MCCIP ARC Science Review 2010-11
Shallow and shelf subtidal habitats and ecology

SILVANA BIRCHENOUGH[1] AND JULIE BREMNER[1]

WITH CONTRIBUTIONS FROM PETER HENDERSON[2,3], HILMAR HINZ[4], STUART JENKINS[4], NOVA MIESZKOWSKA[5] AND JEROEN VAN DER KOOIJ[1]

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

[2] Pisces Conservation Ltd., IRC House, The Square, Pennington, Lymington, Hants.

[3] University of Oxford, South Parks Road, Oxford. OX1 3PS, United Kingdom.

[4]School of Ocean Sciences, University of Wales, Bangor, Menai Bridge, Anglesey, LL59 5AB.

[5]The Marine Biological Association of the UK, Citadel Hill, Plymouth, PL1 2PB

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EXECUTIVE SUMMARY

- There is evidence that climatic processes influence species abundance and community composition in soft-sediment habitats in the North Sea. There is no obvious signal of warming effects in sediments in southern and south-western areas where changes would be most expected. However, changes in crustacean abundance in some locations and the occurrence of previously undocumented species in others (e.g. brittle star *Amphiura incana* and shrimp *Athanas nitescens*) suggest some degree of climate-influence.
- Hard-substrate habitats in southern and south-westerly waters appear to be affected, with disease outbreaks in seafans, changes in algae distribution and abundance and the appearance and increased occurrence of a previously unrecorded warm-water barnacle all linked to increased seawater temperatures.
- Climate change is likely to impact the benthos in future. The changes documented in soft-sediment communities are expected to continue, and probably escalate, in response to the cumulative effects of seawater warming and ocean acidification. Species forming cold-water coral reefs and maerl beds may experience shifts in distribution as a result of intolerance to altered seawater temperature and chemistry, with knock-on effects on community composition and function.
- Future impacts on these habitats are likely to have socio-economic ramifications, as cold-water coral reefs and maerl beds are protected under European legislation and soft-sediment communities are an important food resource for commercial fish.
- There are knowledge-gaps in a number of areas. We are currently unable to fully assess the scale of benthic species and community responses in relation to climate change, understand links between impacts in benthic and pelagic systems or model future species distributions. An appropriate benthic monitoring and assessment programme, coupled with continued involvement in international initiatives, is essential for characterising climate impacts in UK benthos.

FULL REVIEW

Scope of the report

This report summarises evidence of current and future climate change effects on shallow and shelf subtidal habitats and ecology. It covers algae and invertebrates (with the exception of non-native species and those subject to commercial fisheries) on soft- and hard-substrates.Fish, fisheries and non-native species are considered in separate MCCIP Annual Report Card (ARC) Science Reviews (Pinnegar & Heath 2010; Pinnegar *et al.*, 2010; Maggs *et al.*, 2010). Seagrasses extend in most cases to subtidal systems, but these habitats are predominantly connected to the intertidal. Therefore, they are dealt with in the Intertidal Habitats and Ecology MCCIP ARC Science Review (Mieszkowska, 2010). The information in the report represents documented evidence available to the authors at the time of writing and relates to UK and in some instances, neighbouring waters (e.g. German and Belgian North Sea waters, Irish Atlantic waters) to provide a wider perspective of the current status of benthic species and habitats in relation to climate change.

Section 1 (*What is already happening?*) is structured around the UK Charting Progress Regions and summarises evidence available for different habitats in each region. Where the available evidence relates to more than one region, these regions are grouped together. Section 2 (*What could happen in the future?*) is based on indirect observational and experimental evidence largely applicable across regions. It is, therefore, structured by species- or habitat-type.

Climate change may influence shallow and shelf subtidal habitats and ecology by a number of mechanisms, including seawater temperature change, increased incidence and severity of storms, changing salinity and oceanographic patterns, sea-level rise and ocean acidification. The present report focuses on seawater temperature change and ocean acidification, as the bulk of the evidence currently available (mainly based on peer-reviewed literature) relates to these two factors.

