Theme Session D

Trends in chlorophyll and primary production in a warmer North Atlantic

ICES CM 2009/D:01

Comparison of *in situ* time-series of temperature with gridded sea surface temperature datasets in the North Atlantic

Sarah L. Hughes, N. Penny Holliday, Eugene Colbourne, Vladimir Ozhigin, Hedinn Valdimarsson, Svein Østerhus, and Karen Wiltshire

Assessment of the effects of climate variability and climate change on chlorophyll and primary production is difficult in regions where long-term observations of ocean temperature may be sparse. Gridded sea surface temperature (SST) products, based on a combination of satellite and *in situ* observations, are often used to examine variability and long-term trends as they provide better spatial coverage than the limited sets of long *in situ* time-series. SST data from three gridded products (Reynolds/NCEP OISST.v2., Reynolds ERSST.v3, and the Hadley Centre HadISST1) are compared with long time-series of *in situ* measurements from ICES standard sections in the North Atlantic and Nordic Seas. The variability and trends derived from the two data sources are examined, and the usefulness of the products as a proxy for subsurface conditions is discussed.

Keywords: climatology, North Atlantic, sea surface temperature, time-series.

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Coherent change in multiyear trends of chlorophyll and bacterioplankton

William K.W. Li

The effects of climate variability and change on pelagic marine ecosystems are often sought as a signal propagated from primary producers to secondary producers. Yet the space and time-scales of direct interaction between phytoplankton and other parts of the foodweb are much smaller than those of climatic drivers. A question arises whether trophic linkage can be discerned on a multiyear scale. We demonstrate from local and regional studies in the North Atlantic that multiyear changes in chlorophyll concentration are accompanied by dampened changes in bacterioplankton abundance. The coherent departure from the norm, both positively and negatively, of both microbial primary and secondary producers provides evidence of directed system level change.

Keywords: bacterioplankton, chlorophyll, North Atlantic.

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ICES CM 2009/D:03

Changes in phytoplankton size structure with warming in the temperate North Atlantic

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In the context of strong warming trends in the world oceans, we have lacked theoretical explanations for the macroecological relationships between phytoplankton total abundance, size structure, and temperature. Picophytoplankton (*Prochlorococcus* and *Synechococcus* cyanobacteria and eukaryotic algae smaller than 2 μm in equivalent spherical diameter) have been long considered to be major contributors to photosynthetic carbon fixation only in oligotrophic regions. By merging two datasets collected mostly at 43°N on both the east and west sides of the temperate North Atlantic across a diverse range of environmental conditions, we demonstrate that the

importance of picophytoplankton might increase with global warming. We combine here two ecological rules—temperature–size relationship and allometric size-scaling of population abundance—to explain a remarkably consistent pattern of increasing picophytoplankton biomass with temperature over the –0.6 to 22°C range. Our results demonstrate that temperature alone explained 73% of the variance in the relative contribution of small cells to total phytoplankton biomass regardless of differences in trophic status or inorganic nutrient loading. Our analysis predicts a gradual shift towards smaller primary producers in a warmer ocean in parallel with a decline in total phytoplankton stocks. Because the fate of photosynthesized organic carbon largely depends on phytoplankton size structure we anticipate future alterations in the functioning of the pelagic ecosystem in the temperate North Atlantic.

Keywords: temperature, phytoplankton, cell size, picophytoplankton, ocean warming, North Atlantic.

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Multidecadal analysis of phytoplankton biomass and production in the northeast US continental shelf large marine ecosystem

