The Continuous Plankton Recorder Survey – Monitoring plankton in the Nordic Sea

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Highlights

The warm-temperate calanoid copepod *Calanus helgolandicus* is becoming more common in the Nordic Seas with high records in 2016, which continued into 2017.

The Pacific diatom *Neodenticula seminae* (an indicator of trans-Arctic migration) was recorded off Svalbard in 2016, which is its most easterly record in the Nordic Seas.

Continuous Plankton Recorder monitoring

The Continuous Plankton Recorder (CPR) survey has been operating on a monthly basis using ships of opportunity from northern Norway to Svalbard for almost 10 years beginning in November 2008. Generally, the route operates every month from Tromso in northern Norway to Longyearbyen in Svalbard when conditions are favourable. Sometimes there can be reduced sampling during the winter period (Fig.1). The northern Norwegian routes were initially established due to the rapid changes to plankton and climate and the movement of plankton northwards observed over the last 50 years in the sub-polar Atlantic. These rapid changes in plankton were originally observed in the North East Atlantic where the majority of CPR routes operate with plankton northerly movement measured at a rapid ~ 23 km per year in this region (Beaugrand et al. 2009). To continue these observations of rapid biological movement and biodiversity changes it was considered crucial to establish more northerly CPR routes covering the Nordic Seas to continue to document these changes as well as to monitor for possible trans-Arctic migrations.

The CPR 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 survey is recognised as the longest sustained and geographically most extensive marine biological survey in the world (Edwards et al. 2010). The dataset comprises a uniquely large record of marine biodiversity covering ~1000 taxa over multi-decadal periods. The survey determines the abundance and distribution of microscopic plants (phytoplankton) and animals (zooplankton including fish larvae) in our oceans and shelf seas. Using ships of opportunity from ~30 different shipping companies, it obtains samples at monthly intervals on ~50 trans-ocean routes. In this way the survey autonomously collects biological and physical data from ships covering ~20,000 km of the ocean per month, ranging from the Arctic to the Southern Ocean. The survey is an internationally funded charity (with operational funding from UK, USA, Canada and Norway) with a wide consortium of stakeholders. The Norwegian government directly funds the Svalbard CPR route through the Institute of

Marine Research in Bergen.

The CPR is a high-speed plankton recorder that is towed behind 'ships of opportunity' through the surface layer of the ocean (~10 m depth). Water passes through the recorder and plankton are filtered by a slow moving silk (mesh size 270 µm). A second layer of silk covers the first and both are reeled into a tank containing 4% formaldehyde. Upon returning to the laboratory, the silk is unwound and cut into sections corresponding to 10 nautical miles and approximately 3 m^3 of filtered sea water.