1. What is already happening?

The North Sea: *Charting Progress Regions 1 (Northern North Sea) and 2 (Southern North Sea).*

Trans-regional patterns: North Sea soft-sediment benthos

Current efforts to describe benthic changes in relation to climate change and its effects are widely scattered across UK waters. There is detailed time-series information available for site-specific areas. Whilst these efforts have merit on their own right, it is also clear that these temporal data-point sources only provide assessments over small areas therefore their relevance to the wider picture is unclear. Documented changes in the North Sea ecosystem that occurred from the late 70s may have been influenced by warming sea surface temperature. Those changes were recorded mainly in the plankton but there are clear links to the benthic communities. Research has found evidence that the benthic community structure in the western North Sea (north east coast of England) and the eastern North Sea (Skagerrak) displayed a transition in the late 70s (Edwards *et al.*, 2002). Similarly, there was also a transition between the 70s and 80s in the holoplanktonic fraction of the zooplankton community from the western and eastern North Sea (Austen *et al.*, 1991; Evans & Edwards, 1993). These observations concord well with an increase in planktonic biomass and extent of the plankton periods (mainly flagellates) in the German Bight (Radach, 1990). Furthermore, climate-focused research in pelagic ecosystems in the North Sea (Kirby *et al.*, 2007, 2008, 2009) has provided clear links to the benthic systems when climate change is the common cause of these effects.

Long-term analysis of the North Sea pelagic system has identified yearly variations in larval abundance of the benthic phyla Echinodermata, Arthropoda and Mollusca in relation to sea surface temperature (SST). Furthermore, the larvae of benthic echinoderms and decapod crustaceans have shown an increase since the mid 1980s that accords with the rise in SST in the North Sea, while bivalve larvae have decreased (Kirby *et al.*, 2008).

Overall, it is clear that uniform benthic monitoring and assessment is needed to characterise species distributions and responses in relation to climate change in UK waters. Current UK efforts to document status and change of benthic assemblages have prompted research scientists to collaborate on a number of initiatives (e.g. MECN, MCCIP). As well of gathering information, the storage of data is also being facilitated by initiatives such as (MEDIN) and the UK National Biodiversity Network. In addition to these clear initiatives, there is also important to acknowledge the value of observations collected by naturalists. The value of these opportunistic observations can help as initial evidence for future assessments in relation to species distributions and responses for climate change investigations. Internationally, the International Council for Exploration of the Sea (ICES) via the North Sea Benthos Project and Study Group on Climate related benthic processes in the North Sea are proving a fora for scientists to conduct benthic communities assessments over larger spatial scales than those typically achievable by national initiatives alone and are, thus, vital for understanding responses to change in multi-nation bounded waters such as the North Sea.

Northern North Sea (Region 1): Soft-sediment benthos

The northern North Sea is influenced mainly by the influx of deep Atlantic water (Reiss & Kröncke, 2004). The area has been intensively studied for decades; examples of early pioneer work relates back to Petersen (1914, 1918), who assessed the distribution of macrobenthic soft sediment fauna. This work has enabled research scientists to continue with long-term assessments to monitor status and change in the region's macrobenthos.

Early work conducted by Buchanan, in 1963, was marked by the commencement of the 'Dove Time series', at stations M1 and P, off the north-east coast of the UK. These assessments were undertaken to understand benthic communities in relation to environmental conditions and human activities in the area. In this area climate change has been implicated in the changes documented by rising total numbers and biomass in the benthic communities at station M1, which have been mainly attributable to a combination of effects of climatic variation, which was caused by: biological interactions, winter temperature (a combination of 'cold water' and 'warm winter state') and carbon flux to the benthos.

Warmer seawater temperatures during winter periods together with phytoplankton supply have been suggested as causal for instability of benthic communities (Buchanan & Moore, 1986a, b; Buchanan *et al.,* 1986) at station P. Clear changes were observed in relation to dominant species (i.e. general rise in number and biomass of infaunal benthos) which were attributable to climatic events. Further work conducted by Frid *et al.,* (2009a) in the same area have described the benthic community changes in relation to fishing impacts, but also identified additional influences on the benthos to be a combination of phytoplankton supply and climatic warming effects.

Another study conducted by Rees *et al.,* (2006) linked reduced density and species richness to warm winter temperatures. Benthic communities of the former sewage sludge disposal site in the area of north-east England (stations located in the proximity of the Dove Time Series station M1) showed a clear temporal correlation between benthic macrofauna and winter values of the NAO index for the preceding year. This represents a pattern of response for benthic assemblages composed of many taxa with a more northern (cold water) distribution in the absence of compensatory increases in those with more southerly associations.

