



Global Marine Ecological Status Report

The ecological status of the marine pelagic environment based on observations from the global Continuous Plankton Recorder surveys

no. 10

Global Alliance of Continuous Plankton Recorder Surveys (GACS)



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Introduction

The general goal of the Global Alliance of Continuous Plankton Recorder Surveys (GACS) is to understand changes in plankton biodiversity at ocean basin scales through a global network of CPR surveys. The initial vision was to unify all the data collected by various CPR surveys around the world into a centralised global database, thus enabling scientists to monitor and understand global plankton changes. By 'understand' we mean characterise, analyse and interpret. GACS has a number of specific aims which include:

- **development of a global CPR database**
- **production of a regular global marine status report (this document)**
- **ensuring common standards and methodologies are maintained**
- **providing an interface for plankton biodiversity with other global ocean observation programmes**
- **to set up and maintain a website for publicity and data access**
- **to facilitate new surveys and develop capacity building procedures**
- **to facilitate secondments of CPR scientists between GACS institutions**

GACS brings together the expertise of approximately 60 plankton specialists, scientists, technicians and administrators from 14 laboratories around the world, towing a common and consistent sampling tool, the CPR, from about 50 vessels. Working together, pooling our data and resources, was considered essential in order to understand the effects of environmental changes on plankton biodiversity at a global level. Numerous local and regional monitoring and observational programmes have been established in the past, but to date we have lacked a holistic perspective on plankton biodiversity in response to global events such as climate warming and ocean acidification. GACS will provide that perspective using CPR data, a well recognised and standardised methodology. It will also allow us to assess changes and events at a local or regional level in a world-wide context. At the heart of GACS is the global database of CPR data that allows us to make such assessments of local, regional and global changes.

Ten regional surveys have currently joined GACS and new regional surveys have been established by France, South Africa, Brazil, Japan, Australia and New Zealand. We are also providing support for new surveys being developed by Cyprus, India and South Korea. The global database has been developed, as well as the website www.globalcpr.org. GACS has established links or formal affiliations with a number of key international stakeholders including SCOR, GCOS, GEOBON, SCAR, GOOS, SOOS, POGO and PICES. At present, there are large areas of the world's oceans, notably the sub-tropical and tropical regions of the Atlantic, Pacific and Indian Oceans where there are no regular CPR surveys or plankton monitoring in general. GACS aims to improve coverage in those areas and hence has the specific aims mentioned above of facilitating new surveys and capacity building.



Global Alliance of Continuous Plankton Recorder Surveys



2012 saw the creation of the world's first global plankton database using identical sampling equipment - the Continuous Plankton Recorder

State of the global CPR network

Existing surveys

CPR coverage of the North Atlantic and North Sea by the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) is very extensive, both temporally and spatially, with data being collected since 1931. Tows are also operating regularly in the Arctic. Tows have been conducted around the rim of the North Pacific from Vancouver to Alaska to northern Japan for nearly two decades. Tows in the Southern Ocean, predominantly south of the Sub-Antarctic Front, have operated since 1991, and provide near circum-Antarctic coverage. Major gaps are Amundsen and Bellingshausen Seas in the Pacific sector and the Weddell Sea. New regional surveys have been established around South Africa, Japan, eastern Australia and New Zealand. At present, there are large areas of the world's oceans, notably the sub-tropical and tropical regions of the Atlantic, Pacific and Indian Oceans where there are no regular CPR surveys.

CPR data have been used at regional levels to understand variation in spatial patterns, bioregionalisation, MPA assessment, seasonal and inter-annual trends, regime shifts, phenological shifts, predator-prey relations, detecting and mapping invasive species and harmful algal blooms, microplastics, impacts of ocean warming and acidification. Collectively, the GACS Global Marine Ecological Status Reports document changes from the regional surveys, biogeographic shifts, phenological change, changes in biodiversity, invasive species, eutrophication and HABs, microplastics and ocean acidification.

Evolution of network and new technologies

SAHFOS has taken the lead in developing genetic/molecular methods that can be applied to CPR samples, current and archived, with considerable success. A molecular group is embedded in the SAHFOS team. Similarly, there is a group active in SAHFOS and supported by the GACS community to develop and add new instruments to the CPR to gather physical/chemical to complement the biological data. This includes micro-samplers to collect water for biological analyses. Miniaturisation of temperature, salinity, fluorometry units for use in biologgers on marine predators (mammals and penguins) has resulted in some very compact physical oceanographic recorders that can also be used on CPR without affecting the efficiency of the CPR and subsequent data stream. The additional instrumentation is important to supplement data collected by merchant ships of opportunity which do not collect physical/environmental data on route. The instrumentation programme is part of the GACS philosophy of going global and going complete.

Global marine ecological status report

This report consists of two main parts: (1) the general plankton status around the world from the CPR global network; and (2) a more applied indicator approach to the NE Atlantic and European waters. The applied indicator approach focuses on providing information for important marine management and policy issues such as climate warming impacts, biodiversity, pollution and fisheries.



SCAR Southern Ocean CPR (SO- CPR) Survey

The 22nd year of the SO-CPR Survey commenced in winter July 2012 with a series of tows from South Africa's new polar research and supply vessel *SA Agulhas II* in the region between the ice edge and Prince Edward Island. South Africa then completed the season in May 2013 after a series of tows near Marion Island. In total 19 tows were completed by *SA Agulhas II* through the 2012-13 austral season.

Australia commenced its season in September 2012 with tows from the research supply vessel *RSV Aurora Australis* between Hobart and the ice edge in Casey station region. During the 2012-13 austral summer season the *Aurora Australis* completed 26 tows in the Southern Ocean/Antarctic waters in the region south and south-west of Australia. Tows were also conducted from the Japanese ice breaker *JMSDF Shirase* (5 tows) and the training research vessel *TRV Umitaka Maru* (7 tows); both working in the same region as the *Aurora Australis*.

Japan has been a long-time partner in the SO-CPR Survey through the National Institute of Polar Research (NIPR), overseeing the Japanese Antarctic Research Expeditions (JARE) and the Tokyo University of Marine Science and Technology (TUMSAT).

To the east, the New Zealand research vessel *RV Tangaroa* conducted 13 tows south-west of New Zealand in January 2013, while the fishing vessel *San Aotea II* conducted nine tows between New Zealand and the Ross Sea between January and March. We are particularly grateful to the New Zealand Ministry of Primary Industries (MPI), the National Institute of Water and Atmospheric Research (NIWA) and the fishing company Sanford Limited, who own the *San Aotea II*, for their combined and continued support.

France joined the SO-CPR Survey and conducted its first set of CPR tows, 15 in total, in the region between the Kerguelen and Crozet archipelagos in the southern Indian Ocean. This is north of the traditional survey area of the SO-CPR but will contribute to and build on the SO-CPR Survey, as well as extending the GACS area.

Overall the SO-CPR Survey will have conducted 94 tows for the 2012-13 seasons, including the winter tows by South Africa and covering much of the Antarctic region. This is in addition to the tows conducted by SAHFOS, the British Antarctic Survey

and the South Georgia Government in the region around South Georgia and the Scotia Arc of the Atlantic sector of the Southern Ocean.

Prof Erik Muxagata (Brazil and GACS member) has already collected samples across the Drake Passage from the *Ary Rongel*. Erik spent two weeks at the Australian Antarctic Division working with John Kitchener (SO-CPR Operations Manager and Chief Analyst) and David McLeod (Analyst for IMOS AusCPR) learning the sample processing and taxonomy of the Southern Ocean plankton. Similarly, Dr Doo Byoul Lee from the Korea Polar Research Institute (KOPRI) spent two weeks with us learning Southern Ocean processing and taxonomy, as well as how the CPR works. Korea has a CPR for use on their ice breaker *RV Araon* and plan to conduct tows in the Pacific sector of the Antarctic, between the Ross Sea and the Antarctic Peninsula. This is a poorly sampled region, and to date we have just two CPR tows collected in 2008 by the Russian research vessel *RV Akademik Fedorov*. It was a busy time for the Hobart based SO-CPR team, but nevertheless, a great opportunity to learn and exchange ideas.



The North Atlantic CPR survey surpassed 6 million nautical miles towed in 2012

New Zealand CPR Survey

The New Zealand CPR Survey was established in 2008 in order to map the changes in the quantitative distribution of epipelagic plankton from NZ's Economic Exclusion Zone to the Ross Sea, Antarctica. The Survey was set up in partnership with the National Institute of Water and Atmospheric Research (NIWA), the New Zealand Ministry for Primary Industries (MPI) and the commercial fishing company Sanford Limited who are providing the *San Aotea II* and her crew to run the CPR. Analysis being carried out by staff at NIWA continues on samples from the Ross Sea CPR from the summer seasons of 2010-2011 and 2011-2012. Preparations are underway for the forthcoming summer season run to Antarctica which is scheduled to be the last of the current five year project, with *San Aotea II* due to leave New Zealand for the Ross Sea in early December 2012. She will return late February 2013. NIWA's vessel, *RV Kaharoa* completed a crossing of the Pacific Ocean from Wellington, New Zealand to

Valparaiso, Chile. Her main mission was to deploy Argo profiling floats, but the opportunity was also taken to run a CPR provided by the SO-CPR team at the Australian Antarctic Division. The route followed the 45° South line and is the first complete CPR run across the Southern Pacific. The crew on board the ship covered 4000 nautical miles and generating approximately 900 samples making a new record for the longest continuous set of CPR tows.

A CPR tow across the Southern Pacific from New Zealand to Chile makes a new record at 4000 nautical miles of continuous sampling.

French CPR tows in the Southern Ocean

The Continuous Plankton Recorder is used in the Southern Ocean under the umbrella of the SO-CPR Survey of SCAR (Scientific Committee on Antarctic Research). This project spatially covers most of the Indian part of the Southern Ocean, except the area between Crozet and Kerguelen. This is where the *RV Marion Dufresne* and *La Curieuse* operates, managed by IPEV (Institut Paul Emile Victor) and TAAF (Southern and Antarctic French Territories).

The Crozet and Kerguelen archipelagos are important areas for seabirds and sea mammals and high fish concentrations are observed. The Kerguelen Archipelago is the largest island group in the Indian sector of the Southern Ocean. Deep fjords and bays dissect the shelf. These coastal zones are dilution basins due to inputs of freshwater derived from precipitation or rivers from the Cook Glacier. CPR Surveys are essential to study the sub-Antarctic area due to its hydrological characteristics arising from the joining of Sub-Tropical and Sub-Antarctic Fronts coupled with the proximity of the Northern Branch of the Antarctic Polar Front. Near Crozet, the influence of the Agulhas Front is important to the North of the Sub-Antarctic Zone. The Marion Dufresne CPR (MDCPR) project aims to use the transit of *Marion Dufresne* to complete the lack of information that we have in the oceanic zone between the two archipelagos. In turn, this will allow us to identify the ecoregions in this area and to define offshore Marine Protected Areas for CCAMLR (Convention on the Conservation of Antarctic Marine Living Resources); or in the French Exclusive Economic Zone (EEZ) to implement the Research and Monitoring Plan of the Kerguelen Marine Reserve. The PI of this MPA project is Philippe Koubbi from Université Pierre et Marie Curie and is supported by Zone Atelier Antarctique, IPEV, TAAF and Ministère de l'Outre-mer.

Benguela Current CPR and South Africa's SO-CPR Surveys

Besides operating CPR tows in the Benguela Current (BC) system along the west coast of Africa from South Africa to Angola, South Africa also did its first Southern Ocean CPR tow from the German *RV Polarstern*. In September 2012 southern Africa's large-scale plankton monitoring capabilities were significantly boosted by the acquisition of five additional CPR bodies, internal plankton sampling mechanisms and four RBR CTD probes. This expanded CPR fleet will in future enable CPRs to be

towed from both commercial and research vessels that at times may operate simultaneously in the three ocean basins (SE Atlantic, SW Indian, and Southern Ocean) surrounding the southern African subcontinent, where DEA is mandated to conduct environmental monitoring and research.

Australian CPR (AusCPR) Survey

To date, the AusCPR Survey has collected 3,478 samples and recorded a total of 648 plankton taxa, including 280 copepod taxa. Together with the network of 9 National

Reference Stations that are sampled monthly using a drop net, the Survey is providing coverage of much of the Australian coastline and beyond. The AusCPR has recently acquired an additional route running across the Great Australian Bight, stretching from Adelaide halfway to Perth, and is an extension of our existing route from Brisbane to Adelaide. The project will be funded by a multi-national oil company and will establish a baseline of ecological data for the region, as the route traverses an oil and gas lease that could be developed in the near future. The AusCPR Survey will be part of a suite of collaborative environmental monitoring projects in the Bight.

The AusCPR team are also produced an Australian Zooplankton Guide and Atlas released in 2013. As we know, identifying zooplankton to species level is challenging, and requires a high level of expertise and experience. In conjunction with Dr Kerrie Swadling (University of Tasmania), we are developing a publicly available online zooplankton guide. This website will become the Australian Zooplankton Guide and Atlas, and will feature species from Australian waters with interactive factsheets and rapid image-based diagnostic keys. There will be 329 zooplankton species included in the Guide.





Credit: Vincent Hilaire

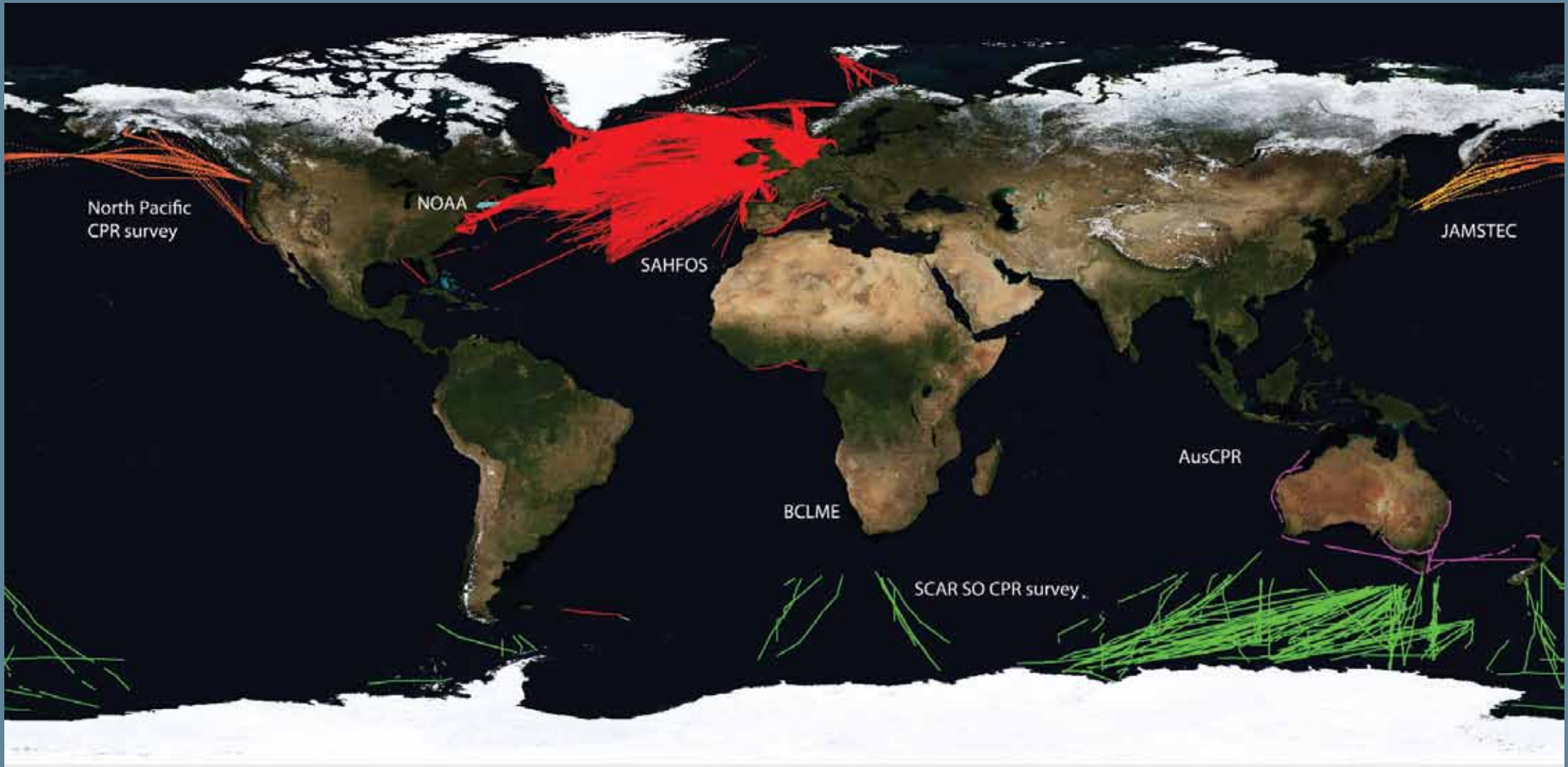


Credit: Romain Trouble

First Polar circumnavigation using a CPR

The *Tara* is a research sailing vessel run by Tara Expéditions. The *Tara* embarked on a scientific cruise in 2013 that was circumnavigating the Arctic to complete the Tara Oceans world study of plankton which started in 2009. The cruise route was from Lorient (France) to Lorient going around the North Pole counter clock wise passing the North East and North West passages in the same season.

The aim of the CPR tow was to collect samples from the high Arctic for standard CPR taxonomic analysis, plus molecular analysis and to add to the sample archive store with physical samples from this hard to access sea area. This polar circumnavigation using a CPR is critical in our understanding of biodiversity changes in this rapidly changing high latitude environment. The CPR survey has already documented the first trans-Arctic migration of plankton species in modern times and this additional sampling will provide a crucial baseline and further evidence of the changing Arctic biodiversity.



