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Report on the Ecosystem changes of different sub-areas of the North Atlantic

Contributoirs: Artur Palacz (DTU-Aqua), Priscilla Licandro (SAHFOS)

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Deliverable 8.2 Report on the Ecosystem changes of different sub-areas of the North Atlantic (Responsible: UHAM, Delivery Date May 2012)

Executive Summary:

This report indicates that climate change effects combined with anthropogenic activities put additional pressure on marine ecosystem resources. Changes in regional climate, caused predominately by the warming of air and sea surface temperatures, and associated changes in hydrodynamics are linked to the observed shifts in plankton community composition and patterns of distribution over the past 50 years. Anthropogenic pressures (e.g. fishing) also affect the community composition and abundance of plankton and may act synergistically with the climate. Changes in phytoplankton and zooplankton communities at the bottom of the marine pelagic foodweb may affect higher trophic levels (e.g. fish, seabirds), because the bottom-up control through predator-prey interactions plays an important role in the successful recruitment of top predators.These changes are not uniform across the different sub-areas of the North Atlantic, hence, further shifts in biogeographic regime boundaries within the North Atlantic are to be expected.

Relevance to the project & potential policy impact:

Deliverable 8.2 summarizes the results of analysis of ecosystem changes of different sub-areas of the North Atlantic from 1960s till present. The long-term ecosystem trend analysis was published in Chapter 7of the ICES cooperative research report no. 310 in September 2011, and it is consistent with the analysis of habitat and species population changes in the North Atlantic biogeographic regions performed within WP3 (Deliverable 3.1). Sub-regional ecosystem changes described in this deliverable are relevant to end-to-end ecosystem efforts in Task 8.2, particularly with respect to model regions and driver data specifications listed in Deliverables 8.1 and 8.3. Furthermore, past to current patterns of variability in structural and functional ecosystem components described in this deliverable provide the necessary reference for meeting the objective of Task 8.3, which is to assess the future development and susceptibility of North Atlantic marine ecosystems and their key species to changes in climate and exploitation patterns. It is concluded that the observed synergistic effects climate change and anthropogenic activities put additional pressure on marine ecosystem resources. This information serves as an important recommendation for policy makers and contributes to meeting the overarching goal of EURO-BASIN which is to advance sustainable management of North Atlantic marine resources through an ecosystem-based approach.

Report

Observed climate-related hydrographic changes have had pronounced effects on marine ecosystems in the North Atlantic and surrounding shelf seas associated with distinct biogeographic regimes. Majority of regime shifts in habitat conditions and species populations have been observed in the semi-enclosed basins of the Baltic and North Seas, where exploitation of marine resources through fishing, eutrophication and pollution have amplified the climate-driven changes. Warming of ocean waters has on the other hand had the dominant effect in the North Atlantic basin. In the colder regions (north of approximately 50°N), sea surface warming is accompanied by increasing phytoplankton abundance, whereas the opposite is true in the warmer regions (south of 50°N). This apparent contradiction is thought to arise because colder waters tend to be strongly mixed and nutrient-rich, whereas warmer waters farther south are more stratified and nutrient-poor (Licandro et al., 2011).

Using long-term Continuous Plankton Recorder (CPR) data collected in the North Atlantic basin and processed by Sir Alistair Hardy Foundation for Ocean Sciences (SAHFOS) as well 12 time series data coincident in space and summarized by ICES through the Working Group on Zooplankton Ecology (WGZE; O'Brien et al., 2008), many decadal trends and patterns of change in spatial distribution of plankton were detected.

1. Northeast Atlantic and North Sea

A large increase in phytoplankton biomass has been recorded in the Northeast Atlantic since the mid-1980s (Figure 1). Largest changes in the North Sea and in the area west of the British Isles appear in part to be related to increasing sea surface temperatures (SSTs; Reid et al., 1998; Edwards, 2000; Edwards et al., 2001b, 2007). In the same area, an extension of the duration of the seasonal maximum of the biomass (i.e. phytoplankton colour index (PCI)) has also been observed (Figure 1).

In the North Sea a pronounced increase in SST and wind speed after the 1980s resulted in an extension of the season favourable for phytoplankton growth, particularly in the southern North Sea. However, McQuatters-Gollop et al. (2007) and Llope et al. (2009) found that nutrient concentrations were not an important contributory factor to the observed changes in phytoplankton standing stock.

