

Towards an ecological status report for phytoplankton and microbial plankton in the North Atlantic

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Abstract

The ecological links between the physical environment of the ocean and the mid to upper trophic levels of pelagic food webs are the lower trophic levels comprising microbial primary producers (phytoplankton) and microbial secondary producers (bacterioplankton, heterotrophic protists). In the North Atlantic Ocean, standardized annual average anomalies of oceanic hydrography (WGOH) and of mesozooplankton (WGZE) derived from time series observations at monitoring sites located across the entire basin provide long term trends suitable for discerning climate variability and change. Here we (WGPME) describe work in progress aimed at establishing contemporaneous trends at similar scales of space and time for phytoplankton and other microbial plankton (and associated variables such as inorganic nutrients), with a view towards understanding climatic and anthropogenic signal propagation through ocean ecosystems. Preliminary analysis hints at a widespread increase in the annual average abundance of smaller phytoplankton cells that presumably may alter the flux of energy from lower to higher trophic levels.

Keywords:

phytoplankton, microbial plankton, ecological status, WGPME

Introduction

The *ICES Science Plan* places a high priority on understanding the functioning of ecosystems through research on key topics that include climate change and biodiversity resilience. To these ends, it is important to discern changes in distributional patterns at the species and community levels, as well as to define indicators that contain information on ecosystem attributes, conditions of change, and external pressures. These are the outcomes towards which the Working Group on Phytoplankton and Microbial Ecology (WGPME) are striving.

A perspective on changing conditions in the world's Large Marine Ecosystems indicate no significant trends in chlorophyll or primary production in the various LMEs of the North Atlantic, except on the East Greenland Shelf and in the Barents Sea where chlorophyll concentrations have been increasing (Sherman and Hempel 2009). However, the evidence in this perspective was drawn largely from satellite ocean colour measurements made over a relatively short time duration (1998-2006). Although these findings have been considered in the context of other existing data (Bode et al. 2011), there remains an ongoing need to

examine species, functional groups, and community descriptors since microbial attributes may prove important for indicating systemic change. Here, we report on the progress of WGPME towards an ecological status report for phytoplankton and microbial plankton in the North Atlantic. Such a report would contribute to the observational description of lower trophic levels required in any ecosystem-based assessment of the state of the North Atlantic Ocean.

Methods

The cooperative research agenda for phytoplankton and microbial plankton is based on the successful model of WGZE for the ICES zooplankton status report (O'Brien et al. 2011). To date, WGPME has a collection of data from 22 discrete monitoring stations. Long-term records of sea surface temperature (1900-2010) and ocean colour (1998-2010) at every monitoring site are extracted from the Hadley Centre SST (<http://badc.nerc.ac.uk/data/hadisst/>) and the GlobColour (<http://www.globcolour.info/>) databases respectively. Multidecade records (1958-2009) of diatoms, dinoflagellates and phytoplankton colour index

in 40 standard geographic areas of the North Atlantic are contributed from the Continuous Plankton Recorder (CPR) database of the Sir Alister Hardy Foundation for Ocean Science (<http://www.SAHFOS.org>).

Datasets contributed into the cooperative collection are analysed using the Coastal and Oceanic Plankton Ecology, Production, and Observation Database (COPEPOD) Interactive Time-series Explorer (COPEPODITE, <http://www.st.nmfs.noaa.gov/copepodite>).

The extraction and analysis methods have been fully described (O'Brien et al. 2011). Essentially, all data values in a time series are converted to a unitless ratio (anomaly) to indicate change over time relative to the long-term average (climatology). This method removes any seasonal signal and the resulting multiyear trend is assessed by linear regression of the annual anomalies. Multiyear change in any variable is designated as strong, weak, or non-significant according to whether the regression slope is highly significant ($p < 0.01$), significant ($p < 0.05$), or not significant ($p > 0.05$) respectively.

Results

Time-series data analysis and visualisation

For each microbial variable, the objectives are to establish the climatology, to describe the interannual variability, and to discern any multiyear trend. An example is shown for the abundance (cells l^{-1}) of diatoms in the Bay of Fundy, Canada (Fig. 1). Here, diatoms exhibit an annual cycle characterised by a broad summer peak and a multiyear increase in annual average abundance that is highly significant ($p < 0.01$). The same presentation of results for data from other sites can be found at <http://WGPME.net>

Diatoms

Multiyear diatom change is weak across the oceanic North Atlantic basin. The trend is generally negative in the east and positive in the west. Closer to, and adjacent to the coasts of Europe and Canada, diatom change appears strong. The trend is generally positive except in proximity to the English Channel and the Bay of Biscay (Fig. 2). Over all CPR areas and WGPME sites, diatom abundance has increased at 27 locations and decreased at 27 other locations.