Southern North Sea (Region 2): soft-sediment benthos

The information compiled in this section is part of extensive work conducted by European colleagues. Currently there is no available research in this area being conducted under UK auspices.

Climatic factors most likely play a dominant role in structuring macrobenthic communities in the North Sea, principally in the winter and spring (Dippner & Kröncke, 2003). Research has also demonstrated that macrofaunal communities are severely affected by cold winters, whereas storms and hot summers have no direct impact on the benthos (Kröncke *et al.*, 1998). Studies in the Southern North Sea demonstrated that macrofaunal communities were sensitive to a combination of hydrographic effects and also affected by temperature changes. These effects showed alteration in species number, abundance and biomass of the coastal macrobenthos (Kröncke *et al.,* 1998). Studies targeted on the effect of severe winters in long-term variability of benthic macrobenthos from the German Bight to the Dogger Bank reflected that benthic communities are mainly influenced by winter temperatures and storm frequencies (Kröncke *et al*., 1998, 2001; Schröeder, 2003).

The bivalve mollusc *Abra alba* has shown significant changes in abundance related to mild (high numbers) and cold (low numbers) winters (Fromentin & Ibanez, 1994; Van Hoey, 2007), which seems to coincide with the regime shift observed in the North Sea in 1998 (Kröncke *et al.,* 1998; Reid *et al.,* 1998, 2001; Weijerman *et al.,* 2005). The observed patterns tend to concord with the changes in the hydroclimatic state of the North Sea, caused by variability in the NAO. However, there is no indication of a trend that might be the result of long-term warming.

Southern and south-westerly waters: *Charting Progress Regions 3 (Eastern English Channel) 4 (Western English Channel, Celtic Sea and South-West Approaches) and 5 (Irish Sea and North Channel)*

Trans-regional patterns: Soft-sediment benthos in the Channel

The western English Channel is located at the biogeographic boundary between northern Boreal and southern Lusitanian fauna and has, therefore, served as an important area for monitoring the effects of climate change on marine organisms. While the consequences of a changing climate have been relatively well documented in the Channel for fish, plankton and intertidal benthos (see, for example, Genner *et al.,* 2004; Hawkins *et al*., 2008; Beaugrand *et al*., 2009), no such data exist to-date for subtidal benthic organisms. During the 1950s, Norman Holme sampled benthic infaunal and epifaunal communities on a large geographical scale spanning the entire English Channel (Holme, 1961, 1966). In particular, Holme was interested in the distribution of warm- (Lusitanian) and cold-water (Boreal) species. Holme's and his colleagues' early surveys uncovered variations in penetration of 'western' species (those normally inhabiting the Celtic Sea and likely to be cold-water species) into the Channel and possible temperature-related penetrations of 'Sarnian' species from the Gulf of St. Malo into wider areas of the Channel, as well as fluctuations caused by mortality during severe winters (Holme, 1983).

Part of Holme's benthic survey was revisited in 2006, covering a large extent of the Channel coast (Hinz & Jenkins, in prep). The main aims of this resurvey were to describe the current status of benthic communities and compare the data to the historic survey to investigate potential changes in the communities. Comparison of the 1950s and 2006 surveys showed benthic species distributions remained similar, in general, with little or no obvious trends consistent with warming sea temperatures. The eastward movements of Lusitanean species that have been observed in some intertidal fauna were not generally reflected in the subtidal benthos, although some additional species not documented by Holme in the 1950s were observed, such as brittlestar *Amphiura incana* and the shrimp *Athana nitescens*. Comparisons between historic and contemporary datasets can be complicated by methodological constraints and fishing is likely to have exerted an influence on the benthic communities in the western Channel (Capasso *et al.,* in press), making it difficult to separate causal factors. Nevertheless, the area is a biogeographic boundary where (arguably) temperature-driven distribution changes are most likely to be displayed and there is ample evidence of change for other species groups, so the observation of additional benthic species in the 2006 survey suggests that further work in this area would be beneficial.

