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Reliability of spatial and temporal patterns of *C. finmarchicus* inferred from the CPR survey☆

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ABSTRACT

The Continuous Plankton Recorder (CPR) survey has collected plankton since 1958 in the North Atlantic Ocean and its adjacent seas. Among all species recorded by the CPR, *Calanus finmarchicus* has probably been the most investigated species because of its ecological importance for the temperate and subpolar regions of the North Atlantic Ocean. However, abundances of *C. finmarchicus* assessed from the CPR survey have been rarely compared to more traditional sampling methodologies. In this study, we examine and compare spatial (surface and vertical) and temporal (diel and seasonal) patterns in the abundance of *C. finmarchicus* with another sampling technique in the gulf of Maine. Our results provide evidence that the CPR survey not only gives internally consistent time series of *C. finmarchicus*, but also an accurate representation of both spatial (surface and vertical) and temporal (diel and seasonal) patterns.

1. Introduction

With the California Cooperative Oceanic Fisheries Investigations (CalCOFI), the Continuous Plankton Recorder (CPR) survey is among the few plankton monitoring programme operated at a basin-scale (Edwards et al., 2010). The method has remained unchanged since 1958, providing one of the most extensive ecological data set available to the marine ecology scientific community (Batten et al., 2003; Reid et al., 2003; Warner and Hays, 1994). The copepod *Calanus finmarchicus* has probably been among the most investigated species from the CPR survey because of its central role in the trophodynamics of some pelagic ecosystems in the North Atlantic Ocean where it transfers energy from the phytoplankton to higher trophic levels (Mauchline, 1998).

Using data from the U.S. Global Ocean Ecosystem Dynamics (GLOBEC) Georges Bank programme, we first examine both diel and seasonal changes in the abundance of *C. finmarchicus* between 0 and 522 m in Georges Bank where *C. finmarchicus* has been extensively sampled at different depths throughout the year (Reygondeau and Beaugrand, 2011). We provide evidence that *C. finmarchicus* in Georges Bank remains mostly distributed above the thermocline and that both seasonal and diel patterns in abundance above 10 m (depth sampled by the CPR machine) are positively correlated to patterns of abundance that take place down to 100 m. Second, we compare the seasonal distribution of *C. finmarchicus* inferred from GLOBEC with the one assessed from the CPR survey. Despite some discrepancies in the abundance values, our results show that both datasets provide similar patterns at a seasonal scale. We finally compare in the North Atlantic the spatial distribution of *C. finmarchicus* based on CPR data and international surveys and campaigns data originating from vertical trawls. Together, these results suggest that the CPR survey gives a correct picture of both temporal (i.e. seasonal and diel scales) and spatial (i.e. regional to basin-scale) changes in *C. finmarchicus*.

☆ All authors agree to the submission of this manuscript. PH and GB conceived the study and performed the data analysis. PH, GB and GR wrote the article.

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2. Materials and methods

2.1. Materials

2.1.1. GLOBEC data

We used data from the U.S. Global Ocean Ecosystem Dynamics (GLOBEC) Georges Bank programme (http://globec.whoi.edu/jg/dir/globec/gb/). This biological dataset extends from 65.64°W to 69.76°W of longitude and 40.27°N to 44.1°N of latitude and data were collected between January 1995 and February 2000 (Fig. 1). Data were collected by a Multiple Opening and Closing Net with an Environmental Sensing System (MOCNESS-1) of 335 μm. Only vertical trawl samples with a depth ranging from 0 to 522 m (44,872 measurements) were chosen to be compared with CPR data, which has a mesh size of 270 μm (936 measurements).

2.1.2. Data from international surveys and campaigns

The dataset (99,618 measurements) came from different sources: the TASC programme (TransAtlantic Study on *Calanus*; http://tasc.imr.no) from 1995 to 1998; the U. S Georges Bank programme (1995–2000); the India survey (data provided by X. Irigoien, sampled by R. Williams and available from the Plymouth Marine Laboratory) from 1971 to 1975; the Norwestlant programme (www.st.nmfs.noaa.gov/plankton, see Heath et al., 2008) in 1963; the BODC programme with Ocean Weather Ship data (British Oceanographic Data Centre; www.bodc.ac.uk/projects/uk/prime/) from 2001 to 2002; the U. S Northeast continental shelf bongo survey (data provided by Jack Jossi, http://www.st.nmfs.noaa.gov/copepod/data/ecomonrv/index.html) from 1977 to 2006; Labrador data in 1997, 2001 and 2002 (data provided by Erica Heard, see Head et al., 2010). The relative presence of copepodite V and adult stages CVI was assessed for each geographical cell of a 1° × 1° spatial grid over the North Atlantic Ocean from 80°W to 19.5°E of longitude and from 25.5°N to 73°N of latitude (Reygondeau and Beaugrand, 2011).