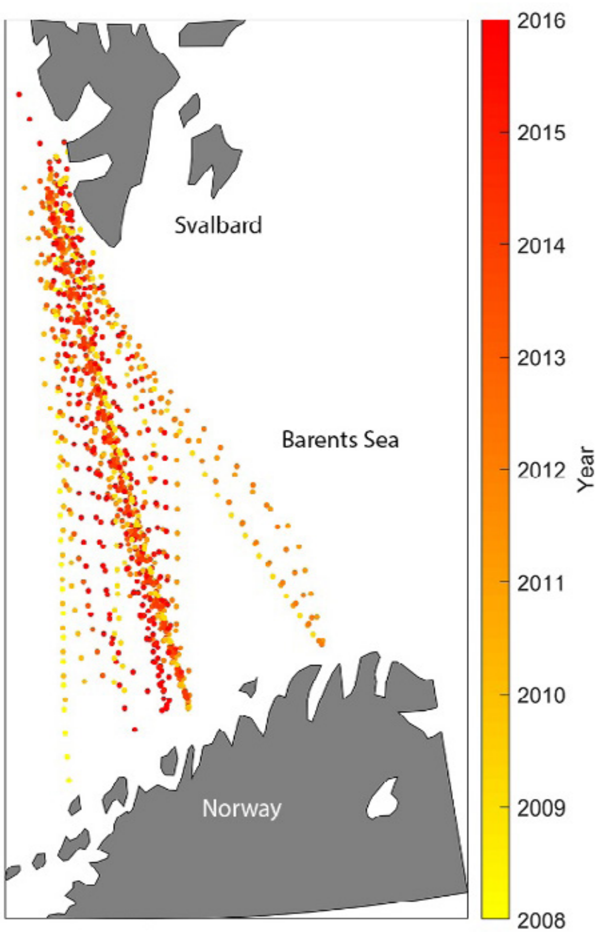

Figure 1: Distribution of CPR samples in the Barents Sea region between northern Norway and Svalbard.

There are four separate stages of analysis carried out on each CPR sample, with each focusing on a different aspect of the plankton: viz. (1) overall chlorophyll (the phytoplankton colour index; PCI); (2) larger phytoplankton cells (phytoplankton); (3) smaller zooplankton (zooplankton traverse); and (4) larger zooplankton (zooplankton eyecount) The phytoplankton colour of each section of the CPR silk is evaluated and categorised according to four levels of 'greenness' (green, pale green, very pale green and no colour) using a standard colour chart; the numbers are given a numerical value as a measure of 'Phytoplankton Colour Index'. Direct comparisons between the phytoplankton colour index and other chlorophyll *a* estimates including SeaWiFS satellite estimates indicate strong positive correlations. This is a semiquantitative measure of phytoplankton biomass; the silk gets its green colour from the chloroplasts of the filtered phytoplankton.

Phytoplankton cells are identified and recorded as either present of absent across 20 microscopic fields spanning each section of silk (representing ~1/10,000 of the filtering silk). 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). Zooplankton analysis is then carried out in two stages with small (<2 mm) zooplankton identified and counted on-silk (representing ~1/50 of the filtering silk) and larger (>2 mm) zooplankton enumerated off-silk (see (Richardson et al. 2006) for further details on CPR methodology). The collection and analysis of CPR samples have been carried out using a consistent methodological approach, coupled with strict protocols and Quality Assurance procedures since 1958, making the CPR survey the longest continuous dataset of its kind in the world. Of particular relevance to the abundance of copepods around Svalbard, the CPR survey currently distinguishes between the species *Calanus finmarchicus* and *C. glacialis* by measuring the prosome length of adult specimens (for C. glacialis, prosome length of CV 3.0-3.5mm; Adult female prosome length 3.5-4.1mm) and therefore in some circumstances may underestimate the abundance of *C. glacialis* as the size ranges can overlap (see Choquet et al. 2018 for further details).

The addition of a water sampler onboard certain CPRs can provide information on 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. In addition to this many CPRs currently have near-real-time sensors for variables such as conductivity, temperature and chlorophyll-a fluorescence from bespoke sensors that are being operated on CPR transects across some coastal to open ocean waters. The Tromso-Svalbard transect has deployed a CTD sensor on the CPR in the past and currently works in collaboration with Norwegian colleagues operating the Ferrybox installed on the vessel.

Plankton trends

Generally, the plankton sampled in the Barents Sea consists of a cold-boreal to an Atlantic assemblage with the occasional temperate species recorded particularly in the warmer waters of the North Atlantic current to the west and south of Svalbard. As the Barents Sea sits at the doorstep to the Arctic Ocean a number of boreal-arctic species are also found such as *Ephemara planamembranacea* and *Ceratium arcticum*. The Barents Sea region is a rich ecosystem with high biomass of phytoplankton and zooplankton leading to lucrative marine bio-resources particularly the fisheries.