Trans-regional patterns: Hard substrates in the Channel and South-West Approaches

i. Seafans

Climate change effects may also be implicated in reductions in fitness in seafans around the south-west of the UK (www.ukbap-reporting.org.uk). During 2003-2006, Hall-Spencer *et al.,* (2007) reported widespread incidence of disease outbreaks in the pink sea fan *Eunicella verrucosa* at sites around Lundy and from Lyme Bay to Plymouth. Laboratory analysis of colony clippings showed water temperatures of 15 °C had no effects, while temperatures of 20 °C induced disease symptoms. Although recovery has been noted at several sites, there is circumstantial evidence that the disease-induced necrosis has resulted in a loss of structural integrity and increased incidence of fouling on diseased seafans (Hall-Spencer *et al.,* 2007). However, temperatures of 20 °C are outwith the maximum experienced naturally by *E. verrucosa* and other environmental factors may play an important role in inducing stress and vulnerability to disease (SPLASH, 2008). There is currently insufficient evidence to confirm the presence or extent of a link between seawater warming and disease incidence, though it is an area that would benefit from further investigation.

ii. Barnacles

The warm-water barnacle *Solidobalanus fallax* has been increasing in occurrence along western European coasts in recent years, thought to be the result of rising seawater temperatures (Southward *et al.,* 2004). *S. fallax* was first recorded in UK waters in 1995, on scallop shells in the western Channel (Southward, 1995). It does not appear to have been described in Europe prior to this, with records limited to Atlantic and north-western coasts of Africa. However, it is difficult to distinguish from related species, so may have been present but recorded as, for example, *Balanus crenatus*.

A 2004 review of distribution records indicated that *S. fallax* has increased significantly around the south and south-west of the UK (Southward *et al.,* 2004). It appears to have become widespread off Devon and Cornwall and has now been recorded from Dorset, Lundy, the Gower Peninsula and Pembrokeshire. The barnacle settles on living and inert substrates and is often found on plastic discards, suggesting that these items may provide a vector for its spread along the southern British Isles (Southward *et al.,* 2004). In this context, seawater warming and increased incidence of plastic discards may have interactive effects on the spread of the barnacle, the plastics providing a transport vector and increased temperatures providing environmental conditions suitable for establishment.

The spread of *S. fallax* and the occurrence of disease in the seafan *E. verrucosa* may be related. The barnacles appear to utilise *E. verrucosa* as a preferential settlement substrate and high proportions have been found colonising diseased seafan skeletons (Hall-Spencer *et al.,* 2007). It is possible that outbreaks of disease have led to increased barnacle settlement and, in turn, further impacts on seafan fitness through impaired ability to repair damaged skeletons. However, such complex and inter-related effects are difficult to establish and remain, in the absence of experimental or observational evidence, purely speculative.

iii. Algae

Effects of increasing seawater temperature can also be seen in algal communities from southern and south-westerly waters. Boreal macroalgae are showing a continual decline in abundance in shallow subtidal zones around the south coast of England, whereas Lusitanian species are increasing in abundance and relative dominance is switching to warm-water species in the Western English Channel and Celtic Sea (unpublished analyses of the MarClim project dataset 2002-2010, www.mba.ac.uk/marclim; see also Mieszkowska *et al.,* 2006). The boreal species *Alaria esculenta* continues to show declines in abundance in shallow subtidal zones around the Western English Channel, close to its southern range limit (Vance 2004, MarClim data - 2002-2010). The Lusitanian kelp *Saccorhiza polyschides* has rapidly increased in abundance in this region over the last few years and is displacing cold water Laminarians over large areas of the intertidal. There is currently insufficient evidence to ascertain whether *S. polyschides* is also displacing Laminarians below the low-water mark, but the distinction between species' intertidal and subtidal populations is somewhat artificial and it is not unreasonable to suggest such effects are also occurring subtidally.

Western Channel, Celtic Sea and South-West Approaches (Region 4): Severn Estuary crustacea

There is evidence of climate-related effects on crustaceans in the Severn Estuary. Standardised long-term monthly sampling has been undertaken for the past 30 years at Hinkley Point in Bridgwater Bay, with 15 macro-crustacean species captured to-date (Henderson & Bird, in press). In addition, monthly plankton samples are taken to monitor changes in isopods, amphipods, cumaceans and mysids. Henderson *et al.,* (2006) found strong evidence for density-dependent control and a positive correlation with average seawater temperature between January and August in the common shrimp *Crangon crangon*. Henderson and Bird (in press) reviewed the population dynamics of the macro-crustaceans and found the species show considerable changes in annual abundance. Three of the most numerous, *C. crangon*, the pink shrimp *Pandalus montagui* and the Atlantic prawn *Palaemon serratus*, have been increasing approximately exponentially since the early 1990s. There have been recent notable increases in the abundance of the velvet swimming crab *Necora puber* and the sardine crab *Polybius henslowii*. Coincident with this increase has been a decline in the abundance of the shore crab *Carcinus maenus*. There have also been notable recent increases in the abundance of the mysids *Schistomysis spiritus*, *Gastrosaccus spinifer*, *Mesodopsis slabberi* and *Neomysis integer*. These changes can, in part, be related to increases in water temperature, particularly an increase in the winter temperature minimum and variation in the NAO. There have been appreciable changes in seasonality and population age structure correlated with changes in water temperature. Variation in salinity is also an important factor associated, in turn, with rainfall, river-flow and the NAO.