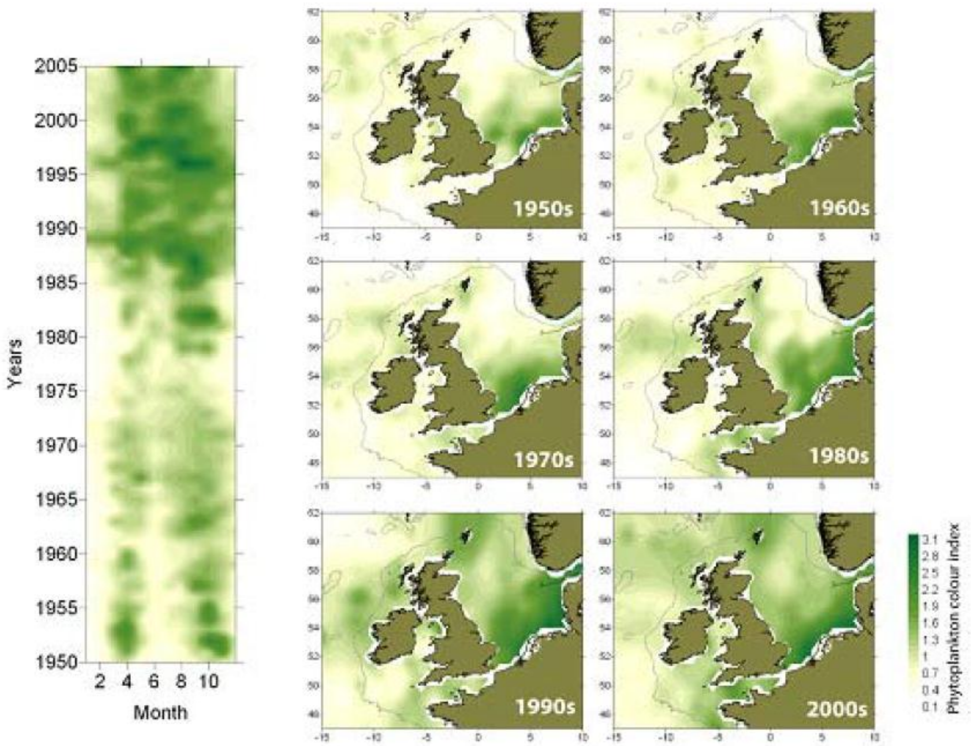

Figure 1. Mean spatial distribution of phytoplankton standing stock (PCI) per decade from the 1950s to the present.Source: Edwards (2009).

Regional climate variability has also affected phytoplankton community structure in the North Sea. In response to warmer SSTs, dinoflagellate abundance increased and diatom abundance decreased (Leterme et al., 2005; Edwards et al., 2006a). These changes are also correlated with the North Atlantic Oscillation (NAO), positively for dinoflagellates and negatively for diatoms (Edwards et al., 2001a, 2006a). Their effect is visible in the response of zooplankton filter-feeder community in the North Sea. While dominant, diatoms had a positive and homogeneous effect on zooplankton filter-feeders. After 1970s, different regional trophic dynamics were observed, in particular a negative relationship between total phytoplankton and zooplankton was detected off the west coast of Norway and the Skagerrak as opposed to a positive one in the southern reaches (Llope et al., 2012).

In recent decades, in parallel with the rise in dinoflagellates, increasing records of harmful algal bloom (HAB) taxa have been reported in some regions of the North Sea. For example, Belgrano et al. (1999) hypothesized a possible link between the occurrence of toxin-producing *Dinophysis* spp., primary production, and the NAO index on the Swedish coast (Gullmar Fjord). Northward expansion of warm-water plankton and possibly some HAB species is also consistent with information from fossil records (Dale and Nordberg, 1993; Thorsen and Dale, 1997).

It is predicted that warmer temperature will increase the intensity and frequency of winter storms, and increase rainfall in certain areas of the North Atlantic (McGrath and Lynch, 2008). Resultant increases in both the depth of deep winter mixing in the ocean and in freshwater run-off are expected to alter phytoplankton abundance and composition. Increased run-off can foster primary production by shallowing the mixed layer, but can also constrain it through less photosynthetically active radiation penetrating elevated concentrations of dissolved organic matter of riverine origin. There is already evidence of earlier stratification of the water column in the Northeast Atlantic (MCCIP, 2008), possibly advancing the onset of the phytoplankton bloom in spring.