Global CPR observations

Global CPR observations

An ecoregional assessment of the North Atlantic

Martin Edwards

Sir Alister Hardy Foundation for Ocean Science

Macro and multidecadal overview of plankton in the North Atlantic

The Continuous Plankton Recorder survey is a long-term sub-surface marine plankton monitoring programme consisting of a network of CPR transects towed monthly across the major geographical regions of the North Atlantic. It has been operating in the North Sea since 1931 with some standard routes existing with a virtually unbroken monthly coverage back to 1946. The CPR instrument is towed at the surface behind volunteer-operated vessels (ships of opportunity), sampling plankton onto a moving 270 μm (micrometre) band of net silk as the vessel and CPR unit traverse the North Atlantic and/or North Sea. Within the CPR instrument, the net silk and its captured plankton are preserved in formalin until they are returned to SAHFOS for routine analysis including the estimation of phytoplankton biomass (Phytoplankton Colour Index), and the identification of up to 800 different phytoplankton and zooplankton taxa (Warner & Hays 1994). Direct comparisons between the phytoplankton colour index and other chlorophyll *a* estimates including SeaWiFS satellite estimates indicate strong positive correlations (Batten et al. 2003; Raitsos et al. 2005). During the processing, the net silk is divided into sections representing 10 nautical miles of towing, and each section is analysed for plankton composition and abundance.

Due to the mesh size of CPR silks, many phytoplankton species are only semi-quantitatively sampled owing to the small size of the organisms. There is thus a bias towards recording larger armoured flagellates and chain-forming diatoms and that smaller species abundance estimates from cell counts will probably be underestimated in relation to other water sampling methods. However, the proportion of the population that is retained by the CPR silk reflects the major changes in abundance, distribution and specific composition (i.e. the percentage retention is roughly constant within each species even with very small-celled species) (Edwards, et al. 2006). The CPR now has a water sampler housed onboard certain CPRs to provide additional data and sample the whole size-spectrum of plankton using molecular techniques from bacteria and viruses to flagellates and other taxa not normally identified using standard CPR analysis. For the purpose of this assessment, the North Atlantic Basin has been geographically subdivided into different ecoregions. The 40 geographical regions shown in the figures are known as the CPR standard areas. The figures 1-4 showing regional trends in standard areas were generated using standard statistical methods for calculating annual means.

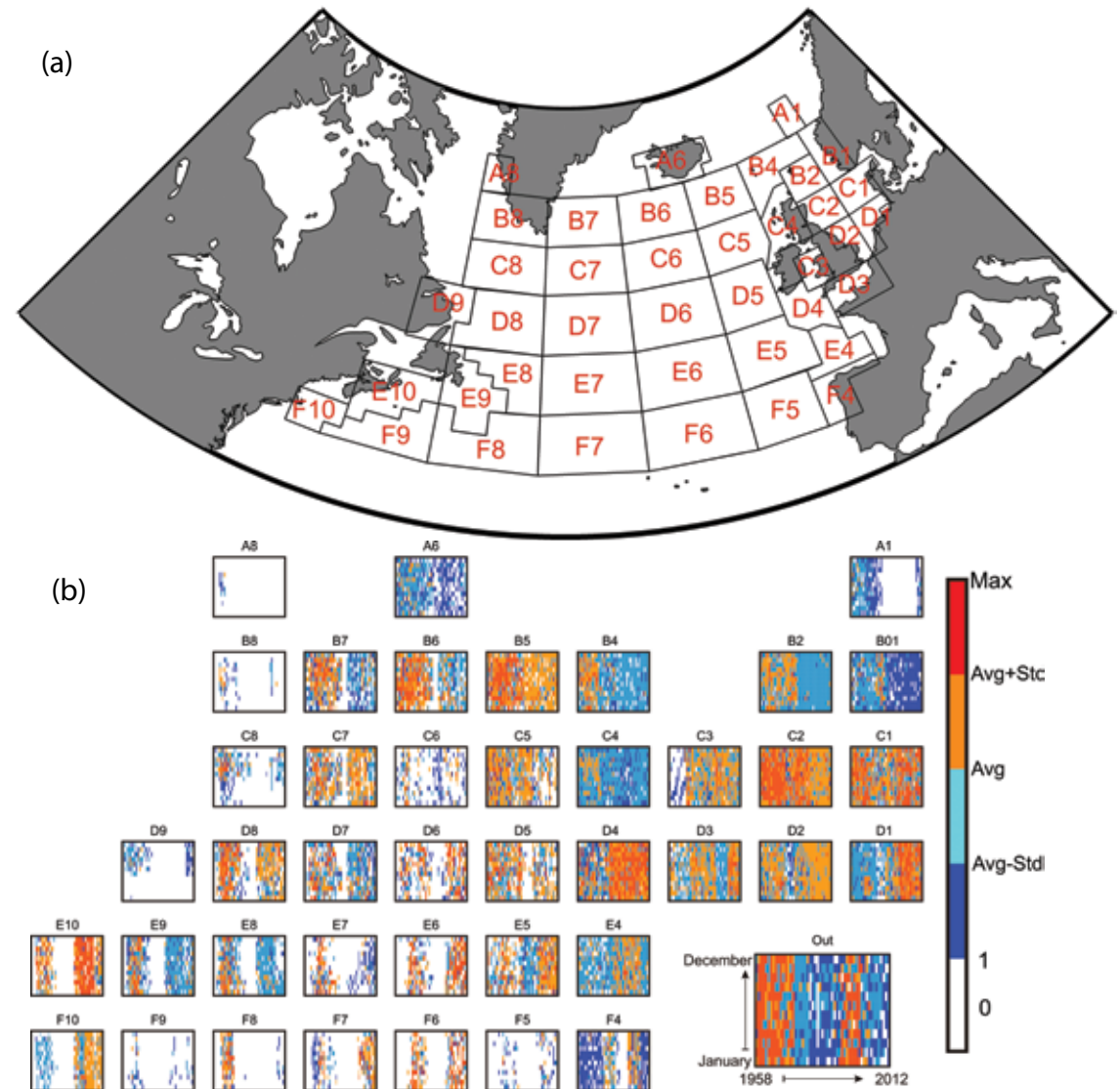


Fig. 1. (a) Continuous Plankton Recorder survey standard areas used in the analysis of regional patterns of plankton for the North Atlantic. (b) Monthly and annual sampling effort for the standard areas from 1958-2012.

Sea Surface Temperature



Phytoplankton Colour Index

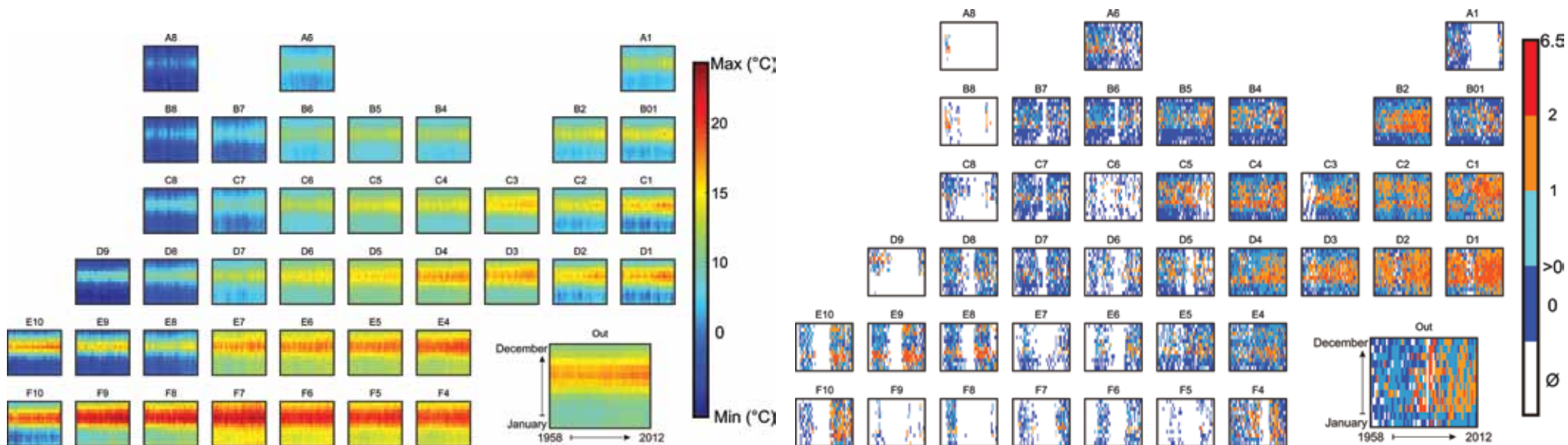
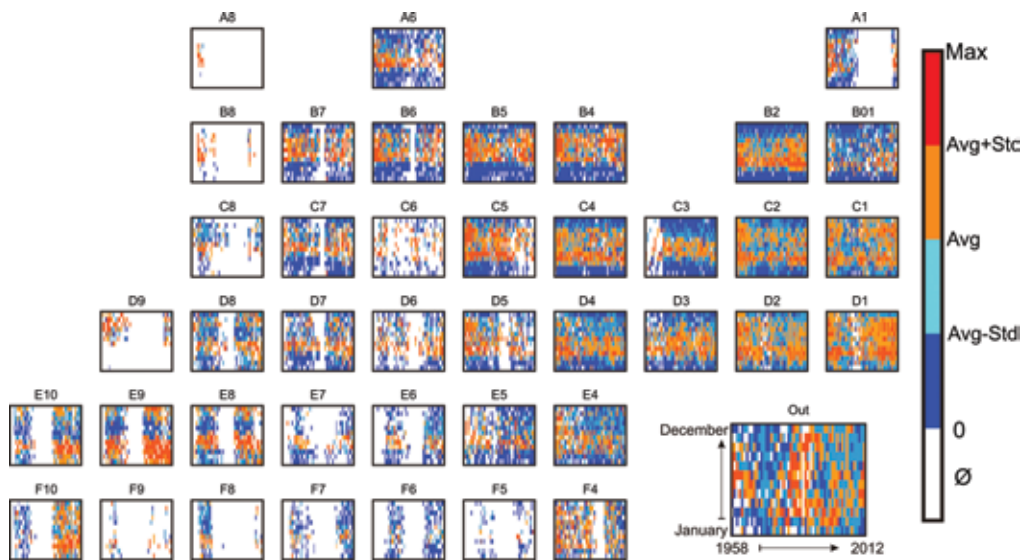


Fig. 2. Long-term trends in Sea Surface Temperature and Phytoplankton Colour in standard CPR regions of the North Atlantic from 1958-2012.



Diatom abundance



Dinoflagellate abundance

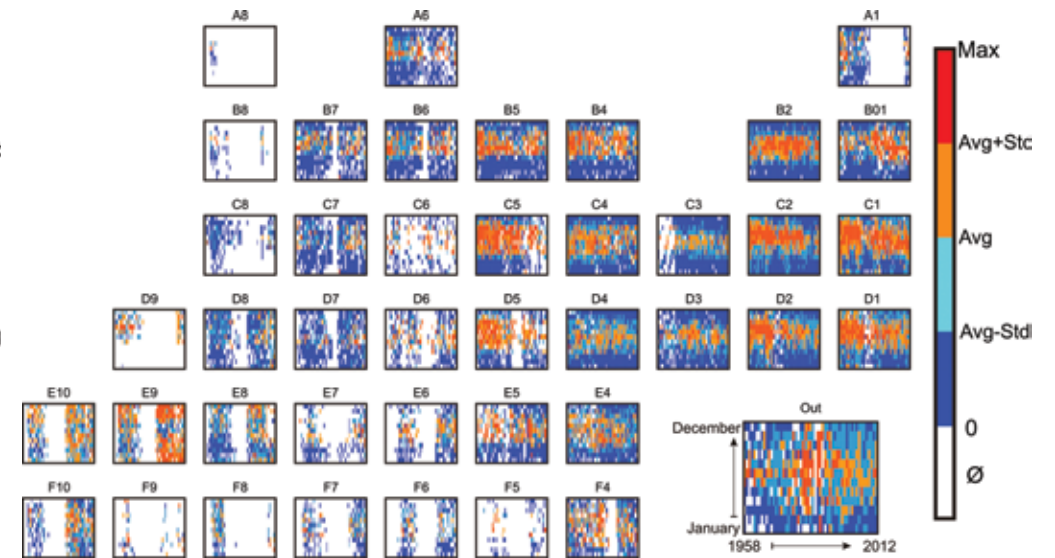


Fig. 3. Long-term trends in diatom and dinoflagellate abundance in standard CPR regions of the North Atlantic from 1958-2012.

Basin scale trends in plankton and natural variability

To summarise the long-term trends in plankton in the North Atlantic Basin we used indices of plankton that included the CPR Phytoplankton Colour Index (PCI) and the sum of the abundance of all counted diatoms and all counted dinoflagellates and total copepod numbers and mean copepod size. Using bulk indices like this are less sensitive to environmental change and will quite often mask the subtleties that individual species will give you; however, it is thought that these bulk indices represent the general functional response of plankton to the changing environment. In the North Atlantic, at the ocean basin scale and over multidecadal periods, changes in plankton species and communities have been associated with Northern Hemisphere Temperature (NHT) trends, the Atlantic Multidecadal Oscillation (AMO), the East Atlantic Pattern (EAP) and variations in the North Atlantic Oscillation (NAO) index. These have included changes in species distributions and abundance, the occurrence of sub-tropical species in temperate waters, changes in overall plankton biomass and seasonal length, changes in the ecosystem functioning and productivity of the North Atlantic (Beaugrand, et al. 2003; Edwards, et al. 2001; Edwards, et al. 2002; Edwards & Richardson, 2004; Reid & Edwards, 2001).

Contemporary observations over a 10 year period of satellite in situ blended ocean chlorophyll records indicate that global ocean net primary production has declined over the last decade, particularly in the oligotrophic gyres of the world's oceans (Behrenfeld et al. 2006). However, over the whole temperate NE Atlantic there has been an increase in phytoplankton biomass with increasing temperatures but a decrease in phytoplankton biomass in warmer regions to the south (Richardson & Schoeman, 2004), as shown in Figure 2. Presumably this is a trade-off between increased phytoplankton metabolic rates caused by temperature in cooler regions but a decrease in nutrient supply in warmer regions.

The amount of nutrients available in surface waters directly dictates phytoplankton growth and is the key determinant of the plankton size, community and foodweb structure. In terms of nutrient availability, warming of the surface layers increases water column stability, enhancing stratification and requiring more energy to mix deep, nutrient-rich waters into surface layers. Particularly warm winters will also limit the degree of deep convective mixing and thereby limit nutrient replenishment necessary for the following spring phytoplankton bloom.

It must be noted, however, that climate variability has a spatially heterogeneous impact on plankton in the North Atlantic and not all regional areas are correlated to the same climatic index. For example, trends in the AMO are particularly prevalent in the oceanic regions and in the sub-polar gyre of the North Atlantic and the NAO has a higher impact in the southern North Sea where the atmosphere-ocean interface is most pronounced (Harris et al. 2013). This is also apparent with respect to the Northern Hemisphere Temperature where the response is also spatially heterogeneous with areas of the North East Atlantic and shelf areas of the North West Atlantic warming faster than the North Atlantic average and some areas like the sub-polar gyre actually cooling. Similarly, regime shifts or abrupt ecosystem shifts do not always occur in the same region or at the same time. The major regime shift that occurred in plankton in the late 1980s was particularly prevalent in the North Sea and was not seen in oceanic regions of the North Atlantic. However, a similar regime shift occurred in the plankton colour index 10 years later in the Icelandic Basin and in oceanic regions west of the British Isles. The different timing and differing regional responses to regime shifts have been associated with the movement of the 10°C thermal boundary as it moves northwards in the North Atlantic (Edwards et al. 2013).

In examining the long-term trends in the plankton indices the general pattern is an increase in PCI for most regions in the North Atlantic with differing timings for the main step-wise increase being later in oceanic regions compared to the North Sea. For the dinoflagellates there has been a general increase in abundance in the North West Atlantic and a decline in the North East Atlantic over a multi-decadal period (see Fig. 3). In particular, some regions of the North Sea have experienced a sharp decline over the last decade. This decline has been mainly caused by the dramatically reduced abundance of the *Neoceratium* genus in the North Sea. However, *Neoceratium* abundance has recovered in the North Sea over the last two years. For the diatoms there is not really a predominant trend for the North Atlantic Basin as a whole (Fig. 3) but some regions show a strong cyclic behaviour over the multidecadal period. The time signal resembles an oscillation of about 50-60 years and a minimum around 1980 reflecting changes in the AMO signal. Trends in copepod abundances have been more stable in offshore regions but have shown a decrease in abundance, particularly in the southern North Sea. In summary, while climate warming is a major driver for the overall biomass of phytoplankton, diatoms are less influenced by temperature and show a strong correlation

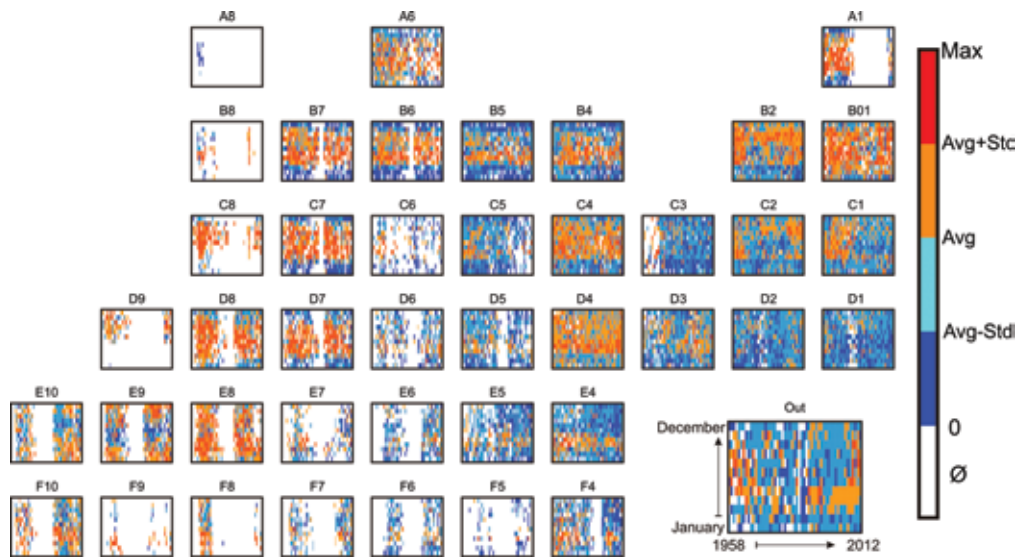
with the AMO signal and wind intensity in many regions (Harris et al. 2013). The increase in diatoms associated with the positive phase of the AMO and the decline in dinoflagellate abundance over the last 10 years in the NE Atlantic can be reflected in the diatom/dinoflagellates ratio favouring diatoms.