Western and northern waters: Charting Progress Regions 6 (West Scotland including the Minch), 7 (Scottish Continental Shelf) and 8 (Atlantic North-West Approaches, Rockall Trough and Faroe/Shetland Channel)

We are not aware of any current evidence of climate-related effects on shallow and shelf habitats and species in these regions.

2. What could happen in the future?

Changes may be expected in a range of seabed systems, particularly those tightly linked to phyto- and zooplankton communities impacted by future climate change. However, there is a severe lack of empirically-based prediction for UK subtidal species and habitats. Shallow and shelf habitats and species are most likely to be affected by changes in SST, near-bottom temperature and stratification patterns, as well as changes to ocean chemistry from increased uptake of CO_2. Acidification effects are summarised here in relation to potential associations with temperature-driven climate impacts. A detailed review of the effects of ocean acidification is presented in the 2009 MCCIP Ecosystem Linkages Report Card on CO_2 and ocean acidification (Turley *et al.*, 2009). Predictions of future change are based on the UKCP09 climate projections medium emissions scenario (Lowe *et al.,* 2009).

UK soft-sediment benthos

Benthic responses to climatic change may be observed to differ when assessed across spatial scales and, even locally, some effects will be ‘masked' by a series of other factors. Specific parameters (i.e. NAO index, SST) might provide rapid signal of change on benthic communities inhabiting shallow waters, when compared with their counterparts in deeper waters (Rees *et al.,* 2007). SST for regions 1 and 2, are predicted to rise by up to approximately 3.0 °C and 3.5 °C for summer conditions in 2070-2098, respectively (relative to the 1961-1990 average). In contrast, SST the winter scenario only shows an increase of approximately 2.8 °C in area 2. Benthic communities are likely to be responsive to changes in temperature and stratification. Schöne *et al.,* (2003) have demonstrated temperature influences in annual shell growth of live collected *Artica Islandica* in the North Sea. During warmer winters, stratification and bottom water currents seem to be stronger, thus preventing downward mixing of nutrients as well of settlement of food particles on the seabed. In contrast, during cold winters, the stratification weakens and phytoplankton produced in the cold surface layers reaches the seafloor. Growth of the shell of *A*. *Islandica*, seems to be directly connected to fluctuations in the NAO, so future warmer winters may continue to produce similar effects in their shell growth. Beukema *et al.* (2009) postulated that understanding the overall effects of temperature on benthic communities will be a difficult task when they are studied in relation to recruitment, mortality and individual weight (with repercussions for abundance and distribution of species). A warming climate may be directly observed in chronic effects and physiological stress and/or indirectly in alterations to specific benthic functions (e.g. predation, competition, etc). Thus, future effects are difficult to predict for the complex biological communities inhabiting soft-sediment systems.

Any changes resulting from seawater warming are likely to operate within the context of a chemically-stressed environment, as seawater uptake of CO_2 leads to increasing ocean acidification. The potential effects of ocean acidification on subtidal soft-sediment fauna are detailed in Turley *et al.,* (2009). Studies of benthic species from UK waters have shown that short-term exposure to low-pH environments seems to have relatively little effect on the polychaete *Nereis virens*, the crab *Necora puber,* or the echinoderm *Amphiura filiformis* (Spicer *et al.,* 2007; Widdicombe & Needham 2007; Wood *et al.,* 2008). However, long-term fitness may be compromised by short-term acclimation responses (Wood *et al.,* 2008) and there is evidence that reduced pH may impact on biologically-mediated benthic nutrient cycling (Widdicombe & Needham 2007; Widdicombe *et al.,* 2009). In addition, evidence from comparable benthic communities in other northern European waters suggests that acidification may impact on the overall diversity of benthic communities, affecting both species composition and abundance (Widdicombe *et al.,* 2009). Such changes are likely to be habitat-specific, with sandy communities appearing more sensitive than those in muds (Widdicombe *et al.,* 2009). Although acidification effects in soft sediments are likely to interact with those of changing temperature and stratification patterns, the cumulative effects of multiple climate-driven changes are, as yet, unknown.