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The northeast US continental shelf large marine ecosystem is a highly productive ecosystem that has experienced a steady increase in water temperature since the 1960s. This dynamic ecosystem reaches from Cape Hatteras, North Carolina in the south to the Gulf of Maine. Within it are four distinct eco-regions (from south to north: Middle-Atlantic Bight, Southern New England Shelf, Georges Bank and Gulf of Maine) that have different spatial and temporal patterns of phytoplankton biomass and production. Comparisons of annual surface chlorophyll concentrations in the northeast shelf ecosystem from the MARMAP study (1977–1988) and ocean colour remote sensing data (1997–2008) indicate that surface phytoplankton biomass is greater during the present decade (geometric mean = 1.47 mg m^{-3}) than during the MARMAP period (geometric mean = 1.05 mg m^{-3}). Coincident increases were also observed in the primary productivity estimates from the two study periods. This study proposes analyses the agreement between the satellite-modelled primary productivity and *in situ* measured productivity, compares the seasonal phytoplankton biomass and productivity patterns during the two study periods in the four major eco-regions, and analyses the influence of increasing temperature and the accompanying changes in stratification on the timing, duration, and magnitude of the winter–spring and autumn blooms. The northeast shelf ecosystem has several important fisheries, therefore it is vital to investigate the changing spatial and temporal patterns of phytoplankton biomass and productivity in order to understand better the linkage between the primary producers and the upper trophic levels.

Keywords: primary production, chlorophyll, interdecadal trends, phytoplankton bloom, northeast US continental shelf ecosystem.

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Long-term trends in phytoplankton colour index in the northeast US continental shelf ecosystem and short-term relationships with satellite-derived chlorophyll estimates

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The continuous plankton recorder (CPR) phytoplankton colour index (PCI) provides a long-term view of chlorophyll concentrations across the North Atlantic. Previous work on the Scotian Shelf and in the Northeast Atlantic has indicated an increase in the PCI from the 1960/1970s to the 1990s. Space-based measurements of chlorophyll from the SeaWIFS satellite started in 1997; although the time-series is short, these measurements also suggest an increase in chlorophyll concentration.

Here we examine PCI data from three CPR routes in the northeast US continental shelf ecosystem, which extends from Cape Hatteras, North Carolina to the western edge of the Scotian Shelf. These routes include one across the Gulf of Maine (1961–present), one across Georges Bank (1991–present), and one across the Mid-Atlantic Bight Shelf and Slope (1977–present). The PCI data are compared with the shorter satellite-based time-series. Similarities and differences are discussed with a focus on interdecadal trends, changes in seasonality, and relationships to long-term temperature patterns.

Keywords: primary production, chlorophyll, interdecadal trends, phenology, northeast US continental shelf ecosystem.

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ICES CM 2009/D:06

Spring bloom development in relation to the Faroe Shelf Front

K. M. H. Larsen, H. H. Debes, E. Gaard, and B. Hansen

The timing of the spring bloom on the Faroe Shelf is highly variable between years. This temporal variability is very important for production in higher trophic levels in the Faroe Shelf ecosystem. The spring bloom may develop in shallow shelf regions or it may develop in the Faroe Shelf Front. In the western shelf frontal area in particular there is often high primary production and phytoplankton biomass during the pre-bloom phase. Based on time-series data taken during April since the late 1990s, the paper presents frontal structure and stratification in relation to primary production and chlorophyll. Possible climatic influences on the frontal structure and the importance of frontal structure for primary production in spring are presented.

Keywords: Faroe Shelf Front, climate, primary production, spring bloom.

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Changes in phytoplankton biomass during a period of significant warming in the southwestern Norwegian Sea

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Chlorophyll and hydrographic conditions have been monitored in the southern Norwegian Sea in spring and summer from 1990 to 2008. The area covers warm and saline Atlantic water in the south separated from colder and less saline east Icelandic water in the north by the Iceland-Faroe Front. During 1990–2008, the Atlantic inflow of water to this region warmed by about 1°C. This paper describes changes in the chlorophyll concentration in spring and summer on a section running from the Faroe Islands and north into the southwestern Norwegian Sea, as well as the distribution of chlorophyll in relation to stratification, water masses and changes in oceanic climate in the area.

Keywords: chlorophyll, hydrography, Norwegian Sea, ocean warming.