Indirectly the progressive freshening of the Labrador Sea region, attributed to climate warming and the increase in freshwater input to the ocean from melting ice, has resulted in the increasing abundance, blooms and shifts in seasonal cycles of dinoflagellates due to the increased stability of the water-column (Johns et al. 2001). Similarly, increases in coccolithophore blooms in the Barents Sea and HABs in the North Sea are associated with negative salinity anomalies and warmer temperatures leading to increased stratification (Edwards et al. 2006; Smyth et al. 2004). It seems likely that an important environmental impact caused by climate change is an increase in the presence of haline stratification in regions susceptible to fresh-water inputs resulting in an increased potential for bloom formation. Other trends including anthropogenic pressures such as ocean acidification and eutrophication are summarised in the next section on applied ecological indicators of the NE Atlantic.





Copepod abundance



Copepod mean size

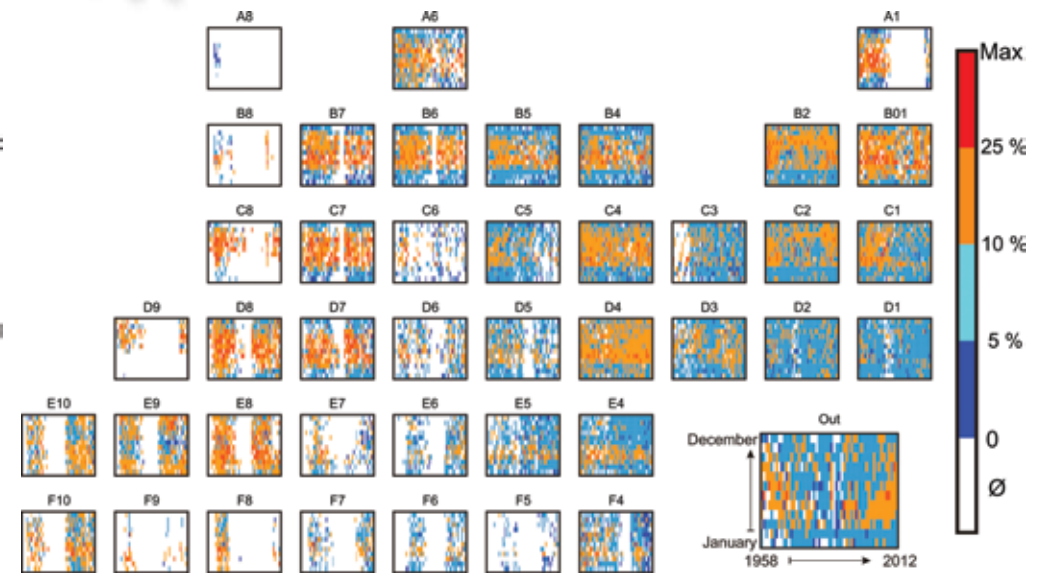


Fig. 4. Long-term trends in copepod abundance and copepod mean size in standard CPR regions of the North Atlantic from 1958-2010.

United States Northeast Shelf Ecosystem CPR survey

Chris Melrose

NOAA Northeast Fisheries Science Center

The NOAA Northeast Fisheries Science Center conducts two CPR transects within the United States Northeast Shelf Ecosystem: one crossing Gulf of Maine (GOM), and one crossing the Mid-Atlantic Bight (MAB) from New York toward Bermuda. Additional oceanographic sampling is also conducted on these transects using expendable bathythermographs (XBT), and thermosalinographs (TSG), in partnership with the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML).

While adjacent, the two sub-regions have distinct physical oceanographic characteristics, resulting in differing ecology and biota. The Gulf of Maine contains deeper basins, stronger tides, and is influenced by cold Labrador Current water entering via the Scotian Shelf. The warmer Mid-Atlantic Bight lacks the deep basins, and has a stronger influence from the Gulf Stream.

Annual means of the monthly standardized anomalies for XBT surface temperature, CPR Phytoplankton Color Index (PCI), total mesozooplankton abundance, the ratio of diatoms to total phytoplankton abundance, and the ratio of dinoflagellates to total phytoplankton abundance were calculated for both regions (Fig. 5).

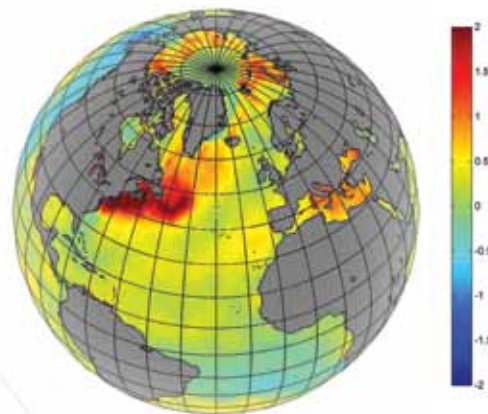
An overall warming trend is evident from the late 1970's to the present for both the Gulf of Maine and Mid-Atlantic sub-regions of the Northeast U.S. However, there is significant interannual variability superimposed on the long-term trends. In addition, the region experienced the warmest water temperatures recorded during this time-series in 2012. The warming trend in the MAB is statistically significant both with and without the 2012 data included. The trend in the GOM is significant only when the 2012 data are included. Due to a lag in the processing of the CPR samples, the possible impacts of the exceptionally warm conditions in 2012 on the plankton remain to be seen.

The Gulf of Maine phytoplankton color index (PCI) values were generally higher in the late 1980s and late 1990s, while values were lower in the 2000s driving an overall long-term decreasing trend. There was also a similar decline in the phytoplankton color index in the MAB, with the highest

values generally occurring prior to 1985. The declines in PCI suggest a decrease in the abundance of the larger phytoplankton cells that are sampled effectively by the CPR filtering mesh.

The ratio of total diatoms to total phytoplankton in the GOM has generally decreased, while the ratio of dinoflagellates to total phytoplankton has generally increased. This suggests an ecological shift favoring dinoflagellates relative to diatoms within the GOM. This same pattern is not evident in the MAB, with diatoms increasing and dinoflagellates decreasing as a fraction of total phytoplankton in the 2000s relative to the 1990s. The MAB's longer-term trend in the relative diatom abundance is also not well defined due to significant inter-annual variability.

The total mesozooplankton abundance in the GOM had generally higher values in the 1990s and lower values in the 2000s. The lowest values of the time series occurred in the late 1970's and early 1980s so overall there has been an increase in mesozooplankton since 1978. Similarly, the lowest mesozooplankton abundance in the MAB occurred in the 1970s and 1980s and has been generally higher since.



Temperature anomalies 2012

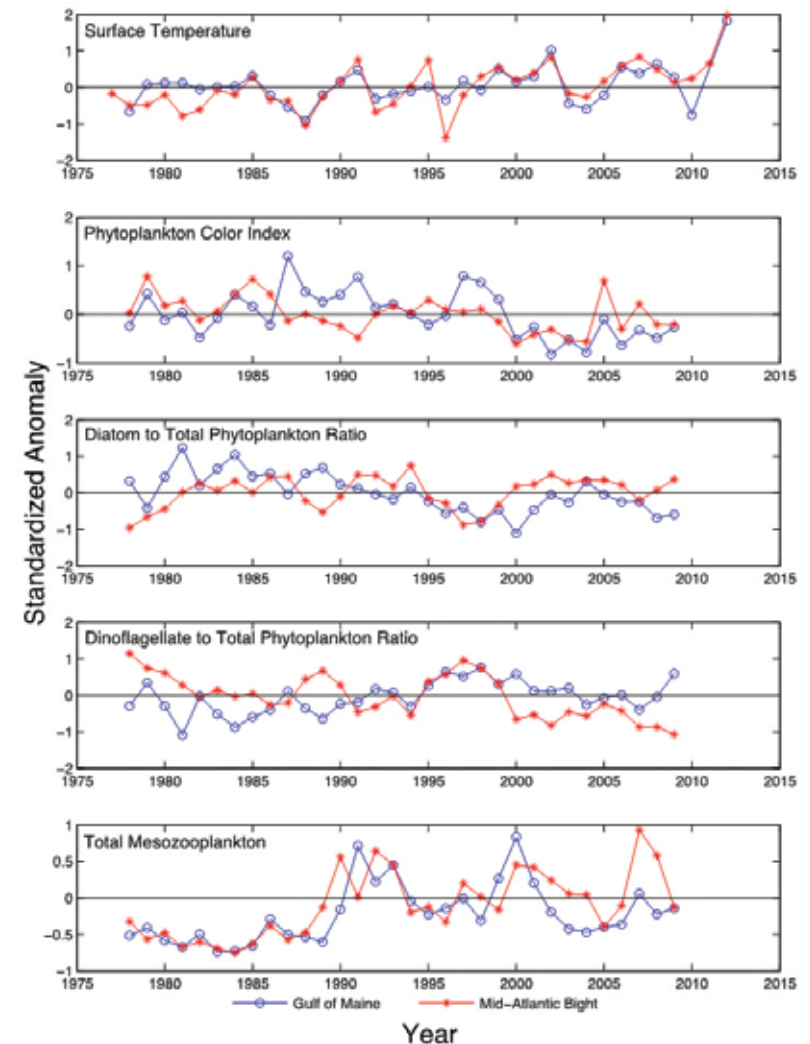


Fig. 5. The annual mean of the monthly standardized anomalies for surface water temperature, PCI, total mesozooplankton, the ratio of diatoms to total phytoplankton and dinoflagellates to total phytoplankton for the Gulf of Maine and Mid-Atlantic Bight CPR transects.

The Southern Ocean

Graham Hosie & John Kitchener

Australian Antarctic Division, Australia.

Karen Robinson, Julie Hall & Matt Pinkerton

National Institute of Water and Atmospheric Research, New Zealand

Kunio Takahashi

National Institute of Polar Research, Japan.

Since the 1930s there has been a systematic and substantial warming of the Southern Ocean with much of this concentrated in the Antarctic Circumpolar Current (ACC) (Aoki et al. 2003, Böning et al. 2008, Gille, 2002, 2008). Surface temperatures have increased by almost a degree, more than a tenth of a degree per decade, but significant increases are recorded at all depths (Aoki et al. 2003, Gille, 2008). Coupled with this has been a southward movement of the ACC fronts of approximately 0.6° of latitude (+60 km) (Sokolov & Rintoul, 2009b). Part of this warming has been attributed to human influence (Fyfe, 2006). The warming of the Southern Ocean is not uniform. Ducklow et al. (2007) described the western Antarctic Peninsula as “experiencing the most rapid warming of any marine ecosystem on the planet”. There has also been a freshening of the upper surface waters of the Southern Ocean (Boyer et al. 2005, Böning et al. 2008, Rintoul et al. 2012), which will lead to increased stratification and potentially a reduction in the input of nutrients into the euphotic zone (Rintoul et al. 2012).

Global warming will affect the extent and volume of sea-ice, which in turn will affect the sea-ice organisms such as Antarctic krill. There has been an approximate 25% loss of sea-ice between the 1950s and 1970s (de la Mare, 1997, 2009). Again, the effects of warming are not uniform. The Bellingshausen Sea in the Pacific sector has recorded the fastest ice retreat, whereas other regions have in particular the Ross Sea has recorded an increase in sea ice extent in the short term. In the long term, it is predicted that there will be an overall decline of winter sea-ice extent and volume of 24 to 34 % by the end of the 21st Century (Arzel et al. 2006, Bracegirdle et al. 2008, Turner et al. 2009).

The Royal Society Report on Ocean Acidification (2005) has predicted that increased absorption of CO₂ will lead to an under-saturation of aragonite by the end of this century which would result in plankton such as thecosome pteropod snails unable to produce a shell. This could occur as early as 2050 (Orr et al. 2005). However, acidification also affects the development of the larvae of Antarctic krill, a key prey species in the Antarctic marine ecosystem, may lead to a substantial decline in Antarctic

krill stocks which will have a substantial impact on the Antarctic food web and survival of large predators such as birds and marine mammals (Kawaguchi et al. 2013).

Atkinson et al. (2004) has already suggested that there has been a substantial wide-scale decline in the abundance and distribution of Antarctic krill, which is likely to be due to a decrease in sea-ice extent. At the same time salps, which usually prefer warmer waters, have increased their abundance in parts of the region north of the sea-ice/krill habitat. The assessment by Atkinson et al. (2004) was based on a dataset collated from numerous surveys which were primarily designed for purposes other than studying long-term trends, e.g. for stock assessment of krill, zooplankton composition, biogeography. Further, while Antarctic krill and salps are major components in the Southern Ocean in relation to biomass, so are numerous species of copepods, other euphausiids and other zooplankton species that were not considered in the analyses.

There have been some small regional scale assessments of long term trends in plankton. One example is the change in zooplankton biomass from the JARE Norpac net sampling operating annually since 1972/73 on two set transects in the Indian Ocean sector of the Antarctic (Takahashi et al., 1998). Another is the hypothesised changes in macro-zooplankton distributions in the southern Atlantic in response to increased ocean temperature using *Discovery* data from 80 years ago (Mackey et al. 2012). The SCAR Southern Ocean CPR Survey, initiated in 1991, is the only ocean scale systematic survey established for the sustained long-term routine observations of zooplankton biodiversity in the Southern Ocean.

In this year's report we look at long-term trends in two metrics, mean Total Zooplankton Abundance (TZA) and Average Copepod Community Size (ACCS) (Beaugrand et al. 2003).

Methods

The TZA, as the name implies, is the sum of abundance of all zooplankton collected in a section (sample) of CPR silk expressed as numbers per cubic metre. In the SO-CPR Survey each sample represents 5 nautical miles of tow, equivalent to 1.5 m³ of water filtered. The ACCS is a weighted mean calculation using the mid-range length of an adult female copepod as an index of the relative size of a species, multiplied by the number of individuals of that species. This is calculated for all copepod species in the sample, summed for all species and then divided by the total number of all copepods to produce a single ACCS value. The

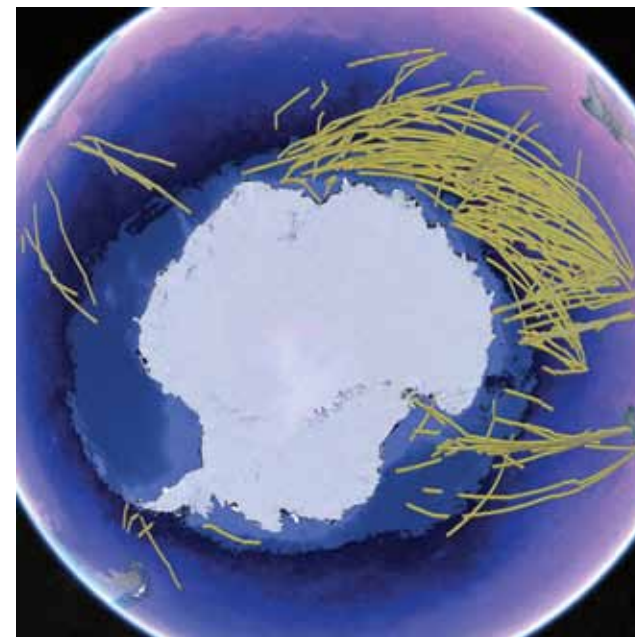


Fig. 6. Continuous Plankton Recorder samples in the Southern Ocean. Courtesy of Google Earth.

ACCS provides an index to compare changes in the dominance of species under the premise that warming oceans would see a shift to warm waters species that tend to be smaller.