***Lophelia pertusa* reefs in northern and north-western waters.**

While shallow southern and south-eastern UK waters are predicted to show the greatest increases in SST and near-bottom temperatures under the UKCP09 projections, deep-water habitats to the north and north-east of the UK may also be impacted by seawater warming. The scleractinian cold-water coral *Lophelia pertusa* forms biodiverse and functionally-important deep-water reef habitats. The majority of the world's *Lophelia* reefs are concentrated in the North Atlantic (Guinotte *et al.,* 2006) and they are represented in UK waters in northern and western Scottish waters (Charting Progress regions 1, 6, 7 and 8). These habitats are in decline in OSPAR regions I-III and V, caused primarily by the damaging effects of bottom fishing (Hall-Spencer & Stehfest, 2008). However, they are also likely to be vulnerable to climate change. Recent modelling work has linked their distribution to temperature (Davies *et al.*, 2008) and *Lophelia* from the Mingulay reef complex, off the Scottish west coast, has shown sensitivity to changes in water temperature of as little as 2°C (Dodds *et al.,* 2007). Near-bottom temperatures in regions 1, 6 and 7 are predicted to rise by approximately 2-2.5°C in 2070-2098 (relative to the 1961-1990 average). Reefs in region 6 may experience summer temperatures in the region of 15-16°C, some 2-3 degrees warmer than their upper required temperature of 13°C (Hall-Spencer & Stehfest, 2008). Bottom temperatures in region 8 may increase by up to 1°C from 2070-2098, so reefs in this area - which include the majority of UK records - are less likely to be impacted than those in regions 1, 6 and 7. The effects of increased temperature may be compounded by further impacts related to seawater acidification. *Lophelia* reefs are thought to be limited, in part, by seawater aragonite saturation (Guinotte *et al.,* 2006) and projected decreases in saturation due to increased CO_2 uptake may lead to impacts on growth and increased vulnerability to dissolution (Davies *et al.,* 2007). These changes will also occur in the context of changing oceanographic conditions, which could affect pelagic productivity and food supply to deep sea habitats such as the *Lophelia* reefs (Hall-Spencer & Stehfest, 2008).

Maerl beds in southern, western and north-western waters

Maerl, species of detached coralline red algae, may be vulnerable to future climate impacts. Of the three major European maerl-forming species, two appear to be limited by temperature in UK waters, with *Lithothamnion glaciale* confined to Scotland and Northern Ireland and *Lithothamnion coralloides* reaching only as far north as the south-west of the British Isles (Birkett *et al.,* 1998). *L. coralloides* from the west coast of Eire have been shown to respond positively to a 4 °C increase in temperature (Blake & Maggs, 2003), suggesting the species may benefit from warming waters. Maerl beds are rare in England and Wales, but there are isolated occurrences in

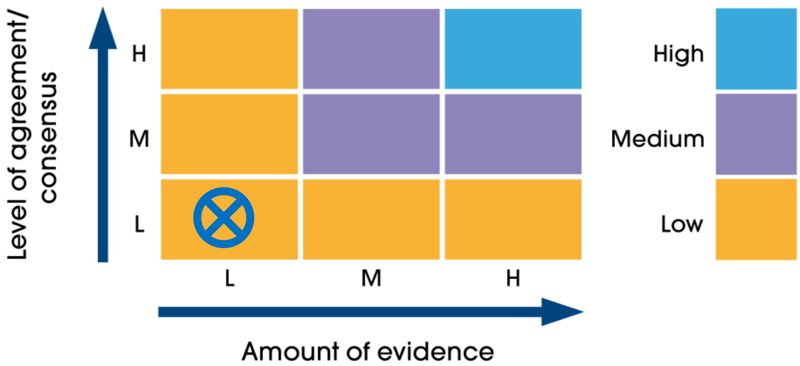
Dorset, Cornwall, Pembrokeshire, the Lleyn Peninsula, the Isle of Man and around Lundy (Hall-Spencer *et al.,* 2008). *L coralloides* in these areas may benefit from the near-bottom temperature increases of up to approximately 2.5-3.5 °C forecast for Charting Progress regions 3, 4 and 5 in 2070-2098. Such increases could facilitate the spread of *L. coralloides* to further locations along the south and south-west coasts of England and Wales, although expansion would also be limited by the suitability of other factors such as water movement and salinity (Wilson *et al.,* 2004).