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ICES CM 2009/D :08

Primary production and chlorophyll concentration in the Baltic Sea

Sergey Aleksandrov

The Baltic Sea is a semi-closed deeply cutting inland sea with a specific hydrological regime. During the twentieth century, there has been intensive eutrophication, especially in the coastal zone. In addition, considerable climate changes have been observed, including an increase in mean

annual water temperature by 0.8°C over 15 years. The current level of productivity in the Baltic Sea has been assessed using data from three seasonal studies during 2005–2006 at 47–89 stations along the whole sea area from the Gulf of Finland to the German coast and 20 seasonal studies during 2003–2008 at 18–22 stations in the southeastern part of the Baltic Sea. Primary production was assessed using the radiocarbon method, and chlorophyll was estimated using spectrophotometry. In 2005–2006 primary production in the vegetation period (March–November) reached 120–150 gC m^{-2} $year^{-1}$ in the Baltic proper (Gotland Basin, Bornholm Basin) and 150 gC m^{-2} $year^{-1}$ in the Gulf of Finland. During the 1970s–1980s primary production was lower: 80–110 gC m^{-2} $year^{-1}$ in the Baltic proper and 70 gC m^{-2} $year^{-1}$ in the Gulf of Finland. The recorded data probably indicates the increased productivity of the Baltic Sea caused by eutrophication and climate change (water warming). This agrees with several researchers' opinion about the trend towards increasing primary production in the Baltic Sea, estimated at up to 1–3% annually. The water warming creates conditions for "blooming" of cyanobacteria, which become more frequent. In the "blooming" period the chlorophyll concentration is 3–4 mg m^{-3} in the open sea areas, whereas in the coastal zone it reaches 10–16 mg m^{-3}. The chlorophyll, phytoplankton biomass, and production in the Baltic proper correspond to mesotrophic status. The increase of phytoplankton production and abundance observed in most eutrophicated gulfs (e.g. in the Gulf of Finland) and coastal zones may be explained by shallow depths and nutrient inputs from the shore.

Keywords: Baltic Sea, chlorophyll, eutrophication, primary production, phytoplankton.

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Changes in seasonal diatom succession and their possible causes at Helgoland Roads

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During recent decades, a coastal region of the southern North Sea, the German Bight, has exhibited pelagic warming. Some phytoplankton may be sensitive to such climatic changes. At a sampling station at the island of Helgoland in the German Bight phytoplankton, nutrients, and physical parameters have been sampled on work-daily basis since 1962. Here we examine patterns of seasonal succession of three important diatom species of the pelagic foodweb at this sampling station: the warm temperate species *Guinardia delicatula* and the two colder temperate species *Thalassionema nitzschioides* and *Odontella aurita*, for evidence of alteration over the period 1962–2008. Developing a clearer understanding of the factors that control the functioning of each population within a phytoplankton group is needed before we can determine how climate change will impact phytoplankton community structure and floristic shifts in the ocean. Therefore, we investigated the environmental factors that may be responsible for determining bottom–up control on these diatom species. Correlations between the biotic and the abiotic factors were traced using diverse methods of multivariate statistics. We discuss our results here in the context of the ecological traits shown be the three diatom species.

Keywords: climate change, diatoms, seasonal succession, bottom–up, ecological traits, Helgoland Roads.

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ICES CM 2009/D:10

Evolution (1998–2008) of early spring blooms in offshore waters within the Bay of Biscay and its relationship with sea surface temperature trends

Y. Sagarminaga

In this study we investigated the evolution of early spring blooms occurring in the offshore areas of the Bay of Biscay during the period 1998–2008 to see whether there is a relationship with trends in

sea surface temperature in the area during the same period. Weekly chlorophyll *a* and sea surface temperature images from SEAWIFS and AVHRR satellite sensors were analysed to derive average distributions, yearly anomalies, and temporal statistics such as beginning and end dates, trends, and variability patterns. Although this study is still under development, preliminary results show that there is a high interannual variability of temporal and spatial patterns of these blooms, mainly caused by interannual differences in the meteorological events that trigger them (seasonal warming and wind regime relaxation). Next we will consider whether within this 10-year period trends can be determined both in SST and early blooms dynamics which could indicate shifts in ecological processes affecting this area.

Keywords: phytoplankton blooms, chlorophyll *a*, SEAWIFS, sea surface temperature, AVHRR, Bay of Biscay.