Two regions of the Southern Ocean were compared, the East Antarctic region from 60 to 160°E where there has been the highest density of CPR tows to date, and the Ross Sea region between New Zealand and the Ross Sea, 160°E to 150°W where CPR tows have been conducted regularly since 2006 (Fig. 7). The SO-CPR Survey has conducted occasional tows in other parts of the Southern Ocean. The East Antarctic region includes FAO/CCAMLR Area 58 south of 55°S and the Ross Sea region includes Area 88 south of 60°S. The Antarctic region is characterised by sea-ice cover which extends from the continent north to about 20 million km² in September (late winter), and retreats to about 4 million km² in February (late summer). The area affected by the seasonal growth-retreat of sea-ice is referred to here as the Sea-Ice Zone (sometimes referred to as the Seasonal Sea Ice Zone) and one of the major drivers influencing the distribution, abundance and survival of biota of the region. Another important characteristic is the Antarctic Circumpolar Current, the largest of the world's currents, which flows uninterrupted eastward around

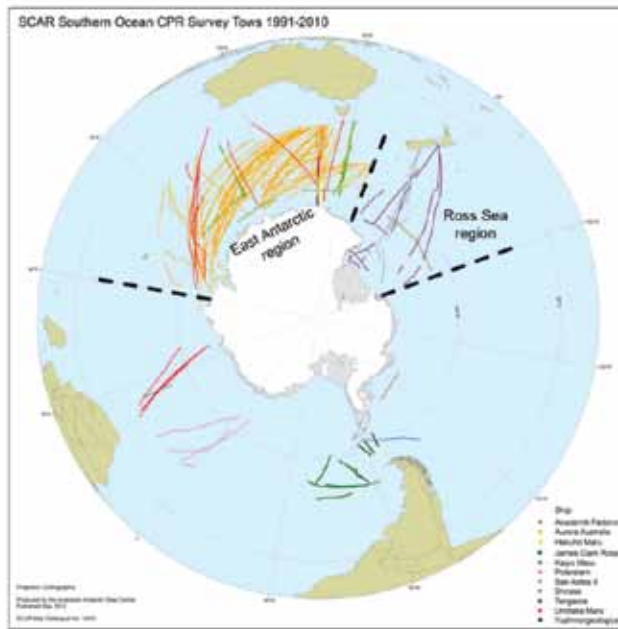


Fig. 7. Continuous Plankton Recorder samples in the Southern Ocean highlighting the three sectors used in the report.

Antarctica. In turn the ACC is characterised by numerous fronts and sub-branches, each with distinct oceanographic features. The northern boundary of the ACC is the Sub-Antarctic Front. The Southern Boundary of the ACC lies within the Sea-Ice Zone. Four predominantly latitudinal zones (Fig. 8) were compared within the East Antarctic and Ross Sea regions, these being (from south to north):

- the SIZ with the northern limit being defined as the maximum northern winter extent based on the 15% ice cover threshold,
- the Permanent Open Ocean Zone (POOZ) between the SIZ and the Polar Front, which lies within the ACC but displays a marked change in temperature and salinity,
- the Polar Frontal Zone (PFZ), between the Polar Front and the Sub-Antarctic Front,
- and the Sub-Antarctic Zone (SAZ), north of the Sub-Antarctic Front, which is a noted biogeographic boundary for zooplankton (Hunt & Hosie, 2005)

We used the positions defined by Sokolov & Rintoul (2009a) for the Polar Front and Sub-Antarctic Front.

Results & Discussion

Figure 9 shows the annual mean TZA for each zone in the East Antarctic (black line) and Ross Sea (red line) regions. Each year shown represents the austral sampling season which starts about September and finishes about March/April, hence year 2000 represents the 1999/2000 season, and 2004 is 2003/04. The value shown are means for each sampling season. Figure 9 shows a steady increase in abundance in all four zones of the East Antarctic region. All increases were statistically significant. The specific causes of these increases still needs to be identified. By contrast the Ross Sea region showed no trend in any of the four zones over the shorter period of CPR tows in that region. However, the total abundances of zooplankton in the Ross Sea region were generally higher than the abundances in the East Antarctic region. This coincides with the Phytoplankton Colour Index (PCI) scores on the CPR mesh being consistently higher in the Ross Sea region.

Figure 9 (bottom panel) shows the corresponding annual variations in ACCS scores. As with the abundances the ACCS scores increased significantly in all four zones of the East Antarctic region. The increase in ACCS values indicates a shift in the abundance and dominance of copepod species to larger species which is contrary to the hypothesis that warming waters, as is occurring in the region, would favour smaller warm water copepods. Other factors are driving the shift in species dominance and need to be determined. The CPR operations in the Ross Sea region have not been operating long enough to identify any trend with ACCS scores. We still need to complete full analyses of samples collected in the East Antarctic region during the 2011/12 and 2012/13 austral seasons, these were both intense sampling years. Inclusion of those data and continued tows in the future will reveal if there is any correspondence in ACCS patterns, within the same zones, between the East Antarctic and the Ross Sea region downstream in the Antarctic Circumpolar Current. Full details of the analyses and results are in Robinson et al. (2014).

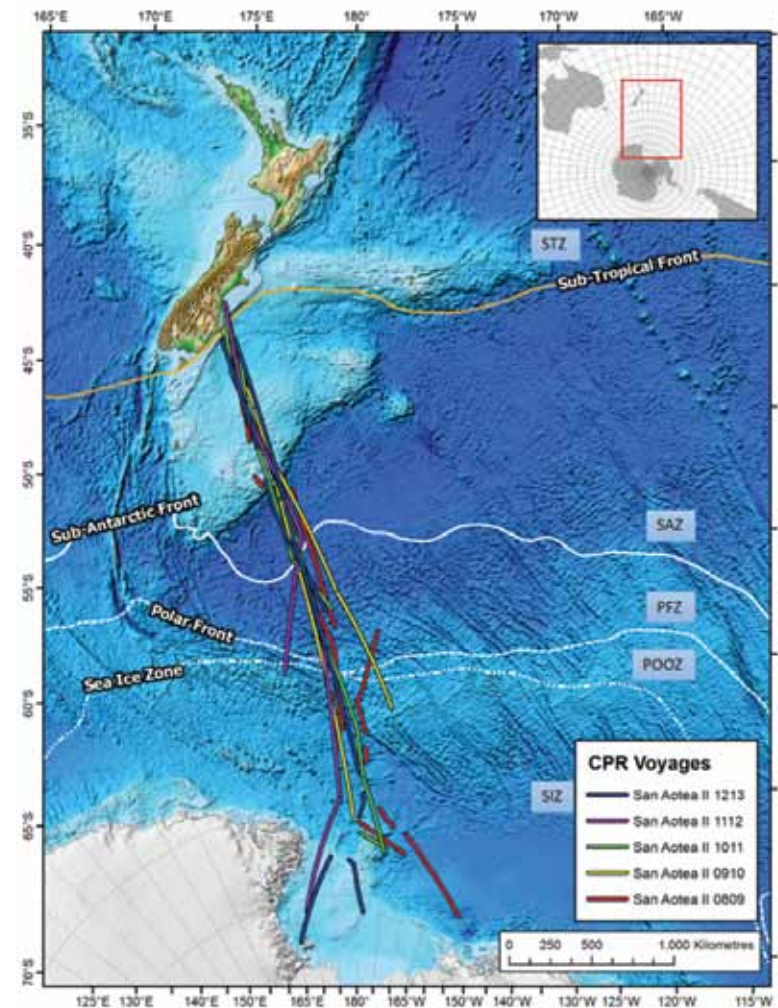


Fig. 8. Description of the latitudinal zones; Sea-Ice Zone (SIZ), Permanent Open Ocean Zone (POOZ), Polar Frontal Zone (PFZ) and Sub-Antarctic Zone (SAZ). The positions of the fronts and ice edge is approximate.

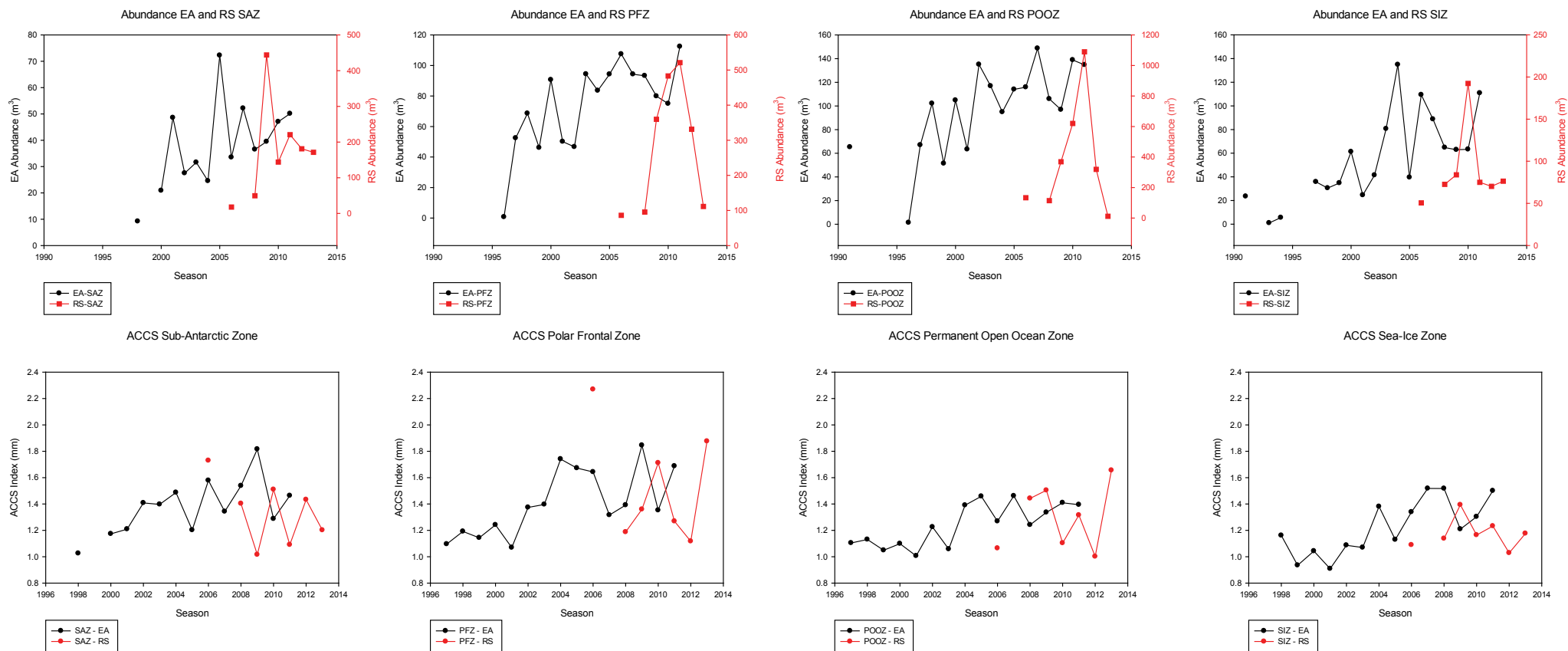


Fig. 9. Top panel. Mean Total Zooplankton Abundance for the East Antarctic (EA) black, and Ross Sea region (RS) red for the Sub-Antarctic Zone, the Permanent Open Ocean Zone and the Sea Ice Zone.. Bottom Panel. Average Copepod Community Size for the East Antarctic (EA) black, and Ross Sea region (RS) red for the Sub-Antarctic Zone, the Permanent Open Ocean Zone and the Sea Ice Zone.

The Northeast Pacific

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The status of two ecoregions in the NE Pacific sampled by the CPR are described here: the oceanic subarctic gyre and the temperate shelf and slope to the east.

The Northeast Pacific continued to be cooler than average through 2012, in contrast to the global mean, making this the 6th continuous year of cool conditions, with the exception of a brief period in late winter 2010 when a moderate El Niño contributed warmth for a few months. Both the subarctic gyre region and the eastern shelf and slope region were cool. The cooling has been linked to stronger westerly winds during this period and further details on the oceanographic conditions in 2012 can be found in Irvine and Crawford (2013).

Continuous Plankton Recorders were deployed as usual during 2012, sampling spring through autumn along two transects which both sample the coastal and oceanic regions described here. The loss of a CPR midway through the August transect meant that no data were collected in the oceanic region in that month, but an additional transect was sampled in October. Summary indices from the CPR data, in the form of mean annual anomalies of diatom abundance and mesozooplankton biomass (estimated dry weight) are shown in Figure 11. 2012 saw positive anomalies in both large diatoms and mesozooplankton abundance, in contrast to the last few years where anomalies were mostly negative.

The positive diatom anomaly in 2008 in the oceanic gyre was likely caused by a volcanic eruption contributing the limiting nutrient, iron, to a large part of the oceanic region (Hamme et al. 2010). There are no long term trends in the time series, but this is the first positive zooplankton biomass anomaly in the oceanic region since 2006. This is somewhat counter-intuitive since cool conditions are assumed to be more favourable for the larger subarctic copepods that dominate the zooplankton in spring and early summer. Subarctic zooplankton are more suitable prey for higher trophic levels in the region, such as juvenile salmon and planktivorous seabirds. More extensive sampling in the shelf region also showed positive anomalies of subarctic species in 2012 (Irvine & Crawford, 2013). Warm water species were still in very low numbers in the oceanic CPR samples in 2012, as they have been since 2007, and negative warm water species anomalies were also recorded for the shelf region.

In summary, the impact of the recent cool period is clearly evident in the plankton; a later spring zooplankton peak in oceanic waters. There was a noticeable reduction in the abundance of dinoflagellates across both regions and a decline in PCI values in the oceanic region. However, by April 2012 the La Niña conditions were becoming neutral so future updates may reveal additional changes in lower trophic level phenology and community composition.

The Northwest Pacific

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Ecoregion

The study area is west of 170°E on the east-west North Pacific CPR transect, 'VJ line' (see the Northeast Pacific Status details on the North Pacific CPR survey and operation for the year of 2011/2012). This region covers two biogeochemical provinces, which are roughly divided at the meridional boundary of 155°E, into Oyashio region (west section) characterized with high nutrient concentration and a distinctive spring bloom, and Western North Pacific Subarctic Gyre (WSG) (east section) with a HNLC condition of inner gyre. Despite differences in biogeochemical properties, dominant zooplankton species are common between the two provinces.

Size structure and species composition of the summertime (June-July) zooplankton community varied responding to the SST anomaly related to Pacific Decadal Oscillation (PDO) for 2000-2010. Copepod community size, CCS (Richardson et al. 2006), which is based on the female total body length, is used as a zooplankton size index, and change in the species composition was examined by Principal Component Analysis (PCA). We did not conduct separate analysis for the Oyashio and WSG because interannual variation of zooplankton community structure is similar in both provinces.

Time-series CCS showed a marked increase in abundance of larger copepods after 2006



Fig. 10. Continuous Plankton Recorder samples in the Northeast Pacific. Courtesy of Google Earth.

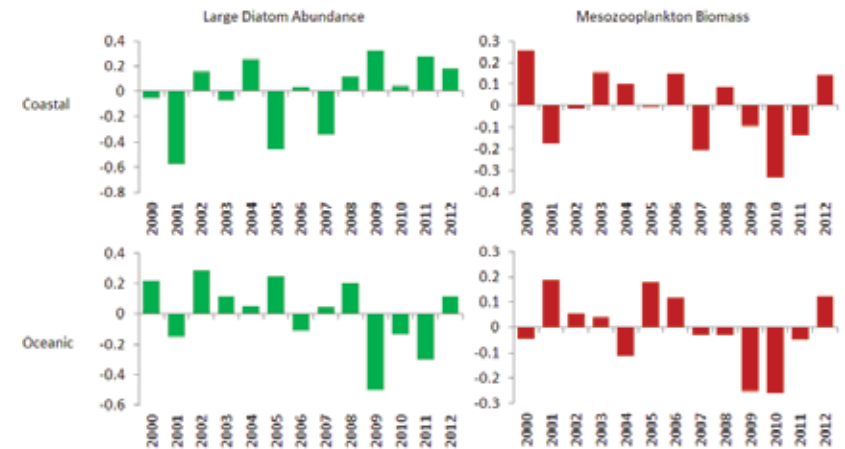


Fig. 11. Mean annual anomalies (log10) of large diatom abundance (left) and estimated mesozooplankton dry weight (right) for the shelf/slope region (upper) and oceanic subarctic gyre region (lower).

(Fig. 12 upper). The 2nd PC indicated an increase in abundance of large, cold-water calanoid species, *Neocalanus plumchrus*, *Neocalanus cristatus* and *Metridia* spp, contributed to higher CCS after 2006 (Fig. 12 lower). PDO is positive for 2003-2005 and gradually shifts negative for 2006-2010 (Fig. 14 upper). Monthly average SST in June and July is warmer in 2006-2011 compared to 2000-2005 over the study area of the Northwest Pacific while it is cooler in the Northeast Pacific, showing an east-west dipole PDO-SST pattern (Fig. 14 lower). Interannual CCS has a significant positive correlation with SST, indicating 'more larger species in warmer condition' (Fig. 15).

This result is counterintuitive as previous studies have reported that regional warming induces increase and decrease in small, warm-water smaller species and large, cold-water species, respectively, both in Northeast Subarctic Atlantic (Beaugrand et al. 2002) and Northeast Subarctic Pacific (Keister et al. 2011). In fact, increase in *Neocalanus* species abundance in the Oyashio during the 1990s with warmer condition after the previous cooler period have been reported in decadal scale, and change in timing of phytoplankton bloom is suggested to be a good-match with copepods production in these years (Chiba et al. 2008). A possible explanation of the observed difference in zooplankton community responses to regional warming might be brought by regionally specific climate-ocean control in the Eastern and Western boundary current systems: PDO related atmospheric circulation influences strength of oceanic currents and advective transport of zooplankton in the former, while it dominates seasonal mixed layer processes and bottom-up control of zooplankton production in the latter (Di Lorenzo et al. submitted).

In recent years, satellite observations and the CPR survey revealed that the spring bloom occurred later in cool years, 2003-2007, and earlier in warm years, 2000-2002 and 2008, 2009. PDO related changes were also reported in phytoplankton phenology and community structure for this region. Relative abundance of dinoflagellates to diatoms significantly increased in the years of rapid summertime warming, rather than merely being correlated to monthly or seasonal mean temperature, indicating seasonal process in mixed layer stratification might be responsible for the formation of seasonal phytoplankton community structure (Chiba et al. 2012).