The temperature-response of *L. glaciale* is not currently known although, as its southern limit is thought to be western Scotland and coasts of Eire, the near-bottom temperature increases of up to approximately 2-3°C forecast for regions 5, 6 and 7 in 2070-2098, could be expected to lead to a reduction and possible exclusion of *L. glaciale* from parts of these areas. Maerl is most commonly found in the northern parts of the UK, including the west coast of Scotland, the Western Isles, Orkney and Shetland (Charting Progress regions 6 and 7, Hall-Spencer *et al.,* 2008), so temperature-related changes in these regions would affect a large proportion of the UK's maerl beds. The third major European species, *Phymatolithon calcareum*, is found from southern Norway to the Mediterranean and does not appear to be susceptible to short-term increases of temperature in UK and Irish waters, although longer-term effects may only be evident after periods of acclimation (Blake & Maggs 2003; Wilson *et al.,* 2004).

Given the different temperature preferences of the individual maerl species, climate-related effects could be manifest as either overall changes to the biomass of maerl in UK waters or alterations in the relative proportions of the three major species. Such effects may have secondary implications for diversity of the biological communities inhabiting the habitat, as maerl beds host a diverse assortment of flora and fauna including rare species and some that may be endemic to the locale (Hall-Spencer *et al.,* 2008). Maerl are calcifying organisms, so predictions of changes in response to temperature must be viewed in the context of the interacting and, potentially, confounding effects of ocean acidification. Acidification effects have been noted in other coralline algae and benthic calcifiers (Kleypas *et al.,* 2006; Hall-Spencer *et al.,* 2008). Changing ocean chemistry may threaten the growth and integrity of maerl matrices, with knock-on effects on associated biological communities. Maerl contribute to calcareous sediment production and seawater pH balance (Hall-Spencer *et al.,* 2008), so dissolution of their carbonate skeletons would likely have implications for ecosystem function.

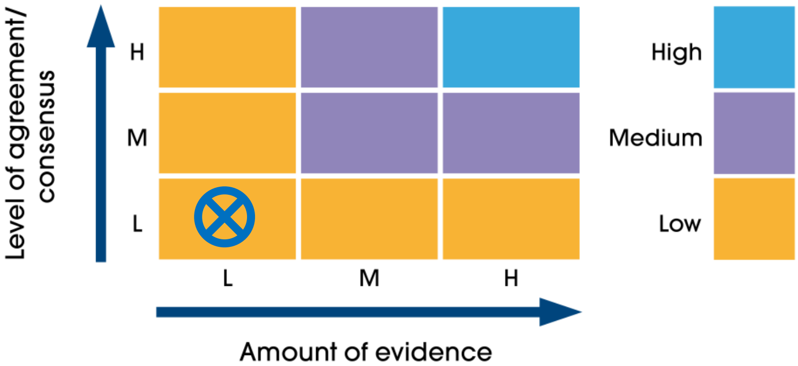
3. Confidence in the science

What is already happening: **Low**



Site-specific research provides strong evidence on the potential effects of climate change on benthic habitats and species in the Northern and Southern North Sea. Whilst this information is appropriate on a localised scale and for individual ecosystem components (e.g. plankton, fish, etc.), there is a need to understand how these components are linked and responding over larger spatial scales. There are indisputable gaps in coverage of some Charting Progress regions, where we have limited information on benthic status and potential responses to climate change. Additionally, in the areas where we currently have a comprehensive understanding of benthic species and communities, there is still a need to explore interactive effects of multiple human pressures (e.g. fishing, aggregate extraction, dredging and construction) as this information is essential for assessing the impacts of climate change in UK waters. Based on the reviewed information on current benthic state and gaps in knowledge, our confidence level is low.