The most commonly recorded phytoplankton in this region are the diatom groups *Chaetoceros* spp., *Rhizosolenia* spp. *Pseudo-nitzshia* spp. The dinoflagellate genus *Ceratium* are also very common particularly during the summer months. Calanoid copepods typically dominate the zooplankton assemblage particularly the boreal species *Calanus finmarchicus*. Euphausids and hyperids also contribute to high zooplankton biomasses. Annual trends in the most common phytoplankton and zooplankton species are shown in Fig.2. Over the course of the time-series a significant community shift was recorded in 2016 and may represent a recent change in the community structure. The spatial distribution of the most common zooplankton *C. finmarchicus* and its relatives are show in Fig 3 and 4. *C. finmarchicus* is most abundant off the northern coast of Norway with the more colder distributed species *C. glacialis* and *C. hyperboreus* found most abundant off the south-west coast of Svalbard and Storfjord Channel. Interestingly the warm-termperate species *C. helgolandicus* is also recorded on this route with highest abundances recorded off northern Norway. Rather surprisingly, the species has also been recorded off the coast of Svalbard itself. There is increasing evidence that temperate species are becoming more commonly recorded in the Barents Sea over the last few years. This is in line with the observed and rapid increase in temperatures recorded in the Barents Sea over the last decade (Lind et al. 2018).

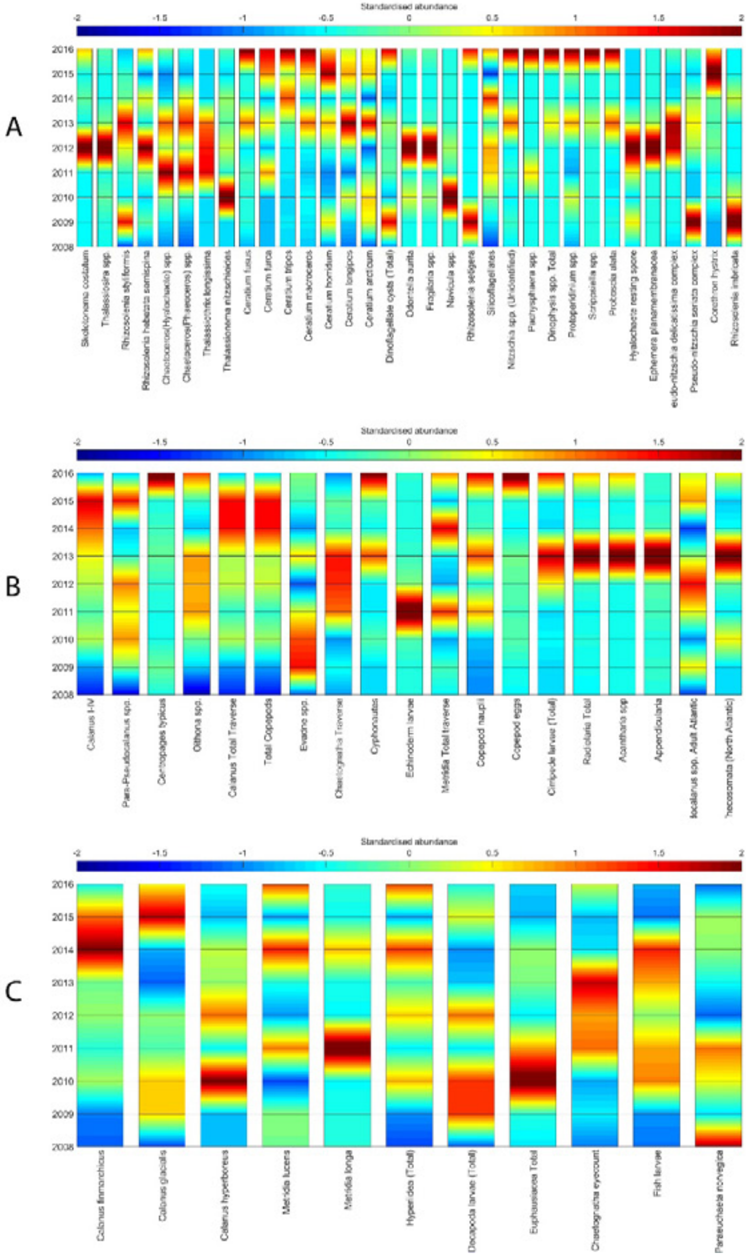

Figure 2: The average annual abundance of the most common plankton taxa recorded since 2008, (A) phytoplankton; (B) small zooplankton (C) large zooplankton. Standardised abundance, 0=mean. Aggregated data for the whole Svalbard transect.