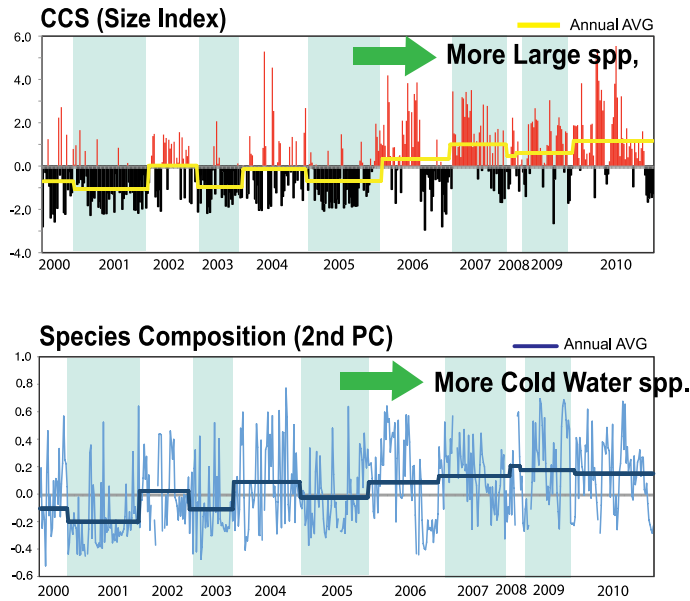


Fig. 12. Interannual variation in Zooplankton size index (Copepod Community Size Index) and the Principal Component of zooplankton species composition (lower). Each bar indicates the value of a sample taken from east to west of the transect each year. Possible bias caused by spatio-temporal sampling variation was corrected using MLR. Indices are residuals of the observed minus predicted.

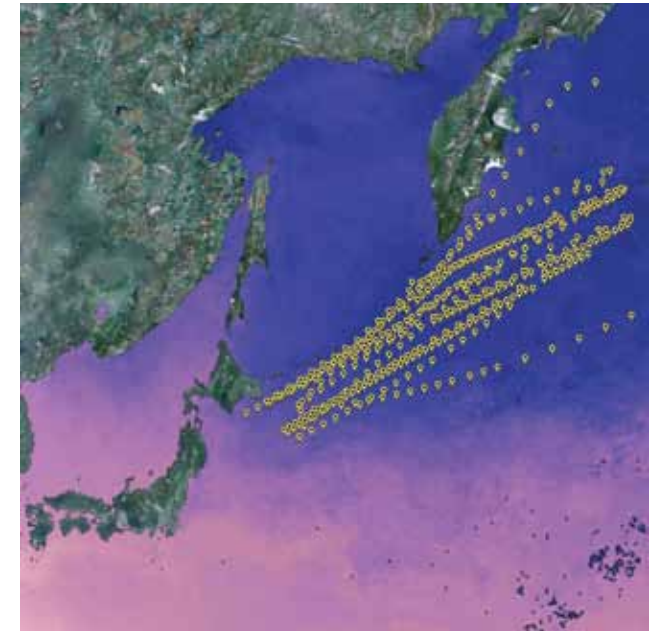
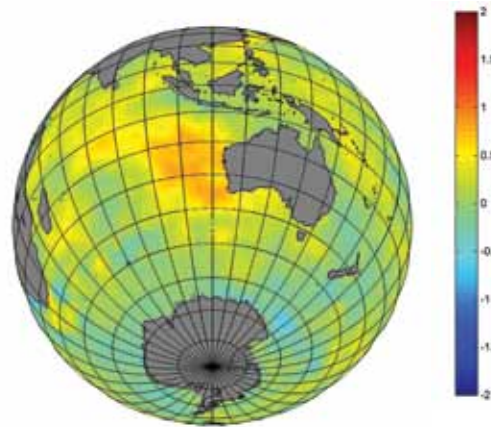


Fig. 13. Continuous Plankton Recorder samples in the Northwest Pacific. Courtesy of Google Earth.



Temperature anomalies 2012

The Benguela Current Large Marine Ecosystem (BCLME)

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The Benguela Current Large Marine Ecosystem (BCLME) off the west coast of southern Africa (5-37°S, 0-26°E), spans the coasts of Angola, Namibia and South Africa. The region is characterised by a narrow coastal belt of cold, phytoplankton-rich water. A unique feature of this eastern boundary current upwelling system is that sharp discontinuities occur at the northern boundary in the Angola-Benguela Frontal Zone (12-18°S) and at the southern boundary with the Agulhas Current (32-37°S), characterized by intensive mixing and high variability. There are seven particularly

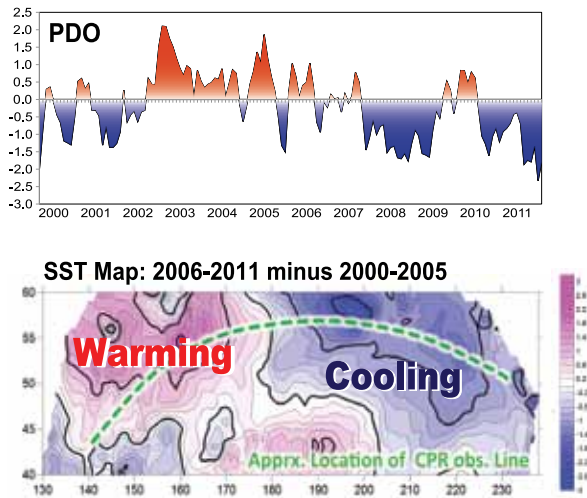


Fig. 14. PDO index (upper) and Sea Surface Temperature (SST) map (lower) over the subarctic North Pacific, showing the SST gradient in the years before and after 2006.

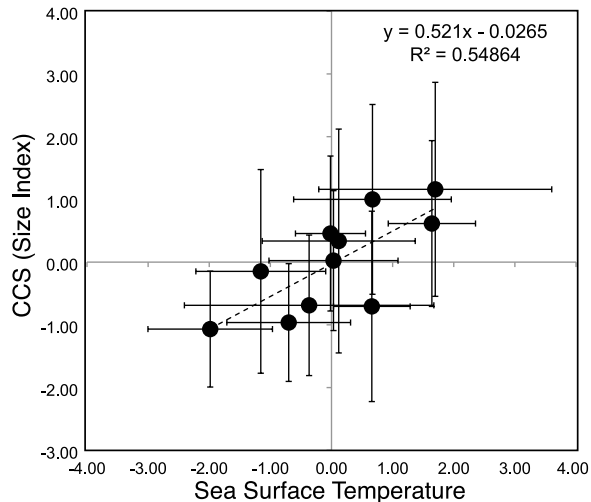


Fig. 15. Annual average of zooplankton size index (CCS) and Sea Surface Temperature (SST). Error bars indicate standard deviation.

active, wind-driven upwelling sites within the major Benguela upwelling region, of which the perennial Lüderitz cell (25-26°S) is the most powerful in terms of Ekman transport and turbulent mixing and separates the northern from the southern Benguela sub-system.

The BCLME is regarded as one of the richest ecosystems in the world with ecosystem goods and services estimated to be worth at least US\$ 54.3 billion per year from offshore oil and gas production, marine diamond mining, coastal tourism, commercial fishing and shipping. On March 18th 2013, the three aforementioned BCLME countries signed the Benguela Current Convention and the launch of the Benguela Current Commission (BCC), a permanent inter-governmental organisation. The convention has been formed to promote a coordinated regional ecosystem approach to the long-term conservation, protection, rehabilitation, enhancement and sustainable use of the BCLME, to provide economic, environmental and social benefits. The BCC is now mandated to, inter alia, guide the management of trans-boundary resources, both living and non-living, through agreeing on conservation and management measures and through promoting harmonisation, implementation and enforcement of existing and applicable policies and laws for these resources and the environment; and to agree on measures to minimise pollution.

The following paragraphs summarize recent observations of ecological conditions prevailing off the west coast of southern Africa, including both the northern and southern Benguela sub-systems. In the current absence of CPR data for this large marine ecosystem, information was extracted from Namibia's Annual Report 2011/2012 (MFMR 2013) and South Africa's most recent reports on the state of the oceans (Verheye, 2013) and status of marine fishery resources (van der Lingen et al. 2012). There has been widespread surface warming at both the northern and southern boundaries of the BCLME as well as in the northern Benguela since the early 1990s. Whereas the northern part of the southern Benguela has also warmed, there has been some increase in summer upwelling and a general cooling of inshore waters in the southern part of the southern Benguela, as well as on the south coast of South Africa, since the mid-1990s. The upwelling-favourable winds off the coast of Lüderitz continued to show a negative trend in 2011 although a positive trend was observed at the end of the year. The sea surface temperature off Namibia was much warmer than average for the first third of 2011, average during the second third of the year and slightly cooler than average during the last third of 2011. Shelf waters off central Namibia exhibited the normal seasonality of low bottom oxygen during summer/autumn changing to oxygenated conditions

during winter/spring. No major low-oxygen events have been documented since 2000/2001.

A time-series of an enrichment index, calculated since 1997 as satellite-derived surface chlorophyll *a* concentrations integrated between the coast and the 1 mg m⁻³ offshore limit, shows clear spatial and seasonal, inter-annual and inter-decadal variability of phytoplankton biomass alongshore of the entire Benguela Current region. High index values are generally observed off the Namibian coast (16-26°S) in the northern Benguela, where upwelling is at a maximum in austral winter/spring, leading to a tendency for chlorophyll-maxima to occur around the middle of the year. In 2010, the mid-year maximum was very conspicuous in the region north of 22°S, with the highest values yet seen in this data series. By contrast, index values during 2011 have been the lowest since 2003. The low satellite-derived chlorophyll values during 2011 were also observed in the time-series of *in situ* measured chlorophyll *a* data. Consistently elevated chlorophyll index values were observed throughout this region from January to July 2012. Off Lüderitz (26-28°S) where upwelling-favourable winds blow stronger and more perennially, a relative chlorophyll-minimum is evident throughout the year, due to the extreme turbulence. Chlorophyll concentrations there seem to have been increasing gradually since the start of the time-series.

In the southern Benguela, upwelling is strongly pulsed and phytoplankton biomass shows strong seasonality, with clear winter minima (i.e. opposite to the northern Benguela). Chlorophyll index values are normally elevated in the region affected by upwelling (28-33°S). In the northern part of this region, chlorophyll concentration tends to peak in spring, whereas in late summer in the southern part. During 2010, concentrations were moderate in the region between 28 and 30°S in late summer, but further south, concentrations were high. The 2011 and 2012 index values suggest low chlorophyll concentrations in the north and high concentrations in the southern part of the region. Low chlorophyll index values are characteristic for the area between 33 and 34°S, but there still is a clear seasonality with summer maxima and winter minima. Chlorophyll concentrations in this area had been moderately high during the 2010/2011 summer, but low during the rest of 2011. Elevated concentrations were observed during the first four months of 2012, contrasting the very low values during the remainder of the year.

During the past six decades there have been long-term changes in the abundance and structure of coastal zooplankton communities in both the northern and southern Benguela sub-systems. Copepod numbers increased by at least one order of magnitude

between the 1950s and mid-1990s in the southern Benguela, and between the 1970s and early/mid-2000s in the northern Benguela. Copepod abundances declined steadily off South Africa from around 1995, whereas off Namibia (Fig. 17), they show a decline only in early 2005 after having reached an all-time high between 2002 and 2004. The seasonality, with highest copepod abundances found in austral spring is clearly seen. Copepod abundances on the 20°S and 23°S transects monitored since 2000 were lowest during 2009 to 2011, and since then abundances have increased again. Both subsystems also experienced a substantial shift in copepod community structure, from a large- to a smaller-species dominance. Likewise, there has been a marked decline in zooplankton abundance on the Agulhas Bank, to the south of South Africa, in spring/summer over the past two decades, in particular that of the large, dominant copepod species *Calanus agulhensis*. This has also led to a gradual shift toward a community dominated by smaller copepod species.

The observed spatial, temporal and size-based heterogeneity of zooplankton abundance in the BCLME suggests that zooplankton fluctuations are mediated locally and differentially through both bottom-up and top-down forcing mechanisms. However, while the observed shift to an increasing dominance of smaller copepods may reflect progressive ocean warming, changes in their abundance could be as much due to changes in predation pressure by the exploited small pelagic fish species as to large-scale environmental effects, but there is presently uncertainty about the relative importance of these forcing mechanisms in the Benguela region.

The virtual removal of the 'wasp-waist' species, anchovy and sardine, from the northern Benguela during the 1970s and 1980s has resulted in a possibly irreversible shift to a less efficient and less environmentally robust regime, believed to be dominated by gobies, jelly fish and horse mackerel. Despite low fishing pressure on anchovy and sardine in Namibia over the past two decades, there is no sign of a recovery of these stocks. The most obvious change in the southern Benguela ecosystem over the past two decades has been a distributional shift of anchovy and sardine (as well as rock lobster) from the West Coast south- and eastward to the Agulhas Bank in the late 1990s. While this shift is not believed to be as far-reaching or as likely to be irreversible as that in the northern Benguela, its causal factors are poorly understood but may be at least partly environmentally driven. Currently, small pelagic resources in South Africa are in optimal or abundant states, and while recruitment of all pelagic species was relatively low in 2011 and the anchovy stock is at the lowest level observed during the past 15 years, sardine and round herring stocks continue to increase.

The South African hake resource comprises two species, shallow-water and deep-water Cape hake. They are distributed on the continental shelf and upper slope around the coast of southern Africa. Uncertainty remains as to the extent to which the deep-water hake resource is shared between South Africa and Namibia. At present, the two fisheries are managed independently, although the recently established Benguela Current Commission aims to work towards joint management of this resource provided there is sufficient sharing of the resource between the two countries to warrant this. Nowadays Cape hake are targeted by four fishery sectors in South Africa: deep-sea demersal trawl, inshore demersal trawl, hake longline and hake handline, with most of the catch being taken by the deep-sea trawl sector. Results of the 2011 updated assessment indicate that, while the status of the shallow-water hake resource is considered optimal to abundant, that of the deep-water hake resource remains depleted but approaching the MSY level more rapidly than was projected previously, owing to the implementation of precautionary management approaches since 2006.

The January/February 2012 swept-area biomass survey for assessing hake in the northern Benguela showed the total relative abundance estimates to be 25% lower from the previous year of around 1 million tonnes. The age-structured production model (ASPM) estimated the status of the Namibian hake stock to be above the state of the stock in 1990, while the overall stock indicator is still well below the MSY level.

Monitoring populations of land-breeding seabirds that feed at sea, especially those with a wide range, facilitates tracking changes lower down marine food webs and detection of effects of fisheries, marine pollution and global change. Of the 15 species of seabird that breed around South Africa's coast, five species (Great White Pelican, Crowned Cormorant, White-breasted Cormorant, Kelp Gull and Roseate Tern), which do not feed to any great extent on fish that are commercially harvested, have been stable or even increased off South Africa over the past three decades. In contrast, three species (Cape Cormorant, Bank Cormorant and African Penguin) endemic to southern Africa that do compete with fisheries for food have recently shown 50% decreases in population size, while two more mobile endemic species (Cape Gannet and Swift (Crested) Tern) that also compete with fisheries have not shown decreases. The decreases of the three less mobile species are attributable to the abovementioned eastward shift of prey resources (anchovy, sardine, rock lobster), which brought about a mismatch in the breeding locations and food of the seabirds. Food scarcity along western South Africa was exacerbated by fisheries seeking to maintain harvests in the



Fig. 16. Continuous Plankton Recorder samples in the South Atlantic. Courtesy of Google Earth.

same region. The Cape Fur Seal is a protected species and the only pinniped breeding in southern Africa, with a preference for islands where they are less vulnerable to land predators and have better access to foraging areas. Their abundance and the number of breeding colonies on the west coast of South Africa have been increasing rapidly since the 1970s. This has necessitated them to colonise the mainland and re-colonise formerly occupied islands. Some of these islands recently turned from a haul-out site into a full-blown breeding colony for seals in a matter of only a few years. This has led to adverse interactions with other island residents such as seabirds, resulting in unsustainable mortality of seabird fledglings and displacement due to reduced breeding space and nesting sites.

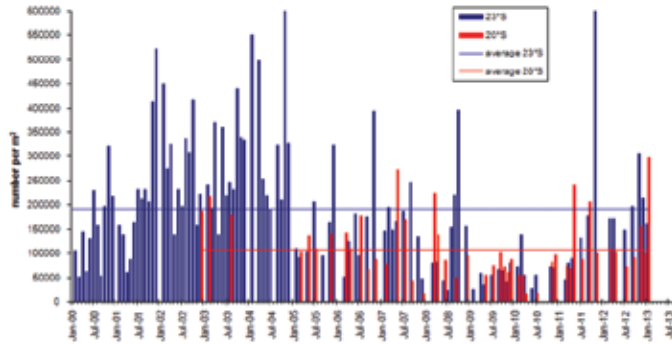


Fig. 17. Copepod abundance in number per m² (averages for the 10 – 70 nm stations) on the 23°S (blue) and 20°S (red) transects in the northern Benguela from February 2000 to February 2013. Horizontal lines represent the average abundance of each transect for the time-series.

The Australian Continuous Plankton Recorder Survey (AusCPR)

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The AusCPR survey samples in Australian waters, in the Tasman Sea across to New Zealand, and in the Southern Ocean (in conjunction with SO-CPR). Australia is unique globally in being bounded by two poleward-flowing warm-water currents and the survey samples the east, west and south coasts of Australia. Since 2009, the AusCPR survey has towed 41,500 nautical miles, counted a total of 3,882 samples for 681 zooplankton taxa and 238 phytoplankton taxa.