What could happen: **Low**



We have indirect evidence of warming effects on maerl and *Lophelia* habitats, based on laboratory observations of temperature sensitivity in the individual species. However, there has been little direct observation of climate-related change *in situ* and we require more detailed understanding of how changes in the reefs and maerl matrices will affect the communities they support. The science relating to acidification effects on particular benthic species is sound, but further evidence is required on a wider range of species and whole-community and functional effects. We currently lack the capability to make quantitative predictions about the nature and extent of any future temperature-driven shifts in benthic species distributions. Hiscock *et al.,* (2004) have developed a conceptual framework for identifying species potentially affected by future temperature increases and quantitative models for predicting future distributions have been developed for marine fish. However, we are, as yet, unaware of such models being developed for predicting future species distributions or community-level effects in marine benthos. The lack of such predictive capability for both warming- and acidification-effects makes it difficult to translate evidence on links between climate and benthos into forecasts for future conditions. Additionally, we have little understanding about the interactive effects of ocean warming, stratification and acidification. Based on this information, we place a low level of confidence in our predictions of what could happen in future.

4. Knowledge gaps

Compilation of this review has identified some clear gaps in our knowledge of climate change impacts on shallow and shelf subtidal habitats and ecology. Generating insight into these areas will allow scientists to provide better advice to policy makers and support the implementation of climate-related policy.

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

1. There is a paucity of large scale benthic distribution data for UK waters, which hinders our ability to detect changes in species distribution over large areas of the seabed. Such information, when combined with experimental studies of the effects of climate warming and ocean acidification, will allow us to confidently describe patterns of benthic response to climate change.
2. The benthic and pelagic components of the marine ecosystem are inextricably linked, but we currently lack understanding of interactions between the components and their common responses to climate change. In order to understand the ecosystem-level consequences of climate change, we need fundamental research on the nature and extent of synchronicity between the benthos and pelagos, including higher trophic levels such fish, seabirds and marine mammals (e.g. food web assessments).
3. There is a real gap in our ability to make predictions about the responses of subtidal species and communities to future climate change. We have the capability to generate such information through statistical modelling techniques yet, with the exception of fish species, these methods remain largely undeveloped in shelf sea systems. We need to develop the capacity to model species' distributional responses to changing environmental conditions and a knowledge-base that will allow us to understand the underlying mechanisms and ecosystem-level implications of such changes.

5. Socio-economic impacts

Little information is available on the current or future socio-economic effects of climate change on shallow and shelf subtidal habitats and ecology. However, some general areas of concern can be identified based on the evidence presented in the review.

Marine protected areas

Although there is currently little evidence of warming-related subtidal species distribution shifts, any such shifts occurring in future will have socio-economic ramifications if they result in the movement of species of conservation concern outwith the boundaries of areas designed for their protection.

For example, maerl and *Lophelia pertusa* have restricted distributions in the UK and are protected under Annex I of the EU Habitats Directive - maerl habitats are qualifying features of the Sound of Arisaig, Loch nam Madadh, Strangford Lough and Fal and Helford marine Special Areas of Conservation (SAC), while *Lophelia pertusa* reefs are a primary features or features of the candidate Darwin Mounds SAC and North-West Rockall Bank and Hatton Bank draft offshore SAC (www.jncc.gov.uk). Others, such as the horse mussel *Modiolus modiolus*, the honeycomb worm *Sabellaria alveolata* and the pink seafan *Eunicella verrucosa*, also have restricted UK distributions and conservation importance at national or international levels.

Temperature-driven range contractions in these species may necessitate boundary-alterations, which are likely to be socially, politically and financially demanding. Range-expansions are likely to be less problematic, unless they introduce new species of conservation concern into UK waters. Even if temperature-driven changes do not result in such extreme scenarios, alterations in the abundance or spatial distribution of conservation species may affect the type and extent of future commercial and recreational activity permitted within protected areas.

Indirect effects on fish and fisheries

Many fish species feed on benthic organisms and climate-driven impacts on benthic communities have the potential to influence population dynamics of fish predators. If changing distributions or abundance of prey species have significant effects on numbers of commercially-important predators, this is likely to have economic repercussions for the fishing industry. However, there is little information available on the socio-economic value of benthic prey. Moreover, it is not currently clear whether fish predators and their benthic prey will respond in concert to changing seawater temperatures or ocean acidification, or how impacts on one trophic level will filter through others.

Acknowledgements

Data are available to enable large-scale investigations of bentho-pelagic predator-prey links in UK waters (see the DAPSTOM database at www.cefas.co.uk/dapstom). Such analyses would provide information that could be used to aid estimations of the potential indirect economic effects of alterations in seabed communities.

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