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ICES CM 2009/D:11

A two-decade record of temperature and chlorophyll in surface waters within the Basque Country (southeastern Bay of Biscay)

M. Revilla, A. Borja, G. Chust, A. Fontán, J. Franco, M. González, and V. Valencia

Since 1986, physico-chemical and chlorophyll *a* data have been obtained by means of conductivity, temperature, and depth (CTD) profiles and bottle samples at an offshore station located in the southeastern Bay of Biscay (43°27′N 1°55′W). The station is not considered to be impacted by anthropogenic influence because of its distance (13.1 km) from the main pollution sources on land. This makes it suitable for exploring the response of phytoplankton to oceano-meteorological forcing. Dataseries of temperature and chlorophyll *a* from surface waters have been analysed to look for long-term temporal trends. Surveyed months and total number of surveys per year are very variable (from 2 to 12). In spite of the irregular sampling, a significant increasing trend in water temperature has been detected. This was also observed at a neighbouring inshore station (Aquarium Donostia-San Sebastián), where daily records of sea surface temperature (SST) are available. In contrast, chlorophyll *a* did not demonstrate a significant trend of variation over the last two decades at the offshore station. Similarly, when the chlorophyll *a* anomaly was studied as an indicator of the frequency of blooms, no significant trend of variation was observed. At this stage, the results obtained do not support the hypothesis that phytoplankton biomass is responding to changes in water temperature in the southeastern Bay of Biscay. The high variability that characterizes the concentration of chlorophyll in the short term, however, may limit the conclusions based upon statistical analysis in this study. Further research is needed to determine the variation of chlorophyll *a* in the water column.

Keywords: climate change, surface temperature, chlorophyll *a*, Bay of Biscay.

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ICES CM 2009/D:12

Trends in oxygen saturation of near-bottom layers in the Barents Sea: a possible indicator of long-term variations in primary production

Oleg Titov

It is common knowledge that a reduction in oxygen content in near-bottom layers generally results in an increase in primary production and water bloom. In the ocean, the biochemical consumption of oxygen for destruction of organic matter is almost equal to its production by photosynthesis (i.e. it is proportional to primary production). A possible explanation for a periodic decrease in oxygen concentrations in near-bottom layers in the Barents Sea, therefore, is an increase in its biochemical consumption for destruction of organic matter subsiding from the photic zone. In the Barents Sea,

the oxygen saturation of near-bottom water has been periodically measured in the Kola Section. From 1957 to 2009, about 300 series of measurements have been carried out. Year-to-year variability of anomalies of oxygen saturation of the near-bottom layers is characterized by deep minima alternating with more long-lasting periods when aeration is slightly above normal. There is an insignificant negative trend in variations in oxygen saturation of the near-bottom layers. In addition, over recent decades during warming in the North Atlantic, aeration in the near-bottom layers has decreased. Long-term variations in oxygen saturation of near-bottom layers in the Kola Section generally correlate well with the key features of oxygen conditions in the Barents Sea. There is a statistically significant relationship between oxygen saturation of near-bottom layers with characteristics of climate variations such as water temperature and ice coverage as well as with important indicators of variations in the Barents Sea ecosystem such as abundance of Northeast Atlantic cod. The majority of authors believe that warming in the North Atlantic has caused an increase in primary production and sedimentation of organic matter into the near-bottom layers of the Nordic Seas, including the Barents Sea. According to model estimates, annual primary production in the Barents Sea may increase by tens of per cent during periods of warming. In this paper a possible relationship between variations in oxygen saturation of near-bottom layers and primary production and other effects of current climate variations in the Barents Sea is studied.

Keywords: Barents Sea, cod, demersal fishery, industry research data.

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ICES CM 2009/D:13 Poster

Year-to-year variability of inorganic nutrients, primary production, and phytoplankton biomass off northwest Spain from 1990 to 2007

Antonio Bode, Ricardo Anadón, José M. Cabanas, Rosario Carballo, Gerardo Casas, Alicia Lavín, Marcos Llope, Jorge Lorenzo, Lorenzo Mene, X. Ánxelu G. Morán, Enrique Nogueira, Carmen Rodríguez, Fernando Rozada, Manuel Ruiz-Villarreal, Jorge Sostres, E. Teira, Luis Valdés, and Manuel Varela.