Warm-water phytoplankton species increased expansion to new areas in recent years in the Northeast Atlantic. For instance, *Ceratium* spp. (e.g. *C. hexacanthum*) has been recorded in the North Sea (Edwards and Richardson, 2004). The non-indigenous diatom *Coscinodiscus wailesii*, originally native to the Pacific Ocean, since the mid-1980s has become well established and abundant in the North Sea and around the British Isles (Edwards et al., 2001b; Wiltshire et al., 2010). Moreover, melting of sea ice in the Arctic caused by climate warming might have caused the Pacific subpolar diatom *Neodenticula seminae* to expand onto the North Atlantic (Reid et al., 2007).

Changes in the distribution of relatively large copepods (e.g. *Calanus* spp.) have had an important effect on total zooplankton abundance and biomass. For example, the abundance of the cold-water species *C. finmarchicus*, a key component of the planktonic ecosystem of the North Atlantic, has changed in several regions since the 1950s, and this has been associated with increases in sea temperature (Planque and Fromentin, 1996; Pershing et al., 2004). Its decrease in the North Sea over recent decades has led to a significant reduction in total zooplankton standing stock, namely 70% in total biomass between the 1960s and post-1990s (Edwards et al., 2006b, 2007). Kirby et al., (2007) reported that in the North Sea, warmer temperature conditions and increased phytoplankton abundance earlier in the year since the late 1980s have been accompanied by an increasing abundance of meroplankton (i.e. temporary planktonic larvae of benthic species), which may now control the trophodynamics of the pelagic ecosystem by competitive exclusion of the holozooplankton (i.e. permanent planktonic species). Such a change in foodweb structure could mean that energy flow shifted from the pelagic to the benthic ecosystem.

Jellyfish have also increased in occurrence likely due to hydroclimatic changes (mainly temperature; Purcell, 2005) in the Northeast Atlantic during the last decade (Lynam et al., 2004; Attrill et al., 2007), both in shelf areas and in oceanic waters (Gibbons and Richardson, 2009; Licandro et al., 2010). The timing of jellyfish seasonal peaks over the shelf and in oceanic waters appears to be regulated by temperature rather than food (Gibbons and Richardson, 2009), which may explain why swarms of warm-temperate species have been observed more frequently in the Northeast Atlantic in recent years (Licandro et al., 2010).

Pronounced biogeographic shifts or translocations have been recorded for zooplankton species over the entire North Atlantic by means of CPR sampling (Figure 2). These have been attributed to increasing regional sea temperatures. Calanoid species with warmer-water affinities have been moving north by as much as 10° latitude in the Northeast Atlantic (Beaugrand, 2005; Edwards et al., 2006b; Beaugrand et al., 2009). In some North Atlantic regions, latitudinal changes have led to an increase in zooplankton diversity and parallel reductions in the mean size of the dominant zooplankton species (Beaugrand et al., 2010).