Dinoflagellates

Multiyear change in dinoflagellate abundance is similarly weak across the oceanic basin, generally being negative in the east and positive in the west. As with diatoms, strong changes in dinoflagellates are evident only closer to and adjacent to the coasts (Fig. 3). Over all CPR areas and WGPME sites, dinoflagellate

abundance has increased at 26 locations and decreased at 27 other locations.

Phytoplankton Colour Index

The CPR phytoplankton colour index (PCI) is a 50 year proxy for *in situ* chlorophyll in the top three meters of the water column (Batten *et al.* 2003). With a solitary exception, the CPR PCI shows a pan-North Atlantic multiyear increase, with weak trends across most oceanic regions and strong trends only at sites generally near the ocean boundaries (Fig. 4). Over all CPR areas, PCI has increased at 39 locations and decreased at only 1 location.

Ocean colour

As an indicator of upper ocean phytoplankton chlorophyll concentration, satellite ocean colour (GlobCHL) shows a general pan-North Atlantic multiyear increase. The trends are weak in the central oceanic basin but strengthen decisively at the ocean boundaries and coastal stations, many of which are monitored by WGZE (Fig. 5). Over all CPR areas and both WGPME and WGZE sites, ocean colour has increased at 58 locations and decreased only at 7 locations.

Cross comparison

At the WGPME sites examined to date, a visual cross-comparison of the variables indicates a striking pattern. Bulk phytoplankton biomass (GlobCHL) is increasing at an overwhelming majority of the sites (20/22=91%), and this is matched only by the phytoflagellates and picophytoplankton (11/12=92%), but not the diatoms (10/14=71%), the dinoflagellates (8/13=62%), nor the bacteria (5/9=56%). There are too few measurements of coccolithophores even for a qualitative assessment. Since many of the rates of change are not statistically significant, this putative pattern needs to be re-examined with additional data from other sites and longer time series at the existing sites. As it stands, there is a suggestion of coherent increases in annual average concentration of chlorophyll and the annual average abundance of smaller phytoplankton cells.

Discussion

In working towards a pan-North Atlantic survey of the state of phytoplankton and microbial plankton change, we recognise the importance of seasonality in ecological development and the likelihood of phenological adjustments to climate change and variability (Cloern and Jassby 2008, Winder and Cloern 2010). However at present, there are insufficient fixed stations that are sampled at a frequency adequate to yield a robust pan-Atlantic pattern of phenological change. Arguably, high

turnover rate microbiota such as phytoplankton and bacteria need to be sampled at sub-monthly frequency for such a purpose. Our major current effort therefore is focused on deseasonalised indicators of long-term change.

Preliminary results indicate a pan-North Atlantic increase in bulk phytoplankton biomass, with coastal areas generally showing a stronger increase than oceanic areas. The pattern is consistent between the independent measures of PCI and GlobCHL. Our result contrasts with the UNEP assessment of little significant change (Sherman and Hempel 2009), which was based on a shorter time series of ocean colour from the SeaWiFS satellite and on a coarser spatial resolution of Large Marine Ecosystems. Our result also seems to contrast with the first order trend of decrease implicated by statistical analysis of the entire North Atlantic Ocean using a century-scale time series constructed by blending different indicators of phytoplankton biomass (Boyce et al. 2010). Parenthetically, our analysis of PCI time series binned into 40 standard CPR geographic areas indicate a half-century increase across much of the North Atlantic in much the same way that is indicated by a coarser binning into 6 larger sub-regions (McQuatters-Gollop et al. 2011).

If water stratification is driving contemporary trends in ocean productivity (Behrenfeld et al. 2006), then we might expect an inverse correlation between change in phytoplankton biomass and change in stratification intensity (Li and Harrison 2008). As a consequence, ocean warming under current salinity regimes could result in lower phytoplankton biomass in the coming years (Morán et al. 2010). We however caution that although stratification in temperate North Atlantic waters is often controlled by temperature at the seasonal time scale, this is not necessarily the case at the interannual time scale. In some places, temperature has a strong seasonal cycle, but yearly averages may not be very different. On the other hand, salinity has a weak seasonal cycle, but yearly averages may be substantially different. Hence, the temperature cycle in these places is reset to a somewhat similar level every year, whereas the salinity cycle may be nudged higher or lower by large scale influences (Li and Harrison 2008). Given that a change in stratification may arise from a change in temperature or a change in salinity or in both, there should be no a priori expectation that interannual change in phytoplankton biomass is necessarily correlated with interannual change in sea surface temperature. We have not yet tested the prediction of pan-North Atlantic phytoplankton control by stratification using matched scales of time and space. However, we suspect that this putative inverse correlation may not be evident in coastal areas, especially near the land-sea interface where other controlling factors are known to dominate, and where