We have used Longhurst provinces to divide up the Australian marine domain into ecoregions (Fig. 19). There are a total of six Longhurst provinces in the Australian region that have AusCPR data: viz. AUSE (Eastern Australia Coastal), ARCH (Western Pacific Archipelagic Deep Basins), TASM (Tasman Sea), AUSW (Australia-Indonesia Coastal), MONS (Indian Ocean Monsoon Gyres), SSTC (South Subtropical Convergence).

There has been a substantial warming trend in all Longhurst provinces around Australia (Fig. 20). Australian regions are generally warming faster than the global average since 1960s (about 0.07°C/decade). The fastest warming in Australia is in the AUSE province (0.14 °C/decade), followed by AUSW (0.11), MONS (0.11), ARCH (0.09), SSTC 0.08 and TASM (0.07) over the past 50 years.

The AusCPR dataset is now 4 years long, allowing the first glimpses of how the current year compares with previous years sampled. In 2012, PCI was generally lower than the long-term mean in the Australian provinces, but was higher in AUSW (Fig. 20). Interestingly, total copepod abundance was generally higher in 2012 than the long-term mean, except in SSTC (Fig. 21). As the time series grows in length, we will be more confident in the long-term mean.

The survey is proving valuable for describing large-scale patterns in community structure and diversity. Mean copepod size was similar in 2012 to previous years (Fig. 21). As waters around Australia are generally warm, so many of the copepods are small – our mean copepod size across all samples is 1.15 mm, considerably smaller than in the Southern Ocean for instance. There is steep decline in mean copepod from 20-65°S, going from <1.5 mm throughout the year from 20-40°S, up to 1.5-3.5 mm in the Southern Ocean. Mean copepod richness declines markedly from 20-65°S in the AusCPR region. Copepod richness declines from 8-20 species per sample in most seasons from 20-40°S, to <5 species per sample in the Southern Ocean.

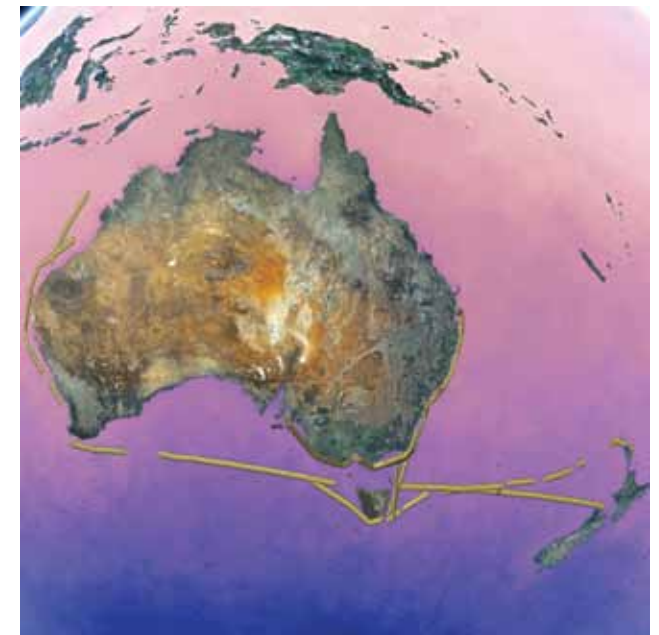


Fig. 18. Continuous Plankton Recorder samples in Australian waters. Courtesy of Google Earth.

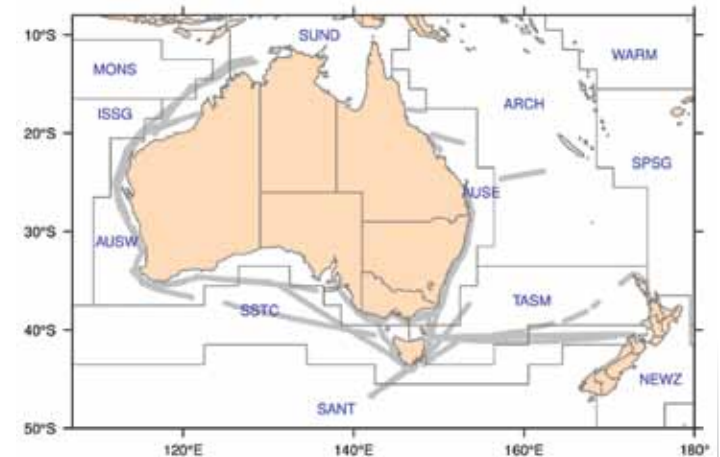


Fig. 19. Longhurst provinces for the Australian region.

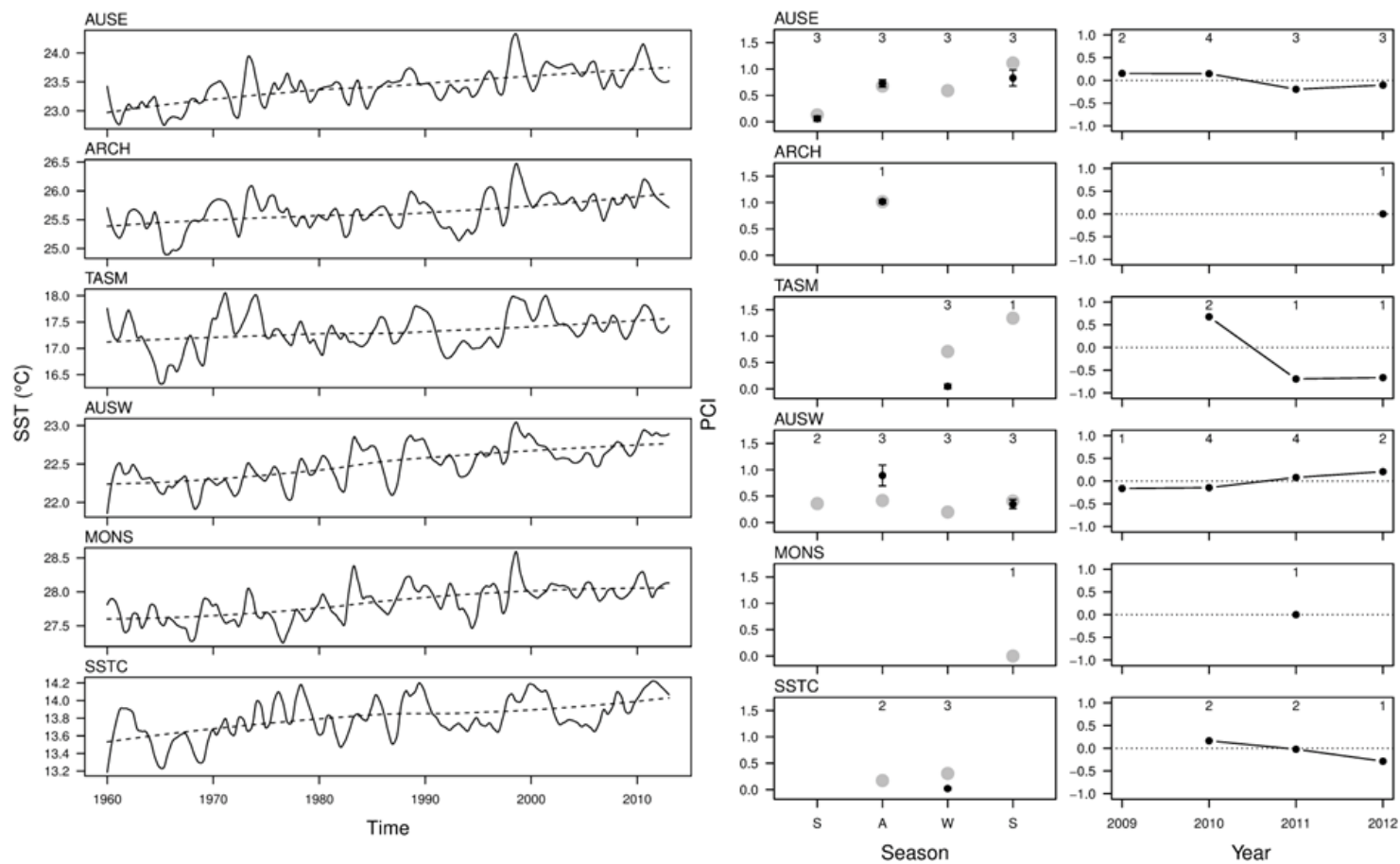


Fig. 20. (left panel) Sea surface temperature since 1960 for the Longhurst provinces in the Australian region. (right panel) Phytoplankton Colour Index in Longhurst biogeochemical provinces in Australia. Left. Seasonal means, with 2012 in black and the climatology in grey. Error bars are 95% confidence intervals. The number of years included in each climatology is shown along the top. Right. Annual mean anomalies, with the number of seasonal anomalies included shown along the top.

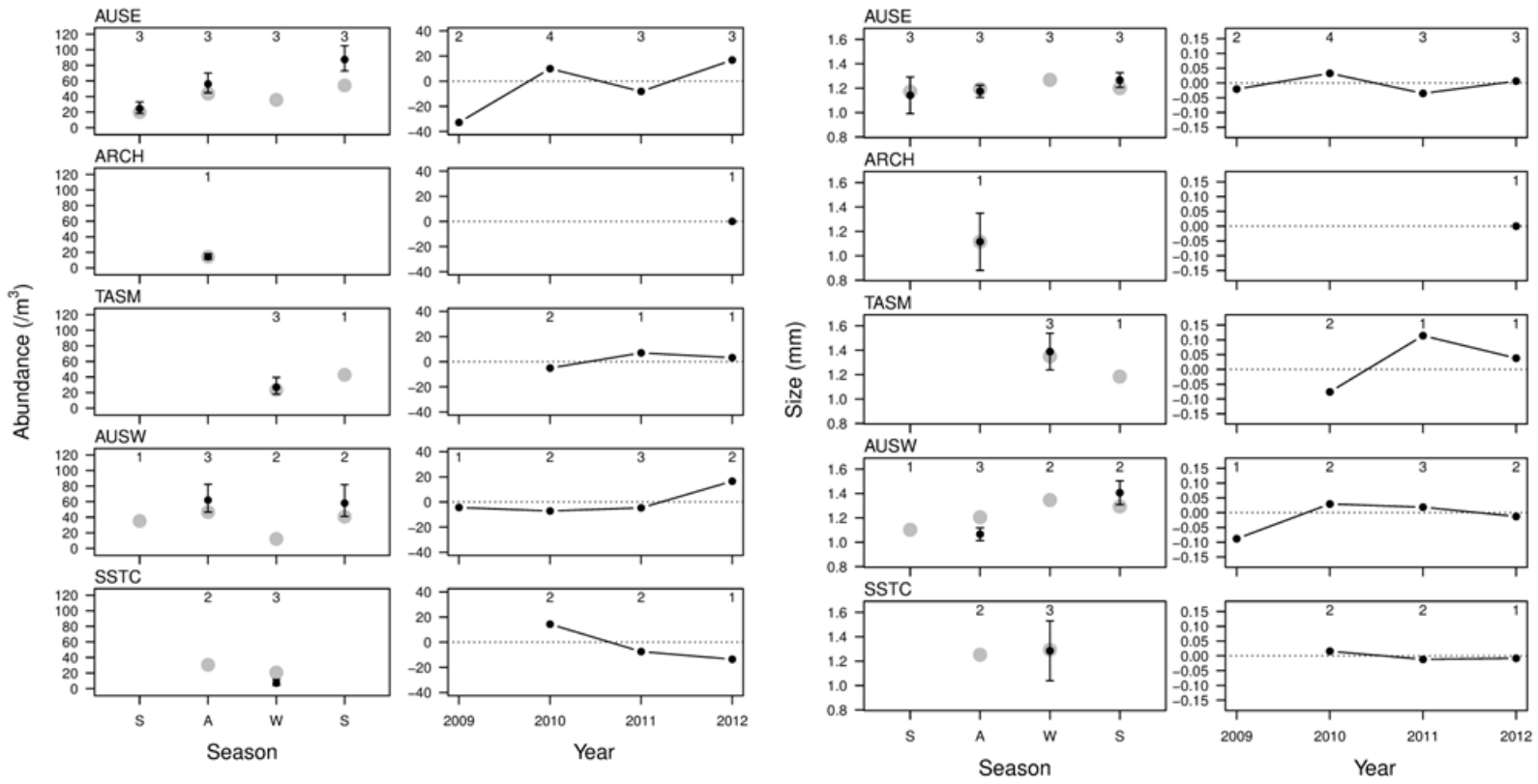


Fig. 21. (left panel) Total copepod abundance in Longhurst biogeographical provinces in Australia. Left. Seasonal means, with 2012 in black and the climatology in grey. Error bars are 95% confidence intervals. The number of years included in each climatology is shown along the top. Right. Annual mean anomalies, with the number of seasonal anomalies included shown along the top. (right panel) Mean copepod size in Longhurst biogeographical provinces in Australia. Left. Seasonal means, with 2012 in black and the climatology in grey. Error bars are 95% confidence intervals. The number of years included in each climatology is shown along the top. Right. Annual mean anomalies, with the number of seasonal anomalies included shown along the top.

Applied ecological indicators of the NE Atlantic

Marine climate change impacts

Marine biodiversity and invasive species

Marine ecosystem and environmental health

Ocean acidification

Summary for policy makers

Introduction

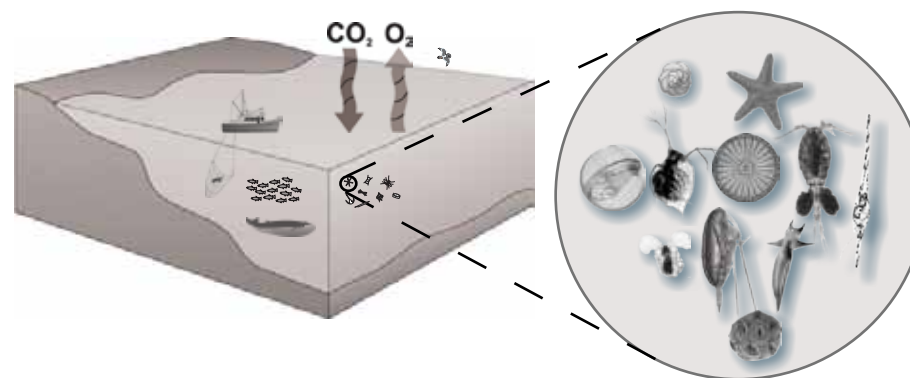
Generally, two definitions of ecological indicators exist. One is an indicator of an environmental (biotic or abiotic) property (e.g. a biological indicator of climate change and its impacts) that can be statistically measured e.g. indicative value of a variable. The other definition is similar to a performance indicator; in which management actions can be measured (e.g. a significant change in status is expected to trigger a management response).

Planktonic indicators are particularly useful in managing the marine environment as they can provide rapid information on a whole multitude of management issues, ranging from climate change impacts; fisheries and marine wildlife; eutrophication/pollution; ocean acidification; marine biodiversity and invasive species.

In an applied ecological indicator sense, the following planktonic indicators are used to track changes that are particularly important to policy and management, for example changes in marine ecosystem health, climate change and acidification impacts. Ecological indicators may be bulk indicators, individual species or entire communities. Bulk indices are less sensitive to environmental change and will quite often mask the subtleties that individual species will give you; however, it is thought that bulk indices represent the general functional response of plankton to the changing environment.

Generally, the CPR survey uses high grade ecological information such as sentinel species and communities to monitor change as these tend to be more sensitive to change (as opposed to bulk indicators such as measures of chlorophyll (see table)).

Plankton communities as ecological indicators



Biological variable	Example	Notes
Bulk Status Variables (index)	Chlorophyll, biomass, total abundance, EOVs, community size.	Not particularly sensitive and a basic indicator, difficult to interpret change and predict through models. Cheaper to monitor. Monitored using taxonomic methods, satellite observations and various optical technologies.
Sentinel Species (univariate taxa)	Individual species of high indicative value and/or key structural species. Targeted indicators for policy and management requirements, e.g. climate change, acidification, fisheries, etc.	Individual species chosen to be highly indicative and highly sensitive to ecosystem change and/or key structural species. Can be highly variable but fluctuations more easy to interpret. Models easier to predict if niche requirements known. Monitored using taxonomic and molecular methods. Molecular methods are not yet completely quantitative they can be designed to be quantitative for specific taxon groups or functional potential.
Community structure based on species information (multivariate taxa)	Multivariate community structure measures. Univariate summaries e.g. diversity indices.	Community indicator fluctuations are statistically more robust and may indicate system wide changes (e.g. regime shifts). More intensive monitoring required to measure. Monitored using taxonomic and genetic methods.



Marine climate change impacts

Biogeographic shifts

Over the last five decades there has been a progressive increase in the presence of warm-water/sub-tropical species into the more temperate areas of the North-East Atlantic and a decline of colder-water species. This trend seems to be accelerating over the last five years. The mass biogeographical movements are related to changes in sea surface temperature. A particularly interesting feature over the last five years is the decline in subarctic species to the south-east of Iceland and their movement to the north and west.

A useful indicator of the warming trend in the North Sea (a biogeographic shift indicator) is the percent ratio of the cold-temperate *Calanus finmarchicus* and the warm-temperate *Calanus helgolandicus* copepod species. Although these species are very similar they do occupy distinct thermal niches. The thermal boundary for the arctic-boreal distributed copepod *Calanus finmarchicus* in the North-East Atlantic lies between ~10-11°C isotherm and is a useful indicator of major biogeographical provinces. *Calanus helgolandicus* usually has a northern distributional boundary of 14°C and has a population optimum lying between 10-20°C; these two species can therefore overlap in their distributions. When these two species co-occur there is a tendency for high abundances of *C. finmarchicus* earlier in the year and *C. helgolandicus* later in the year. There is clear evidence of thermal niche differentiation between these two species as well as successional partitioning in the North Sea, probably related to cooler temperatures earlier in the year and warmer temperatures later in the year.