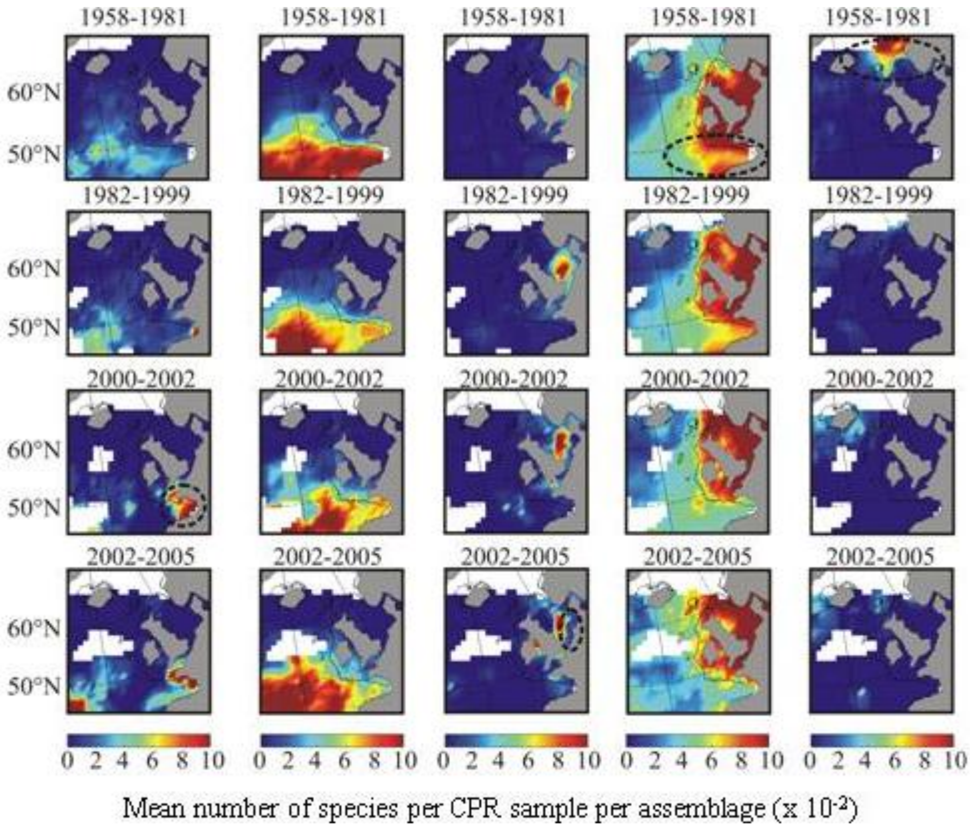

Figure 2. *Maps showing biogeographic shifts of calanoid copepod communities in recent decades based on CPR data with warm-water species shifting north by more than 10° of latitude and cold-water species retracting to the north. Source: Beaugrand et al. (2009).*

Observed changes in timing of occurrence (phenology) of many zooplankton taxa (Greve et al., 2001; Edwards and Richardson, 2004; Edwards et al., 2006b) have varied among species, functional groups, and trophic levels, leading to potential mismatches in prey – predator relationships (Edwards and Richardson, 2004; ICES, 2006). In addition, recent investigations have demonstrated that winter temperature influences the time of spawning of some commercially important North Sea fish species, with warmer sea temperature being associated with earlier fish recruitment (Greve et al., 2005).

In the North Atlantic, substantial ecosystem changes seen across multiple trophic levels were demonstrated to be associated with temperature increases above a critical thermal boundary (Beaugrand et al., 2008). This thermal threshold of 9–10°C, if crossed, will lead to changes in community structure, biodiversity, and carrying capacity. Such changes, especially when combined with fishing, may initiate a marked reduction in some fish stocks (e.g. the North Sea cod (*Gadus morhu*a) stock).

Altered seasonal timing of phyto- and zooplankton production due to warmer SSTs are linked to changes in predator species populations, including fish (Edwards and Richardson, 2004; Richardson and Schoeman, 2004; ICES, 2010a). In the Northeast Atlantic, poor recruitment of several commercially important fish species and low seabird breeding success were observed, particularly in the North Sea (Beaugrand and Reid, 2003; Beaugrand et al., 2003; Frederiksen et al., 2006; Payne et al., 2009).

Although most studies demonstrate that hydrographic variability is the main factor controlling long-term changes in the plankton, recent research has suggested that removal of top predators from an ecosystem may also affect the trophic levels below by what is known as a “trophic cascade”. Studies in both the eastern and western North Atlantic suggest that climate and fishing may have synergistic effects on the community composition and abundance of phytoplankton, zooplankton, and fish (Frank et al., 2005; Casini et al., 2008; Baum and Worm, 2009; Kirby et al., 2009).

2. Norwegian Sea and other Nordic Seas

Hydrographic changes may have an important influence on annual mean spring productivity in waters around Iceland (Gudmundsson, 1998), with a high inflow of relatively warm Atlantic Water corresponding to increased primary production. Similar changes are predicted for the Barents Sea under a warming scenario (Ellingsen et al., 2008), and are partially supported by field studies (Dalpadado et al., 2003).

In the Norwegian Sea hydrographic changes caused a progressive reduction (by 80 %) in zooplankton biomass since 2002. On the other hand, the drop in zooplankton biomass may also be the consequence of higher predation pressure due to a marked increase in planktivorous fish stock abundance in the Norwegian Sea (ICES, 2010a).

In Fram Strait northward shifts of the Atlantic hyperiid amphipods *Themisto abyssorum* and *T. compressa* have been observed since 2000, and are thought to be related to the increased influence of warm Atlantic waters (Kraft et al., 2010). Euphausiids form a significant part of the zooplankton biomass in the North Atlantic, where they may play an important role as conveyors of energy between trophic levels.