the strongest increase in GlobCHL is evident (Fig. 5). Furthermore, it should not be expected that a linear model for multiyear change is entirely appropriate since trophic interactions are non-linear and feedback can cause system oscillations (Frank et al. 2011).

With the data at hand, it appears that the increase in bulk phytoplankton biomass does not bear a general coherent match to the changes in the 2 major microphytoplankton groups. However, the pattern is idiosyncratic at local scale, with the Bay of Fundy being a notable exception where GlobCHL, diatoms, dinoflagellates, and other phytoplankton are all increasing in tandem (Table 1). A pan-North Atlantic trend of increasing abundance in phytoflagellates and picophytoplankton is putatively suggested by the data as a whole. Every study site is unique at a local scale and has its particular contingent history. Thus it would not be surprising if the increases around the ocean basin are shown to be driven by different mechanisms. Notwithstanding possible variation in local mechanisms, a plausible general mechanistic explanation involving the temperature-size rule has been suggested (Morán et al. 2010). If the phenomenological increase in smaller phytoplankton cells is confirmed, it may be a signal that North Atlantic ecosystems are progressing towards an alternate state in which energy flow through the microbial food web becomes more important at the expense of energy made available for export or harvest. The diagnostic of bulk phytoplankton biomass would fail to reveal such a shift in the ecosystem, but an indicator based on picophytoplankton and nanophytoplankton abundance might serve such a purpose.

In order to understand climatic and anthropogenic signal propagation from the abiotic environment to higher trophic levels, it will be important to delineate the pathways through the lower trophic levels of the phytoplankton and other members of the microbial food web. The WGPME ecological status report will be assembled at the local scale but developed to address the issues of climate change and biodiversity resilience, both of which are, by definition, large scale processes.

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Appendix

Site Name	Region	WGPME Contact
<i>Arkona Basin</i>	Baltic Sea	Norbert Wasmund
<i>Nervion Estuary</i>	Bay of Biscay	Emma Orive
<i>Xixon</i>	Bay of Biscay	Xelu Morán
<i>Gulf of Naples</i>	Mediterranean	Adriana Zingone
<i>Kastela Bay</i>	Mediterranean	Mladen Solic
<i>Thau Lagoon</i>	Mediterranean	Yves Collos
<i>Helgoland Roads</i>	Northsea & English Channel	Alexandra Kraberg
<i>Loch Ewe</i>	Northsea & English Channel	Eileen Bresnan
<i>Loch Maddy</i>	Northsea & English Channel	Eileen Bresnan
<i>Millport</i>	Northsea & English Channel	Eileen Bresnan
<i>Plymouth L4</i>	Northsea & English Channel	Claire Widdicombe / Glen Tarran
<i>Scalloway</i>	Northsea & English Channel	Eileen Bresnan
<i>Scapa</i>	Northsea & English Channel	Eileen Bresnan
<i>Stonehaven</i>	Northsea & English Channel	Eileen Bresnan
<i>Bay of Fundy</i>	Northwest Atlantic	Jennifer Martin
<i>Bedford Basin</i>	Northwest Atlantic	Bill Li
<i>Labrador Sea: Labrador Shelf</i>	Northwest Atlantic	Bill Li
<i>Labrador Sea: Labrador Basin</i>	Northwest Atlantic	Bill Li
<i>Labrador Sea: Greenland Shelf</i>	Northwest Atlantic	Bill Li
<i>Scotian Shelf: Western</i>	Northwest Atlantic	Bill Li
<i>Scotian Shelf: Central</i>	Northwest Atlantic	Bill Li
<i>Scotian Shelf: Eastern</i>	Northwest Atlantic	Bill Li
SAHFOS CPR Survey	Pan-North Atlantic	Martin Edwards / Rowena Stern

Additional sites will be included in the 2012 WGPME Phytoplankton and Microbial Plankton Status Report

Bay of Fundy

Total Diatoms (cells/liter)

