmaa (2013). The toxicity of weak acids and bases varies markedly with their dissociation status and the uptake of chemicals in organisms depends mainly on their lipophilicity, which is much higher for the acid form than base form. Acidification may also reduce organism' tolerance to a number of other environmental factors including pollutants (Widdicombe and Spicer, 2008). Whilst it is recognised that there are multiple potential interactions between toxicants and ocean acidification, it is not known if such interactions actually occur (Nikinmaa, 2013). Recent experimental studies conducted under simulated ocean acidification (based on predictions for 2100 onwards) demonstrate increased DNA damage and mortality in burrowing amphipods exposed to contaminated sediments from a dredging disposal site off the Tees Estuary (Roberts *et al.*, 2012). Although higher metal concentrations were measured in the sediments from the disposal site, the metal flux from these and control sediments was similar under simulated ocean acidification and the authors hypothesised that additional stress due to acidification in combination with exposure to the metals in the sediments is primarily responsible for the biological effects observed. Increasing temperatures may also enhance biodegradation of contaminants and therefore reduce pollution impacts. Therefore acidification and warming effects must be considered in combination and are of relevance to future adaptation research.

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 not known.

3. KNOWLEDGE GAPS

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/SEPA 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 affects 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:

a. 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 microbial pollution.

b. 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.

c. A better understanding of the resilience of organisms and communities to the different physical and chemical interactions likely under climate change and the translation of this community level; and to ecosystem functioning.

4. 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 and in the future the potential combined stress of decreased pH and pollution. 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 commercial species with the recreational fishery also having a high social and commercial value: 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 12,400 full or part time fisherman in the commercial sector (UK Sea Fisheries statistics, 2011).

In 2011, the value of fish landed by UK vessels (in UK and abroad) was £828m (UK Sea Fisheries statistics, 2011).

The Scottish Atlantic salmon farming industry is worth in excess £585 m/yr.(Scottish Government Facts and Figures)

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 e.g. development of velvet crab fishery in Scotland http://www.scotland.gov.uk/Publications/2012/05/9899/22, and off the North-East coast of England

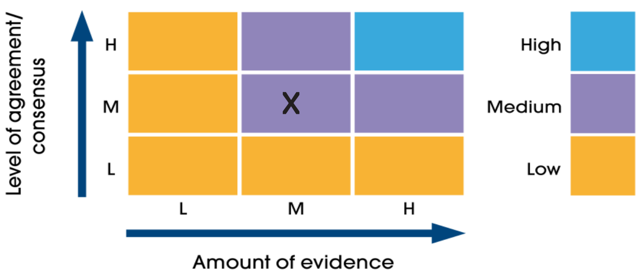
Cultivated shellfish total value for 2006 ~£23m to the UK economy (SAGB, 2007)

By comparison wild shellfish from near-shore intertidal and subtidal beds (cockles, mussels and oysters) have a relatively modest commercial value (although still >£6m /yr). 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 (SAGB, 2007).

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).

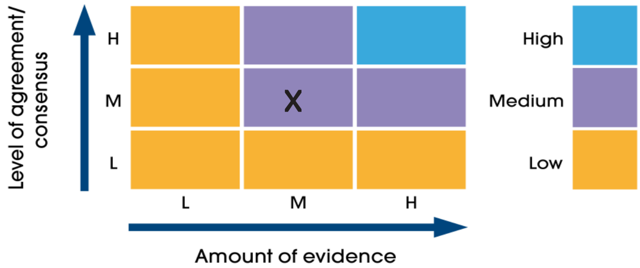
5. CONFIDENCE ASSESSMENTS

What is already happening?



In some areas our current understanding, using the inputs, behaviour and impact of ammonium as an example, is reasonably good and would warrant a higher value for evidence and consensus. This is also the case for microbial pollution 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. In particular our knowledge and ability to extrapolate the effects in single species studies to higher levels of biological organisation (population, community, ecosystem) is not good.

What could happen?



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.

CITATION

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