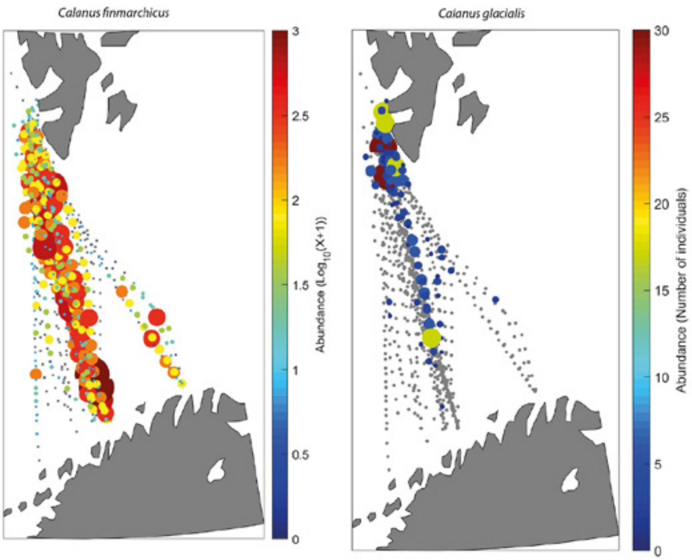

Figure 3: The spatial distribution and abundance of the calanoid species *Calanus finmarchicus* and *Calanus glacialis*. Colours represent abundances per sample.

Trans-Arctic invasive species

It has recently been highlighted that Arctic ice is reducing faster than previous modelled estimates and the seas around Svalbard continue to warm at an accelerated pace compared to other global regional areas. As a consequence of this the biological boundaries between the North Atlantic Ocean and Pacific may become increasingly blurred with an increase of trans- Arctic migrations becoming more common. 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 and eastwards (Reid et al. 2007). The diatom species itself has been absent from the North Atlantic for over 800,000 years and may itself 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 (Reid et al. 2008) .

The species has been recently found in the Barents Sea north of Iceland and west of Svalbard and also on the ST route in the spring of 2016 at 77.387 N and 13.557 E which is currently its most easterly record. Independent of the CPR survey the presence of *N. seminae* has recently been recorded from sediment samples along the west Spitsbergen slope (Miettinen et al. 2013). It is possible we could witness more trans-Arctic exchanges in the near future if the ongoing warming trend and reduction of sea ice continues in the Arctic. Currently the consequences of such a change to the function and biodiversity of Arctic systems is not yet known.

Future recommendations

Within this region of the Nordic Seas, the CPR survey adds to and compliments other monitoring methods in this area by providing a larger spatial and temporal perspective as most other surveys are coastal or are sporadically sampled through time. In addition to this, the CPR survey data adds value by providing multi-decadal data at the Atlantic basin scale that can help disentangle and interpret changes observed in the Nordic Seas and help predict these changes over the next coming decades. For example, current Arctic systems will become sub-Arctic systems within the next 10 to 20 years (if not sooner) and the biological signals of change we see further south in Atlantic sub-polar systems now can be used to detect the early warning signs of change in the Arctic.

To develop the operation system further the CPR survey currently works closely with Norwegian scientists to coordinate its sampling on board this ship of opportunity. For example, the CPR survey coordinates its activity with the Norwegian ferrybox system on board this ship of opportunity to obtain further and complimentary information such as pCO_2. It is hoped in the near future that the CPR survey will form part of a more integrated observation system within these waters and improve its monitoring with an additional suite of biogeochemical and molecular sensors. It is also foreseeable in the future that additional CPR routes could be towed using other ship of opportunity in this region such as tourist vessels.