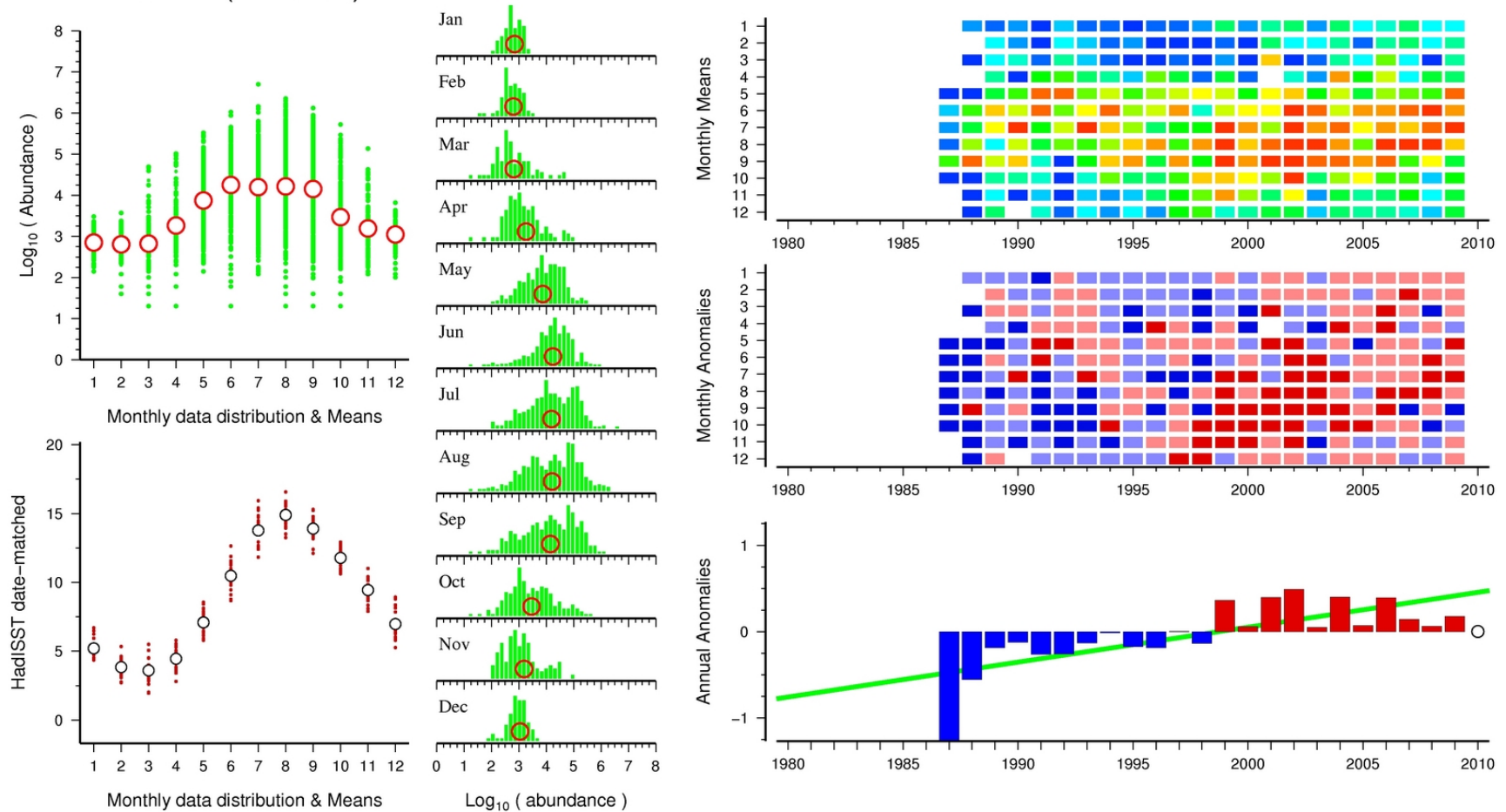


Fig. 1. The monthly climatology and multiyear change in diatoms in the Bay of Fundy recorded by Jennifer Martin, DFO Canada.