The percentage ratio between *C. helgolandicus* and *C. finmarchicus* between 2009 and 2010 was for the first time in twenty years dominated by *C. finmarchicus* in spring. This was a reflection of the particularly cold winter experienced in Northern Europe caused by a very low winter NAO index. The spring of 2012 was also dominated by *C. finmarchicus*. Between the 1960s and the post 1990s, total *Calanus* biomass has declined by 70%. This huge reduction in biomass has had important consequences for other marine wildlife in the North Sea including fish larvae larvae.

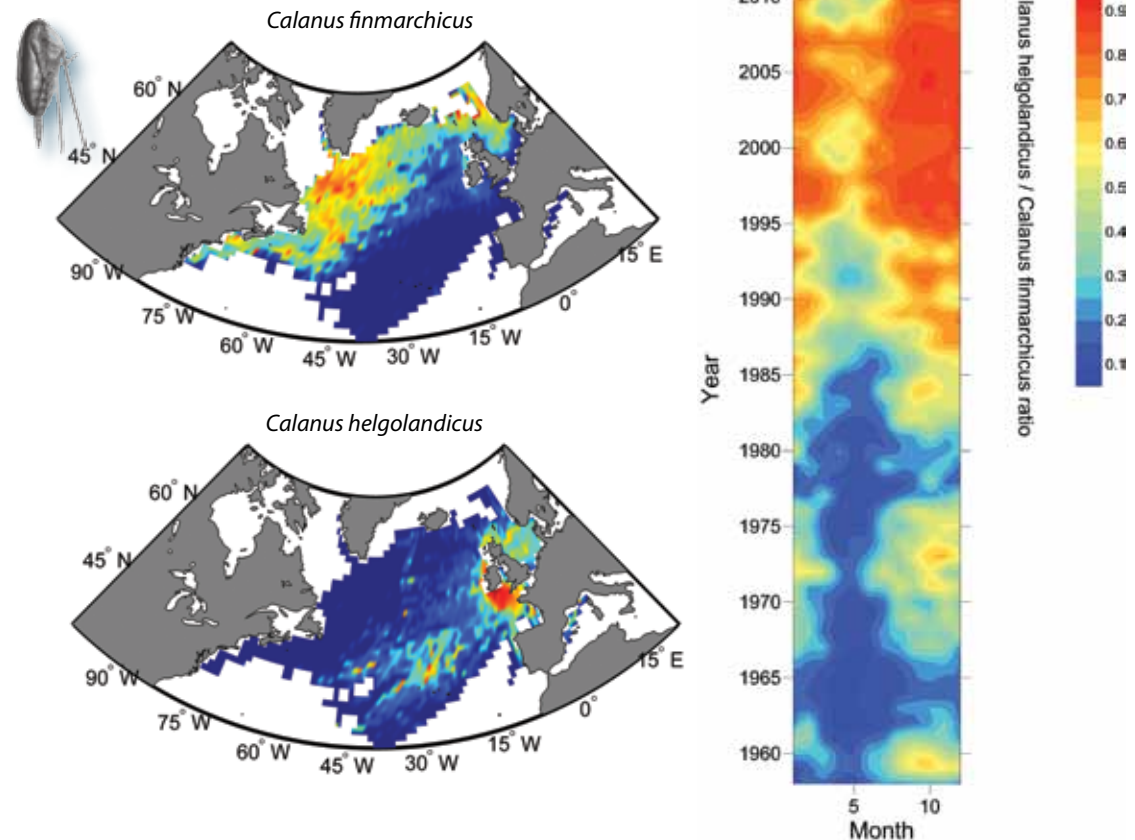


Fig. 22. A simple ratio between a warm-water species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) per month from 1958-2012. Red values indicate a dominance of the warm-water species and blue values the dominance of the cold-water species. (0= total *C. finmarchicus* dominance, 1=total *C. helgolandicus* dominance)

Phenology

Phenology - the study of natural phenomena that recur periodically, as migration or blossoming, and of their relation to climate and changes in season. Seasonal timing, or phenology, is occurring earlier in the North Sea and is related to regional climate warming. For example, some species have moved forward in their seasonal cycle by 4-5 weeks. However, not all trophic levels are responding to the same extent, therefore in terms of a productive environment, this change is considered detrimental because of the potential of mis-timing (mismatch) of peak occurrences of plankton with other trophic levels including fish larvae. There is a high confidence that these trends are related to regional climate warming. In particular, the trend towards an earlier seasonal appearance of meroplanktonic larvae over the last few decades is highly correlated with sea surface temperature. The trend in 2012 was slightly earlier than average for the whole time-series.

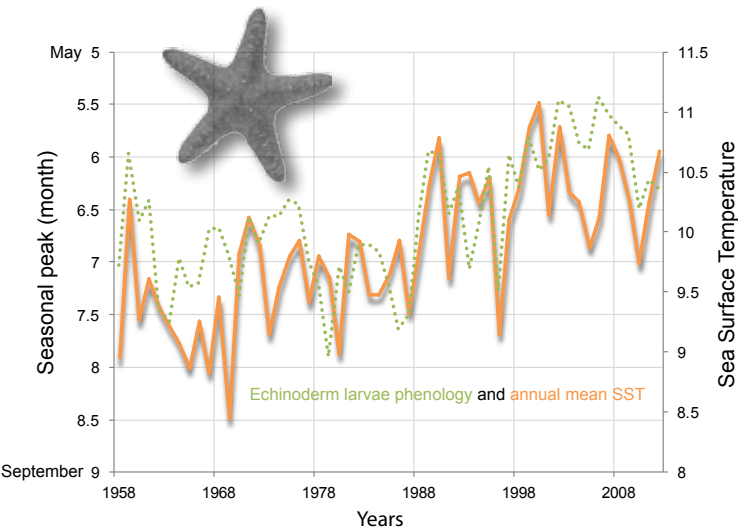


Fig. 24. Phenological shifts in echinoderm larvae and mean annual SST in the North Sea from 1958-2012. The main decadal trend is towards an earlier seasonal cycle. Based on *Nature* (2004) 430: 881-884.

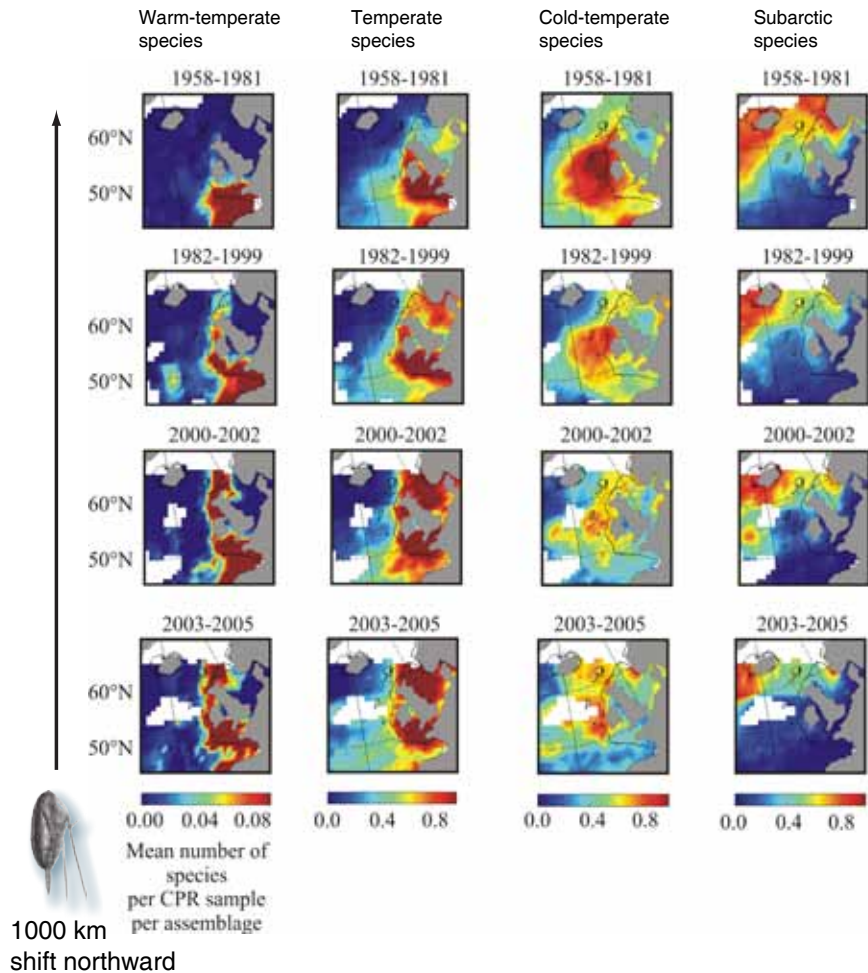


Fig. 23. Biogeographical changes in plankton assemblages spanning five decades. Warm-water plankton (e.g. warm-temperate species) are moving north and cold-water plankton (e.g. subarctic species) are moving out of the North Sea. Based on *Science* (2002) 296: 1692-1694.



Marine biodiversity and invasive species

Multi-decadal trends in ocean biodiversity

At the ocean basin scale studies on the pelagic biodiversity of zooplankton copepods are related to temperature and an increase in warming over the last few decades has been followed by an increase in diversity. There is also a direct link between diversity and the size-structure of the zooplankton community. The overall diversity patterns of pelagic organisms, peaking between 20° to 30° north or south, follow temperature gradients in the world's oceans. Similarly, phytoplankton show a relationship between temperature and diversity which is linked to the phytoplankton community having a higher diversity but an overall smaller size-fraction and a more complex foodweb structure (i.e. microbial-based versus diatom-based production) in warmer, more stratified environments. The parallel decrease in size-structure of pelagic organisms with increasing diversity may have implications for marine ecosystem services such as smaller-sized fish communities and reduced carbon drawdown (PNAS (2010) 107: 10120-10124).

Unusual biodiversity records in 2012/2013

Neoceratium breve, a warm water dinoflagellate, was recorded on an August 2013 sample from the mid-Atlantic. The SAHFOS CPR survey identifies over 40 species belonging to the *Neoceratium* genus, however this particular species has only previously been recorded four times in the survey. The North Atlantic CPR analysis team has added a new species to the list of planktonic organisms found in the North Atlantic survey. *Aetideus acutus* is a type of microscopic crustacean, which belongs to the subclass copepoda. A specimen of *A. acutus* was found on a warm water oceanic sample from November 2012. Although there are some previous records of *A. acutus* in this region, it is the first time an *A. acutus* has been found on a CPR sample. In 2013, unprecedented numbers of juvenile *Branchiostoma* were found in the North Sea, off the northwest coast of Denmark. *Branchiostoma*, sometimes known as lancelets, are regularly recorded in North Sea CPR samples in low numbers. However, in August the highest abundances ever recorded in the survey, many hundreds per sample, were observed. *Heterophryxus appendiculatus* was found on a sample taken from the northeast coast of the USA in October 2012. *H. appendiculatus* is a parasitic isopod crustacean that infests euphausiids (krill).

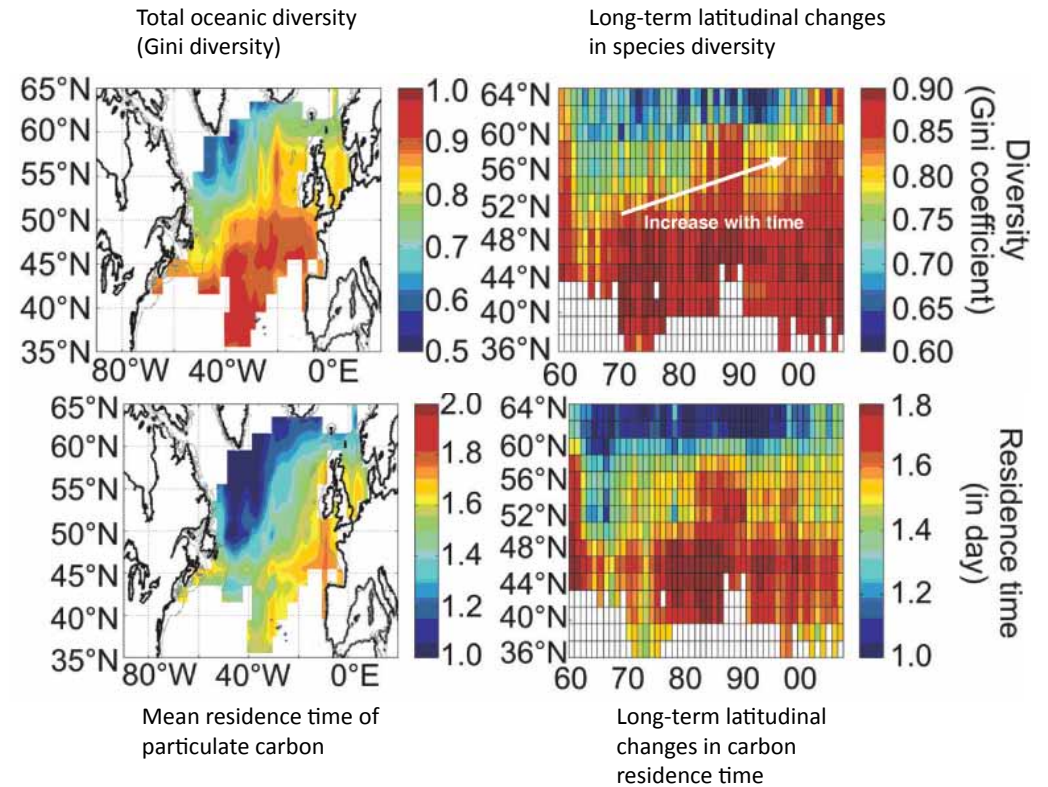


Fig. 25. Relationships between the spatial distribution and long-term latitudinal changes in the diversity and a size-derived functional characteristic of calanoid copepods in the extratropical North Atlantic. Diversity was measured by first-order jackknife performed on the Gini coefficient. Left panel: mean spatial distributions (1960-2007) of copepod diversity and mean residence time above 50 m of sinking copepod particles (in days). Right panel: long-term latitudinal changes in copepod diversity and mean residence time above 50 m of sinking copepod particles. Based on PNAS (2010) 107: 10120-10124.

Invasive species

Because of its extensive geographical coverage and long time frame, data from the CPR have provided invaluable information on the spread of non-native plankton. For example, the invasive diatom *Coscinodiscus wailesii*, which has become a persistent and significant member of the plankton community, has spread from its first record off Plymouth in 1977 throughout all coastal waters of northern Europe and out into the Atlantic in a matter of only 30 years. *JMBA (2001) 81: 207-211*. It is also now found in Canadian and US coastal waters.

A recent review of non-native marine species around the British Isles that includes plankton and HAB species provides more detail on planktonic introductions. The discovery of the comb jelly *Mnemiopsis leidyi* in North Sea waters is of particular concern, even though it has not yet been recorded in the British Isles, because of the very marked impact it appears to have had on fisheries and the general ecosystem when it has appeared in other parts of the world.

A new invasive copepod species has been found in the North Sea in 2011 and has continued to establish itself in the North Sea over the preceding years. The copepod species *Pseudodiaptomus marinus* naturally occurs in east Asiatic waters but has been subsequently spreading more widely in the Indo Pacific region over the last decade. The first record of the species in European waters comes from its discovery in the Adriatic Sea in 2007. In October 2011 the species was recorded on CPR routes operating in the southern North Sea (*Marine Biodiversity Records (2013) 6: 1-3*). The present records extend the known distribution of *P. marinus* across the southern Bight from the Netherlands to the British coast and to the German Bight and more recently at the entrance to the Skagerrak. It is highly probable the species presence is due to human activity linked to ballast water release or aquaculture. The CPR survey will continue to monitor its establishment in the North Sea and its probable spread to other regions.

Climate warming will open up new thermally defined habitats for previously denied non-indigenous species (e.g. sub-tropical species in the North Sea) and invasive species allowing them to establish viable populations in areas that were once environmentally unsuitable.



Apart from these thermal boundary limits moving progressively poleward and in some cases expanding, the rapid climate change observed in the Arctic may have even larger consequences for the establishment of invasive species and the biodiversity of the North Atlantic. It has recently been highlighted that Arctic ice is reducing faster than previous modelled estimates. As a consequence the biological boundaries between the North Atlantic Ocean and Pacific may become increasingly blurred with an increase of trans-Arctic migrations becoming a reality. The CPR survey has already documented the presence of a Pacific diatom, *Neodenticula seminae*, in the Labrador Sea since the late 1990s which has since spread southwards, eastwards and northwards. In 2012 it was found most abundant off Newfoundland and to the north of Iceland. The diatom species itself has been absent from the North Atlantic for over 800,000 years and could be the first evidence of a trans-Arctic migration in modern times and be the harbinger of a potential inundation of new organisms to the North Atlantic. The consequences of such a change to the function and biodiversity of Arctic systems are at present unknown.