In the Barents Sea, lipid-rich euphausiids (mainly *Thysanoessa inermis* and *T. raschii*) have increased since 2000, probably as a result of the recent warming, which provides favourable conditions for growth and survival of these species (Eriksen and Dalpadado, 2011). They have in turn provided good feeding and growth conditions for several fish species, including capelin and young cod (Dalpadado et al., 2012). Decrease in Arctic zooplankton biomass may on the other hand have negative implications for polar cod and other zooplankton predators linked to the Arctic foodweb. Nevertheless, the Barents Sea seems to maintain relatively stable levels of boreal zooplankton biomass and production, and the abundances of *Calanus finmarchicus* or the episodic immigrant *C. helgolandicus* show no significant changes so far (Dalpadado et al., 2012).

3. Bay of Biscay and Iberian Coast

Evidence that the climate impact on growth of phytoplankton depends on the physical structure of the water column is seen off the north and northwest coasts of Spain (Valdés et al., 2007). There, primary production is predicted to decline over the long term in the more stratified regions while increasing in regions where upwelling is relatively intensive (Valdés et al., 2007).

Hydrographic changes may have caused the increase in HAB events in this region. For instance, blooms of *L. polyedrum* have been described from off the Portuguese coast since the 1940s, and the toxic autotrophic dinoflagellate *G. catenatum* has been associated with upwelling events along the Iberian coast since 1976 and farther off the Portuguese coast since 1986 (e.g. Pinto, 1949; Moita et al., 1998; Ribeiro and Amorim, 2008). HABs are also often triggered by events associated with loading from local rivers after heavy rainfall (Smayda, 2006). The projected increase in average precipitation under a warming climate and related increased river run-off is likely to enhance this feedback mechanism.

Changes in distribution of warm-water species/groups are also evident in this region. For example, *Calanus helgolandicus* increased in densities in Bay of Biscay (Helaouët and Beaugrand, 2007), while T*emora stylifera* exhibited a northward shift into the Bay of Biscay.

Altered local wind patterns can also affect water-column stability and nutrient availability below the pycnocline off the Iberian Peninsula, where strong upwelling occurs. Changes in the intensity and frequency of local prevailing winds will affect the amount of fresh nutrient input to the euphotic zone and new primary production. The increased warming of the sea surface and thermal stratification should mitigate against wind-mixing events, if it were not for the expected movement towards a more variable climate with more extreme weather events (Licandro et al., 2011).

4. Northwest Atlantic

In the Northwest Atlantic, an increase in phytoplankton standing stock has been recorded in the past decade in both shelf and deep-ocean regions. The observed changes on the continental shelf and in the Gulf of Maine have been related to changes in the circulation and freshwater export from the Arctic Ocean, likely due to climate warming (Greene and Pershing, 2007). In the Subpolar Gyre, these changes are thought to be the direct result of increasing stratification caused by rising temperature (Head and Pepin, 2010).

Non-native phytoplankton species have also been observed in the region. Melting of sea ice in the Arctic caused by climate warming is linked to the first records of the Pacific subpolar diatom *Neodenticula seminae*. This species was first found in CPR samples from the central Irminger Sea south of Greenland during spring, following the ice-free period in 1998 (Reid et al., 2007). The progressive spread of *N. seminae* in the Northwest Atlantic was confirmed by the presence of large numbers in the Gulf of St Lawrence in 2001 (Starr et al., 2002).

There is also an apparent decrease in the abundance of *C. finmarchicus* and in zooplankton biomass in the Gulf of Maine and on Georges Bank, potentially caused by changes in the circulation patterns of slope water in the 1990s (Greene and Pershing, 2003). Contrary to that trend, *C. finmarchicus* abundance increased again in the 2000s (Pershing et al., 2010).

In general, changes in circulation probably contributed to increased stratification in the water column, earlier and more intensive phytoplankton blooms, and changes in the zooplankton community. For example, although the abundance of the boreal-temperate species *C. finmarchicus* decreased on the Newfoundland Shelf (and also over the North Atlantic as a whole (Reygondeau and Beaugrand (2011)), two species of Arctic Calanus (*C. glacialis* and *C. hyperboreus*), which had previously been relatively rare, increased in numbers in the 1990s and remained abundant in the 2000s. Concurrent changes in stratification and lower and higher trophic levels may not be caused by changes in circulation alone. It has also been suggested that removal of top predators by overfishing would alter the plankton through a cascading effect (Frank et al., 2005).

It is likely that the recently observed ecological responses to Arctic climate change in the North Atlantic will continue into the near future if current trends in sea ice, freshwater export, and surface ocean salinity continue (Licandro et al., 2011).

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