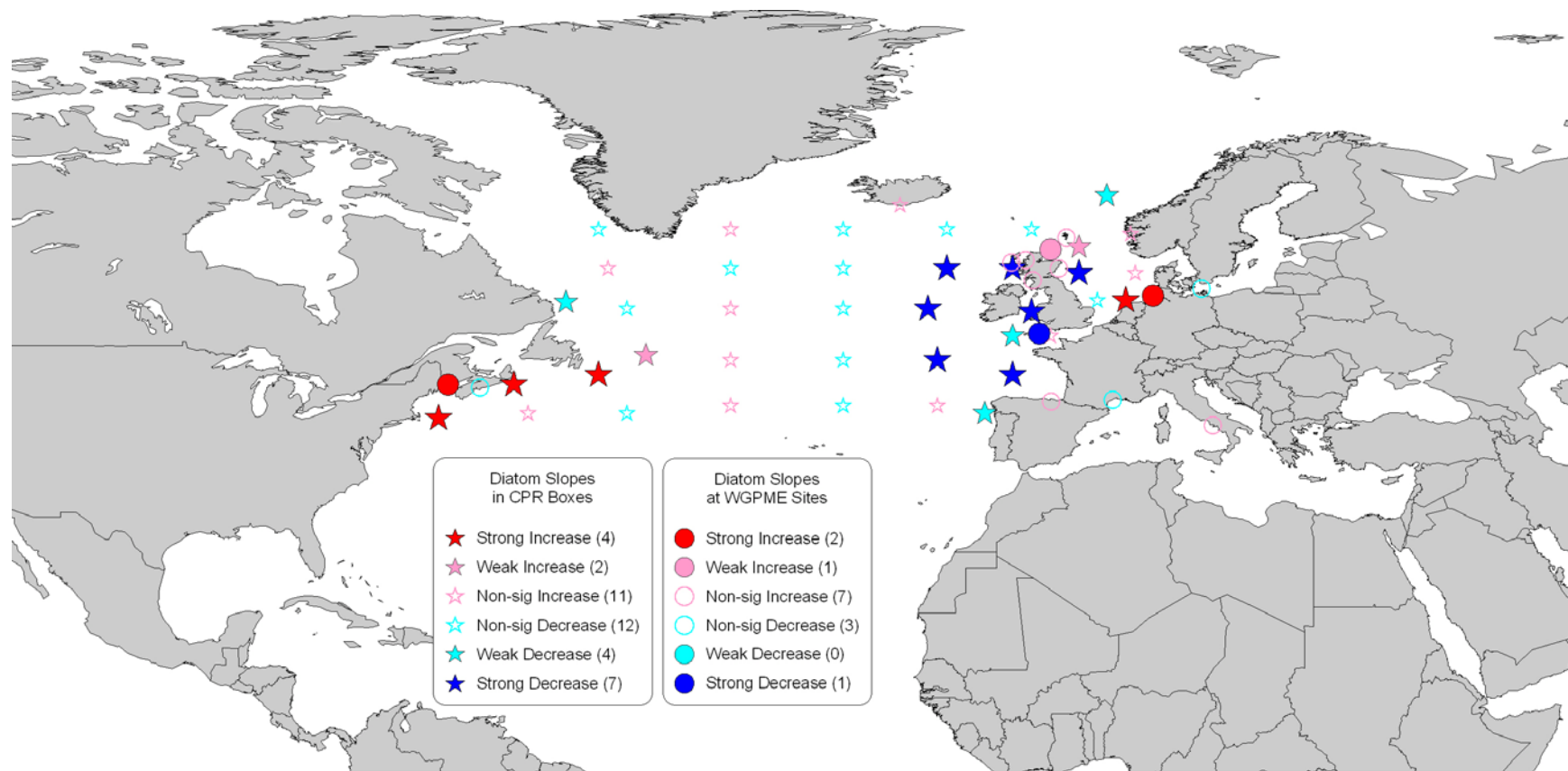


Fig. 2. Multiyear change in diatom abundance across the North Atlantic Ocean and in the Mediterranean Sea showing trends observed at individual monitoring stations and at the geographic midpoint of Continuous Plankton Recorder standard survey areas.