2.1.3. CPR data

We used data on the abundance of adult *C. finmarchicus* from the CPR survey (Fig. 1; 914 measurements). The CPR instruments are towed at a single depth of 7 m (Batten et al., 2003; Reid et al., 2003). Water enters the CPR through an inlet aperture of 1.61 cm^2 and passes through a 270 μm silk-covered filtering mesh (Batten et al., 2003). Individuals >2 mm, corresponding to copepodite stages CV and CVI (i.e. adults) of *C. finmarchicus*, were subsequently removed from the filter and covering silk.

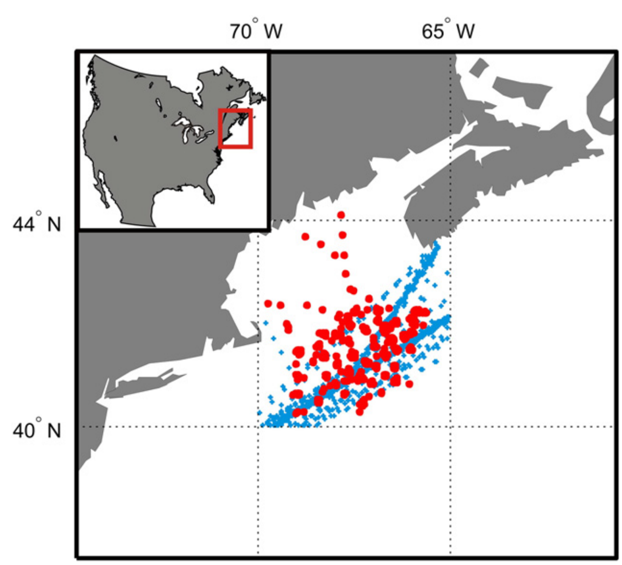

Fig. 1. Spatial distribution of CPR samples (in blue) and GLOBEC samples (in red) in Georges Bank (the Gulf on Maine) for the period 1995–2000.

2.1.4. Hydrological data

The depth of the thermocline was calculated from 9482 profiles of temperature covering the period from January 1995 to February 2000 from 65°W to 70°W of longitude and 40°N to 44.5°N of latitude. Profile data were downloaded GLOBEC (http://globec.whoi.edu/jg/dir/globec/gb/) and from the World Ocean Database website (http://www.nodc.noaa.gov/OC5/SELECT/ dbsearch/dbsearch.html). All profiles were taken from the surface to the bottom sea in continental shelf area and down to 500 m in oceanic regions (de Boyer Montégut et al., 2004). The depth of the thermocline was calculated by applying an Exponentially Weighted Moving Average (EWMA; (Montgomery, 1991)) of the depth-to-depth temperature differences (here 0.05 °C m^{-1}; (Thomson and Fine, 2003)) to identify the depth and the intensity of the maximal temperature gradient for each profile (Reygondeau and Beaugrand, 2011).

2.2. Statistical analyses

2.2.1. Calculation of profiles of abundance in Georges Bank

To examine the vertical distribution of each copepodite stage of *C. finmarchicus*, we calculated the abundance (ind m^{-3}) of each stage as a function of depth from 0 to 522 m by increment of 1 m. For this analysis, we did not use CPR data but, rather GLOBEC data. As we performed this procedure for each month and each 2-hour period, vertical profiles were composed of 144 time periods (12 months × 12 2-hour periods; Fig. 2). We superimposed the location of the thermocline in Fig. 2 (see previous section).

2.2.2. Correlations in the abundance between the surface and other depths for each copepodite stage in Georges Bank

To examine how temporal patterns of abundance may be altered as a function of depth, Pearson correlation coefficients were calculated between subsurface abundance (patterns of abundance at 1 m) and all other depths from 1 to 100 m every metre (Fig. 3). This analysis was performed on the previous calculated profiles. Only data ranging from 0 to 100 m are represented because the number of missing data was too high to allow the calculations of the correlations between 100 and 522 m (Fig. 3). Correlations were tested using a Monte Carlo procedure based on 10,000 simulations and the random selection of half (72) of the total number of couple of points (144). For each simulation, the minimum, the maximum, the 5th, 50th (i.e. median) and 95th percentiles of all correlations were represented (Fig. 3).

2.2.3. Seasonal comparison in the abundance of *C. finmarchicus* estimated from CPR and GLOBEC data in Georges Bank

A monthly time series of the abundance of CV and adult *C. finmarchicus* was calculated by averaging data from the CPR dataset which were extracted following the same temporal resolution (12 months × 12 2-hour periods = 144) and in the same geographical box than in the previous analyses (Fig. 1). Using the GLOBEC dataset, an average of the first 10 m for stages CV and adult was calculated corresponding to the depth of the CPR sampling. CPR and GLOBEC time series were then standardised using their respective minimum and maximum values (*i.e.* $\frac{X - \min(X)}{\max(X) - \min(X)}$) and were represented in Fig. 4A using a boxplot. The number of samples per month for both CPR and GLOBEC datasets are represented in Fig. 4B. On each box, the central mark is the median and the edges of the box are the 25th and 75th percentiles. The whiskers extend to the most extreme value that is not an outlier. Although not shown, outliers are defined here as any value greater than the 99.5th percentile or lower than the 0.5th percentile.