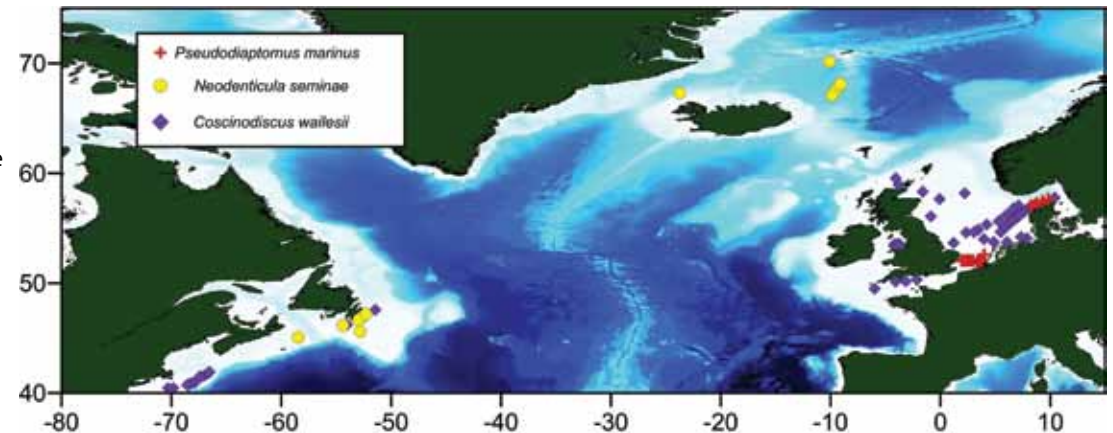


Fig. 26. The recorded distribution of three prominent non-indigenous species in the North Atlantic for 2011-2012. All three species are thought to have originated from the Pacific.

More information on *N. seminae*: *Global Change Biology (2007)13: 1910-1921*



Marine ecosystem and environmental health

Eutrophication and Habs

There has been a considerable increase in phytoplankton biomass (Phytoplankton Colour Index) over the last decade in certain regions of the North-East Atlantic and North Sea, particularly over the winter months. Increased phytoplankton biomass may be an indicator of eutrophication; however, similar patterns of change have been found in both coastal and offshore waters. In the North Sea a significant increase in phytoplankton biomass has been found in both heavily anthropogenically-impacted coastal waters and the comparatively less-affected open North Sea despite significantly decreasing trends in nutrient concentrations. The increase in biomass appears to be linked to warmer temperatures and evidence that the waters are also becoming clearer (i.e. less turbid), thereby allowing the normally light-limited coastal phytoplankton to more effectively utilise lower concentrations of nutrients (*Limnology and Oceanography* (2007) 52: 635–648). These results may indicate that climatic variability and water transparency may be more important than nutrient concentrations to phytoplankton production in the North Sea. Despite the overriding influence of climate, elevated nutrient levels may be of concern in some localised areas around European seas. In general, HABs are naturally occurring events although some exceptional blooms have been associated with eutrophication in coastal waters. HAB taxa are generally most numerous along the Dutch coast and off the northern Danish coast. In particular the red-tide forming species *Noctiluca scintillans* naturally forms extensive blooms during the summer period in these areas as well as in the Irish Sea. Large HABs during 2012 occurred within the range of natural variability and were similar to the long-term average occurrences. However, the large blooms of *Pseudo-nitzschia* spp. occurring in the North Sea were particularly numerous in 2012 and are becoming generally more common in the North Sea over the last decade.

Trends in marine pathogens

As sea surface temperatures increase, predictions favour an increase in number and range of pathogenic micro-organisms. Such changes are difficult to determine over short time periods that cannot separate short-term variations from climate change trends. In a unique long-term time study, Vezzulli et al. (2011) investigated the spread of the pathogenic bacteria, *Vibrio*, the causative agent of cholera in the North sea over 50 years, between 1961-2005, and revealed that *Vibrio* bacteria are increasing in this region. The *Vibrio* Abundance Index (VAI) was found to steadily increase over four decades which was linked to temperature and copepod abundance but not PCI. The Rhine area was significantly correlated with VAI, which has higher summer SST over 18°C, where *Vibrio* thrives best (Vezzulli et al. 2011), and was especially marked in the late 1980s when step-wise increase in SST was reported in the Southern North Sea. No significant increase was found in the Humber, which never exceeds 18°C. *Vibrio* attaches to chitin surfaces so the relationship with copepods may reveal the mechanism by which this pathogen spreads.

Marine microplastics

From the presence of microplastics that have been recorded on CPR samples it is clear that microplastics are widely distributed in the North-East Atlantic with the frequency increasing towards the coasts (particularly in the southern North Sea). From retrospective analysis of some CPR samples spanning three decades it appears that microplastics are increasing in frequency through time (*Science* (2004) 308:834). The incidence of monofilament netting snagged by the CPR towed body also seems to be increasing, particularly in the southern North Sea.

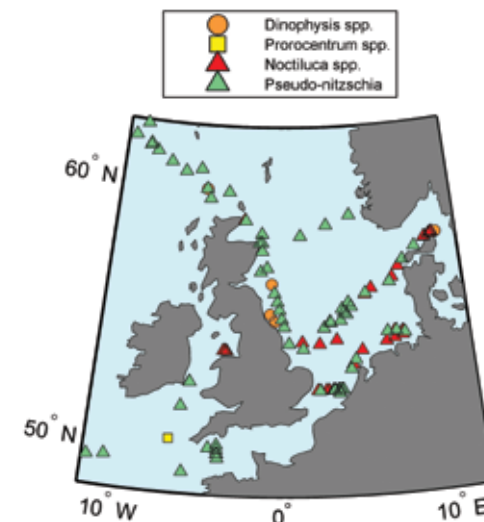


Fig. 27. The distribution of large HAB blooms in Northern European waters in 2012. Large or exceptional HAB blooms are equivalent to 4 standard deviations above the long-term mean (1958-2011).

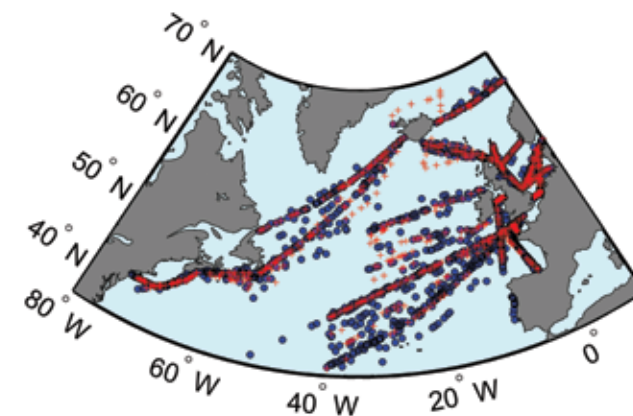


Fig. 28. The geographical distribution of microplastics recorded on CPR samples in 2012 (red) and between 2004-2011 (blue). While the distribution largely reflects CPR sampling frequency it does show that microplastics are widely distributed in the North Atlantic including the offshore oceanic environment.





Ocean acidification

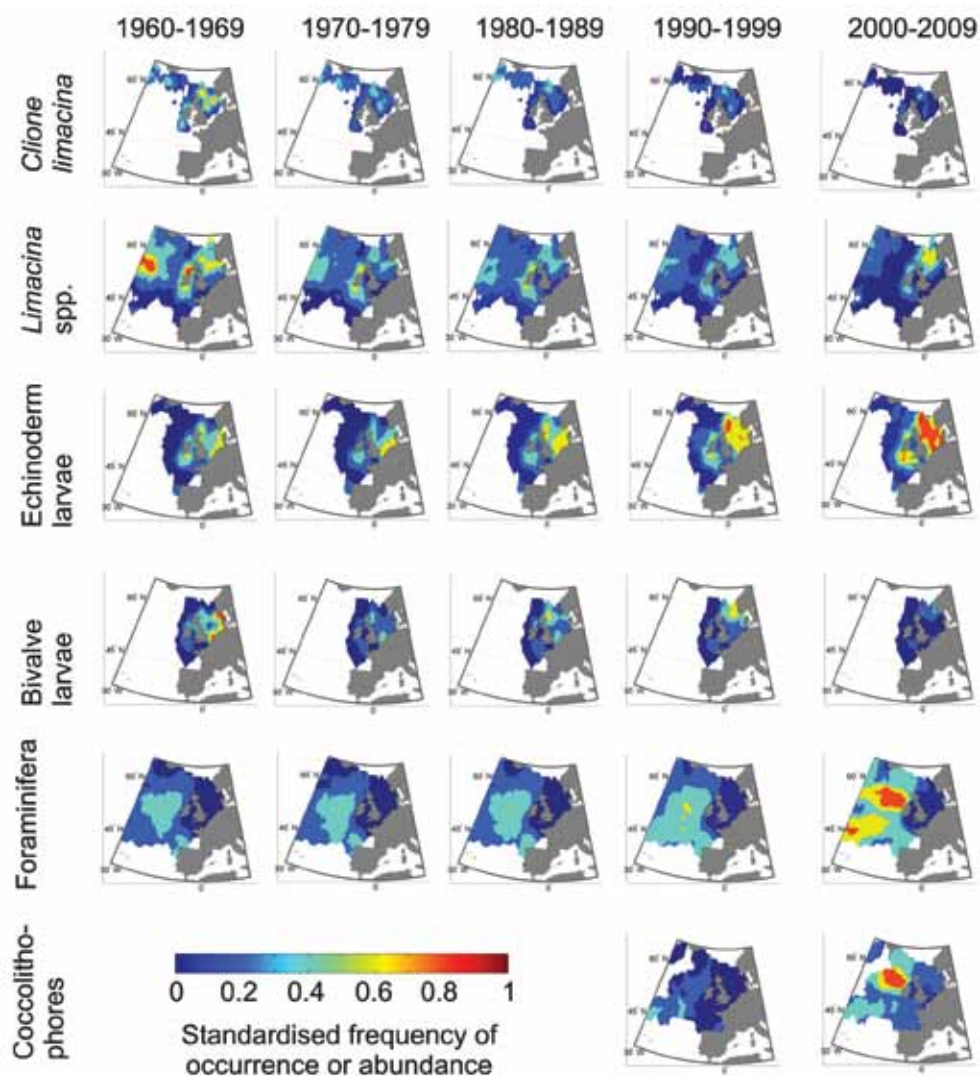


Fig. 29. The abundance and distribution of calcifying plankton over decadal periods in the NE Atlantic. Based on *Nature Climate Change* (2013) 3: 263-267.

The global increase in atmospheric carbon dioxide concentration is potentially threatening marine biodiversity in two ways. First, carbon dioxide and other greenhouse gases accumulating in the atmosphere are causing changes to the earth's climate system. Secondly, carbon dioxide is altering sea water chemistry, making the oceans more acidic. Although temperature has a cardinal influence on all biological processes from the molecular to the ecosystem level, acidification might impair the process of calcification or exacerbate dissolution of calcifying organisms. Ocean acidification has the potential to affect the process of calcification and therefore certain planktonic organisms (e.g. coccolithophores, foraminifera, pelagic molluscs, echinoderms) may be particularly vulnerable to future CO₂ emissions. Apart from climate warming, potential chemical changes to the oceans and their effect on the biology of the oceans could further reduce the ocean's ability to absorb additional CO₂ from the atmosphere, which in turn could affect the rate and scale of climate warming.

Results from the CPR survey show that over the last 50 years certain calcareous taxa are actually increasing in terms of abundance, a trend associated with climate shifts in the Northern Hemisphere temperature. Large increases in abundance are particularly seen for echinoderm larvae, foraminiferans and coccolithophores (see Fig. 29). The research found that the calcifying plankton were primarily responding to climate-induced changes in temperature during the period 1960-2009, perhaps masking the effects of ocean acidification over that time-period. Most of the calcareous taxa recorded by the CPR survey exhibited an abrupt shift *circa* 1996 at a time of a substantial increase in global temperature and that taxa exhibited a poleward movement in agreement with expected biogeographical changes under sea temperature warming (*Nature Climate Change* (2013) 3: 263-267).

It is not yet known how much of an effect acidification will have on the biology of the oceans in the 21st century, whether rapid climate warming will override the acidification problem, and whether or not species can buffer the effects of acidification through adaptation. Equally, ocean acidification could become the driving change in oceans around the world in the next few decades. Despite these uncertainties, the CPR survey is providing a critical baseline (both in space and time) and is currently monitoring these vulnerable organisms in case in the future these organisms begin to show negative effects due to acidification.

Summary for policy makers



Marine climate change impacts: Northward shifts

Warmer-water species are currently increasing in the North Sea due to regional climate warming and the NAO. In terms of a productive environment this change is currently considered detrimental because the warmer-water species are not replacing the colder-water species in similar abundances which may negatively impact other trophic levels including fish larvae. For example, an important zooplankton species has declined by 70 % in the North Sea. There is a high confidence that these trends are related to regional climate warming.



Marine climate change impacts: Changes in seasonality and phenology

Seasonal timing, or phenology, is occurring earlier in the North Sea and is related to regional climate warming. For example, some species have moved forward in their seasonal cycles by 4-5 weeks. However, not all trophic levels are responding to the same extent; therefore in terms of a productive environment, this change is currently considered detrimental because of the potential of mis-timing (mismatch) of peak occurrences of plankton with other trophic levels including fish larvae. There is a high confidence that these changes are associated with regional climate warming.



Marine biodiversity and invasive species

Oceanic plankton biodiversity is increasing in the North Atlantic associated with temperature increases. There is a strong relationship between biodiversity and size-structure in pelagic communities. Increasing biodiversity is associated with a decreasing size-structure of the community. This in turn may have implications for marine ecosystem services such as smaller-sized fish communities and reduced carbon drawdown.



Marine ecosystem health and water quality

At the regional scale, it has been found that most phytoplankton trends are related to hydro-climatic variability as opposed to anthropogenic input (e.g. nutrient input leading to eutrophication). This means that the North-East Atlantic as a whole is generally considered to be fairly healthy. This is not to say, however, that certain coastal areas and the southern North Sea are not vulnerable to eutrophication and climate change may also exacerbate these negative effects in these vulnerable regions. It has also been found that the number of microplastics collected on CPR samples is increasing and the frequency of occurrence and bloom timing of some Harmful Algal Bloom species are related to regional climate warming.



Ocean acidification

Organisms that could be particularly vulnerable to acidification are the calcifying organisms such as coccolithophores and foraminifera. The CPR survey is proving a critical baseline and is currently monitoring these vulnerable organisms in case these organisms start to show any negative effects due to acidification in the future. Over the last few decades trends in calcifying organisms recorded by the CPR survey have been correlated with changes in Northern Hemisphere Temperatures rather than changing pH. However, acidification may become the main driver of change in the future.

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Monitoring marine biodiversity from genes to ecosystems

BIOLOGICAL MEASUREMENTS 1931-

PHYSICAL MEASUREMENTS 1991-

Instruments placed in rear of CPR or onboard vessel

Genetic analysis

Mega and macro plankton



(1) Continuous Plankton Recorder (CPR)

Longest sustained marine biological time-series in the world (1931-). Routine analysis of ~500 plankton taxa.

Multi-decadal sample and molecular archive at ocean-basin scale (1950-).

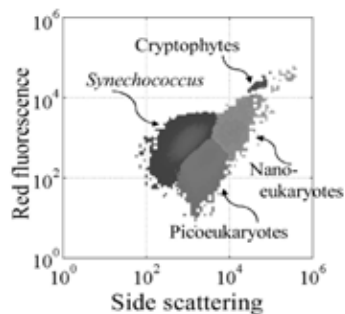


Light microscopy

Meso and micro-plankton

Upto 500 species routinely recorded making the CPR database one of the richest ecological datasets in the world

Nano and pico-plankton (example)

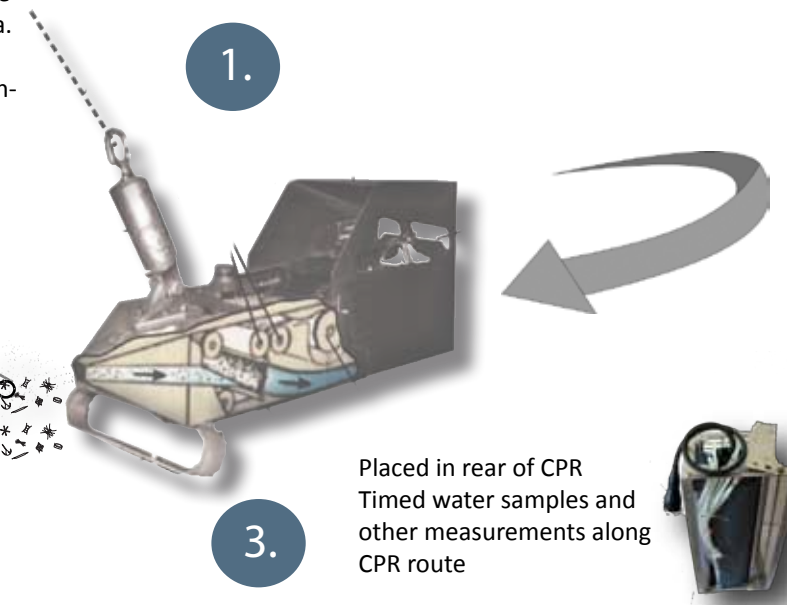


Flow cytometry

(2) Water and Microplankton Sampler (WaMS)

Aimed at smaller size-fraction nano and pico plankton community.

Flow cytometry (2010-)
Molecular probes and barcoding (2010-)
Harmful Algal Bloom microarrays (2010-)



(3) Physical measurements

Sea surface temperature, salinity, depth and chlorophyll (1991-)
pCO₂ (2002-)
Microplastics (2004-)
Other measurements: Dissolved Inorganic Carbon, Alkalinity, Oxygen content, nutrients.



The Sir Alister Hardy Foundation for Ocean Science (SAHFOS) is an internationally funded charity (Canada, Norway, UK and the USA) that operates the Continuous Plankton Recorder (CPR) survey. The Foundation has been collecting data from the North Atlantic and the North Sea on biogeography and ecology of plankton since 1931. More recently, work has been expanded to include other regions around the globe including the Arctic and Southern Ocean. The results of the survey are used by marine biologists, scientific institutes and in environmental change studies across the world. The SAHFOS team is based in Plymouth, England and consists of analysts, technicians, researchers and administrators, who all play an integral part in the running of the survey.

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