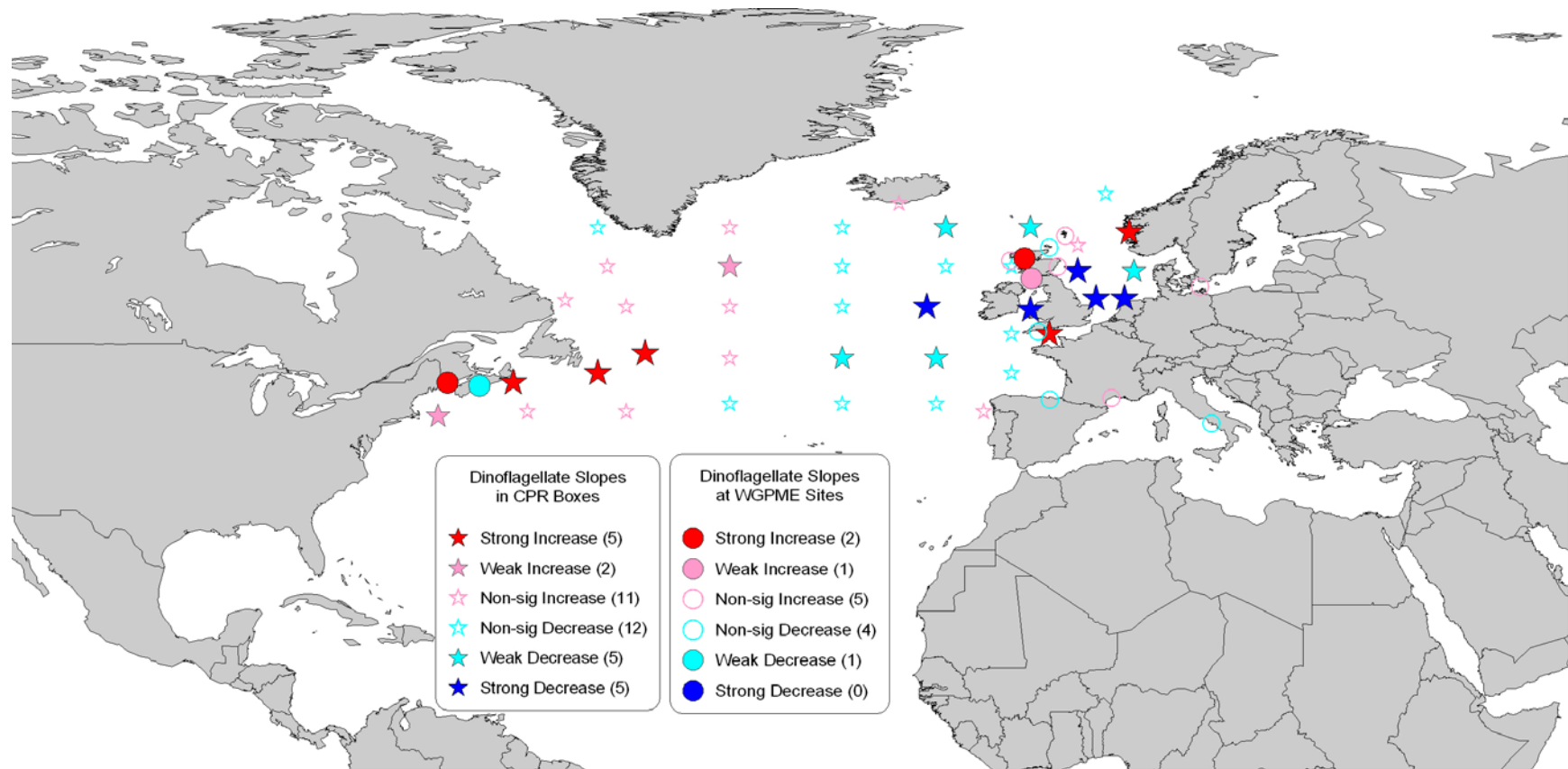


Fig. 3. Multiyear change in dinoflagellate abundance across the North Atlantic Ocean and in the Mediterranean Sea showing trends observed at individual monitoring stations and at the geographic midpoint of Continuous Plankton Recorder standard survey areas.