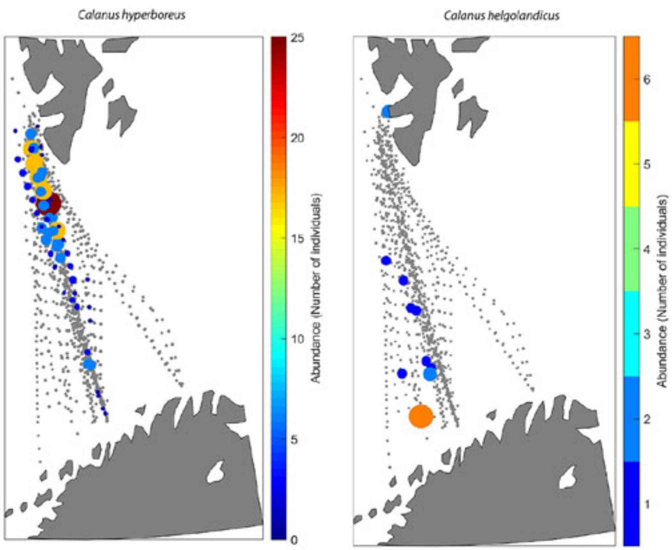

Figure 4: The spatial distribution and abundance of the calanoid species *Calanus hyberboreus* and *Calanus helgolandicus*. Colours represent abundances per sample.

Data accessibility

All data is freely available on request by contacting the Continuous Plankton Recorder Survey at the Marine Biological Association (MBA), United Kingdom. Data requests to the MBA Head of Data, Information and Technology (Dan Lear: dble@mba.ac.uk).

Additional CPR information: microplastics

In addition to recording upto 1000 taxa of plankton the CPR survey has also been recording for the presence of microplastics since 2004. Quantitative counts of microplastics have been recorded since 2016. The occurrence of microplastic in the Nordic Seas seems to be regular and echoes the normal frequency of occurrence in the North Atlantic

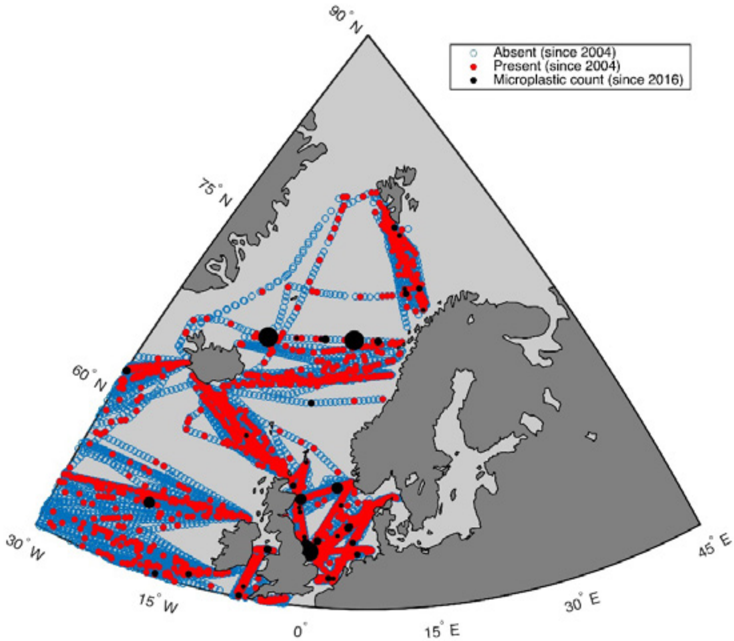

Figure 5: The distribution of microplastics on CPR samples since 2004. Red indicates presence on CPR samples and blue values indicate absence on CPR samples. Black values indicate quantitative counts of microplastics since 2016.

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