The nature and periodicity of changes in the concentrations of inorganic nutrients, phytoplankton chlorophyll–biomass and primary production rates on annual time-scales were investigated along the northwest coast of Spain. The time-series analysed included monthly *in situ* measurements obtained at mid-shelf (80–100 m depth) stations at four locations along the coast between 1990 and 2007. In addition satellite-derived chlorophyll data covering the period 1998–2007 were also studied. Local and large-scale forcing mechanisms were included in the form of upwelling offshore water transport and climatic indices, respectively. Linear trends, changes in seasonality, and multiyear cycles were different in each location. All sites showed increasing sea surface temperature and decreasing upwelling intensity, along with a sensible increase in surface stratification, more pronounced in the northern (southern Bay of Biscay) than in the western sector (Galicia). As a result, there was a marked decrease in nutrient concentrations, chlorophyll, and primary production in the former, whereas the trends were barely significant in the latter. Multiannual cycles in nutrient concentrations, with a periodicity between 3.5 and 9 years, were found. Such non-linear changes affect the interpretation of long-term trends in nutrient supply and primary production as primary effects of climate-driven changes in this ecosystem.

Keywords: phytoplankton, nutrients, primary production, coastal, upwelling, northwest Spain.

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ICES CM 2009/D:14 Poster

Changes in the timing of the North Atlantic spring phytoplankton bloom during the last decade

Fernando González Taboada and Ricardo Anadón

The spring phytoplankton bloom is a key event in the global carbon cycle and is tightly linked to the larval ecology of many exploited fish species. The ephemeral nature of this process and its spatial dimension make its characterization by classical sampling techniques difficult, but this is helped to a great extent by the availability of long-term, high-quality remotely sensed monitoring of chlorophyll *a* concentration. Here we use SeaWiFS data to study recent changes in the timing of the spring phytoplankton bloom in the North Atlantic Ocean, as well as the associated changes in chlorophyll *a* concentration. A Bayesian approach was employed to propagate uncertainty in the detection of the timing of the bloom to estimate rates of advancement and delay for the period 1998–2007. We found a heterogeneous pattern with clearly defined regions demonstrating advances or delays in spring phytoplankton bloom located mainly within the Subarctic gyre and throughout the Gulf Stream boundary system. In some cases, the observed responses have also been accompanied by changes in mean chlorophyll *a* concentration, although these were more the exception than the rule. Jointly, the results suggest that mean chlorophyll *a* levels or its variation could lead to spurious results in situations where the spatio-temporal coupling between secondary and primary producers is important.

Keywords: climate change, spring phytoplankton bloom, North Atlantic Ocean, remote sensing, SeaWiFS.

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ICES CM 2009/D:15 Poster

Links between phytoplankton, CO_2 emissions, and water properties: a case study in Portuguese coastal waters

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Changes in seawater chemistry observed in Portuguese coastal waters and trends predicted for the end of the century are known to cause shifts in phytoplankton and alter the structure and biodiversity of coastal ecosystems. An example of these shifts was observed in May 2002 sampling in the Tagus and Sado estuaries adjacent to the coastal shelf (Portugal). This period was characterized by a moderate but persistent upwelling and low Tagus River discharge, favouring a weak plume and elevated CO_2 values. In the spring bloom in the Tagus plume large phytoplankton, dominated by chain-forming diatoms, reached densities up to 1000 cells ml^{-1}. Separated spatially from the main phytoplankton bloom, a development of *Coccolithus braarudii* (up to 60 cells ml^{-1}) occurred, associated with the thermally stratified water mass in Tagus Bay. Diatoms proliferated in turbulent waters, whereas coccolithophores developed under more stable conditions associated with relatively low nutrient levels. The same trend was observed for the small phytoplankton, which increased in abundance (>106 cells ml^{-1}) from inshore to the deeper surface-mixed layer offshore, where the light was dimmer and nutrient concentrations lower. The small phytoplankton consisted of *Synechococcus*-like cyanobacteria and eukaryotes and reached 721 and 466 cells ml^{-1}, respectively.

With regard to the relative importance of each phytoplankton size group in terms of carbon, coccolithophores and small phytoplankton represented 2% and 0.2%, respectively, of the total phytoplankton biomass. Our findings illustrate the sensitivity of phytoplankton species composition in the shelf system under study to climate variations and its importance in the carbon cycle.

Keywords: Tagus coastal waters, phytoplankton, CO_2 emissions.

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