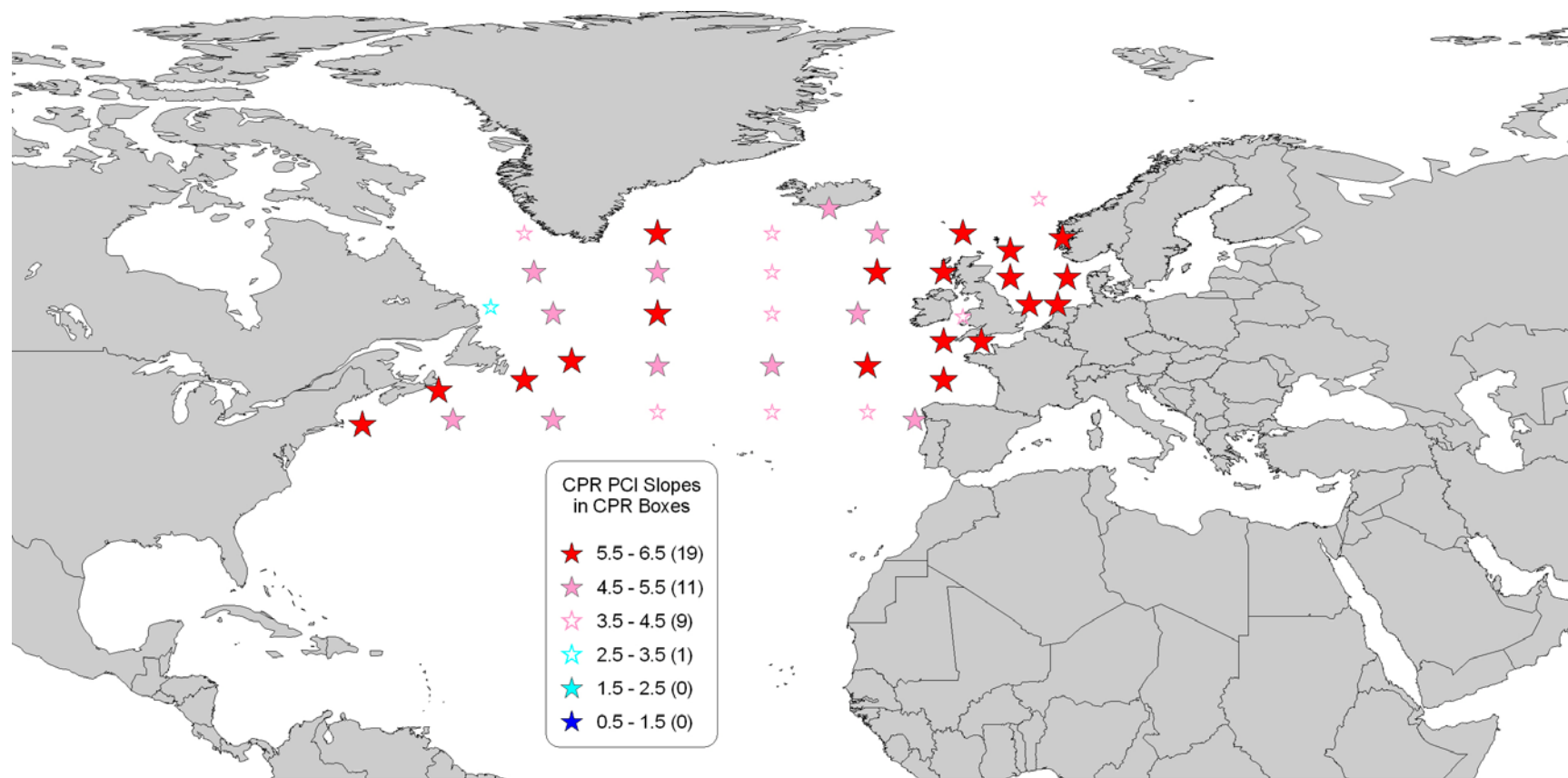


Fig. 4. Multiyear change in the Phytoplankton Colour Index (PCI) at the geographic midpoint of Continuous Plankton Recorder standard survey areas.

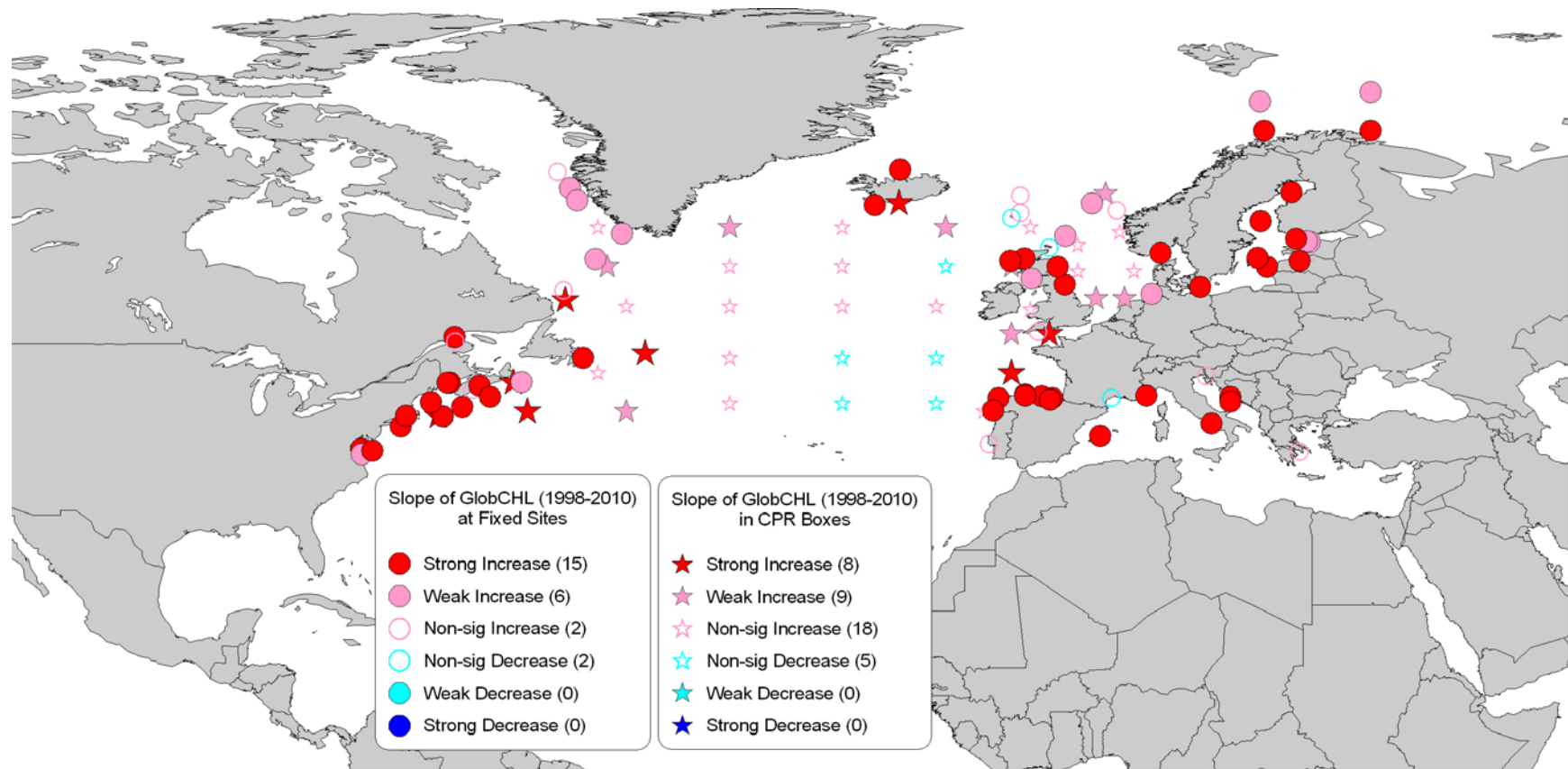


Fig. 5. Multiyear change in chlorophyll concentration (ocean colour extracted from the GlobColour database) across the North Atlantic Ocean and in the Mediterranean Sea showing trends at individual monitoring stations and at the geographic midpoint of Continuous Plankton Recorder standard survey areas.

Table 1. Cross comparison of multiyear change in microbial variables at WGPME sites.

Site	GlobCHL	Diatoms	Dinoflagellates	Phytoflagellates / Picoplankton	Coccolithophores	Bacteria
<i>Bay of Fundy</i>	6	6	6	6		
<i>Gulf of Naples</i>	6	4	3	6	4	
<i>Nervion Estuary</i>	6	4	3	5		
<i>Scotian Shelf: Western</i>	6			4		4
<i>Scotian Shelf: Central</i>	6			4		4
<i>Xixon</i>	6			4		5
<i>Loch Ewe</i>	6	4	6			
<i>Loch Maddy</i>	6	4	4			
<i>Stonehaven</i>	6	4	4			
<i>Arkona Basin</i>	6	3	4			
<i>Kastela Bay</i>	6					1
<i>Labrador Sea: Labrador Basin</i>	5			4		4
<i>Labrador Sea: Greenland Shelf</i>	5			4		4
<i>Scotian Shelf: Eastern</i>	5			4		3
<i>Helgoland Roads</i>	5	6				
<i>Millport</i>	5	4	5			
<i>Scalloway</i>	5	4	4			
<i>Bedford Basin</i>	4	3	2	6		3
<i>Labrador Sea: Labrador Shelf</i>	4			4		3
<i>Plymouth L4</i>	4	1	3	3	6	
<i>Scapa</i>	3	5	3			
<i>Thau Lagoon</i>	3	3	4			

KEY
1 Strong decrease
2 Weak decrease
3 Not significant decrease
4 Not significant increase
5 Weak increase
6 Strong increase
No data