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Estimation of latitudinal shift of *Calanus* from 1959 to 2004 using generalized additive models

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Summary

This study aims to verify the poleward shift of zooplankton species (*Calanus finmarchicus, C. glacialis, C. helgolandicus, C. hyperboreus*) in the North Atlantic Ocean, and to assess how much of this shift may be due to sea warming, using Generalized Additive Models. To this end, the population gravity centre of observed data from the Continuous Plankton Recorder survey was compared with that predicted from simulation experiments: 1) a model using only climate factors (i.e. niche-based model) to simulate species habitat suitability, 2) a model using temporal and spatial terms to reconstruct the population distribution, and 3) a model using both factors combined, cross-validated. Our findings show that only *C. finmarchicus* had a consistent poleward shift estimated as 8.1 km per decade in North Atlantic (16.5 km per decade for the Northeast Atlantic) associated with sea warming. This value is lower than that reported by previous studies for zooplankton assemblages in the Northeast Atlantic. *C. helgolandicus* population has expanded in all directions. *C. glacialis* and *C. hyperboreus*, shifted southward, probably responding to cool water penetrating southward in the Labrador Current.

Introduction

Data from Continuous Plankton Recorder (CPR) survey in the Northeast Atlantic Ocean indicate that zooplankton exhibit distribution range shifts in response to global warming that are among the fastest and largest of any marine or terrestrial group (Beaugrand et al., 2002). Habitat models based on CPR data have been also developed to provide projections of future climate-driven shifts (Helaouët et al., 2011). Our objective is to develop models of habitat suitability (at species level) and data reconstruction for analysing past changes in zooplankton species (*Calanus finmarchicus, C. glacialis, C. helgolandicus, and C. hyperboreus*.) due to prominent climate drivers, particularly sea warming within the North Atlantic, using Generalized Additive Models (GAMs). Zooplankton are good indicators of climate change for several reasons: highly sensitive to temperature, most species are short-lived so there can be tight coupling of climate and population dynamics, copepods are usually not commercially exploited avoiding confusion with trends in exploitation, and the distribution of zooplankton can accurately reflect temperature and ocean currents because plankton are free floating. In this work, habitat suitability models were built for each one of the four copepod species within the temperate to subarctic North Atlantic from 1959 to 2004.

Materials and Methods

Data on the abundance (mean density (ind./m^3) of four species (*C. finmarchicus, C. glacialis, C. helgolandicus, C. hyperboreus*), total diatoms and dinoflagellates and the phytoplankton colour index (PCI) were obtained from the CPR data base. The CPR data used here represent monthly data

collected between 1959 and 2004 within 35º to 65ºN and 75ºW to 9ºE. Sampling frequency was analysed as a function of year and latitude in order to test the uniformity of sampling effort over the time period. Environmental data compiled had a spatial resolution of 1º longitude and 1º latitude. Sea surface temperature (SST), salinity, vertical velocity, and sea level anomaly, extracted from reanalysis OS3 ECMWF model. The habitat modelling approach consisted in fitting the species occurrence as a function of climatic factors, surrogates of environmental factors and population features (latitude and longitude, month), temporal trend (year), and potential food resources, using GAMs. We built and compared three different models for each species: 1) A spatial and temporal Model. A GAM using spatial (latitude, longitude) and temporal (month, year) terms only. This model is employed as data reconstruction method to identify trends on population over the analysed period. 2) An SST Model. A GAM based upon only SST to identify species habitat suitability shifts. The comparison of the output of this model with the previous one permits to verify whether populations have shifted due to sea warming or if only their habitat suitability has shifted. 3) A combined Model. A GAM based on spatial, temporal and environmental factors. We validated the models based on the cross-validation resampling procedure, which use independent data sets for model building and model validation.

Results and discussion

Results show that only *C. finmarchicus* had a consistent poleward shift, associated with sea warming, estimated in 8.1 km per decade in the North Atlantic (16.5 per decade for the Northeast) (Figure 1), which is substantially lower than previous works at assemblage level and restricted to the Northeast Atlantic (Chust et al., submitted). On the contrary, *C. helgolandicus* is expanding in all directions, although its northern distribution limit in the North Sea has shifted northward. *C. glacialis* and *C. hyperboreus*, which have the geographic centres of populations mainly in the NW Atlantic, showed a slight southward shift, probably responding to cool water penetrating southward in the Labrador Current. Our approach, supported by high model accuracy (80%), shows its power in detecting species latitudinal shifts, and identifying its causes, since the trend of occurrence observed data is influenced by the sampling frequency, which has progressively concentrated to lower latitudes with time.

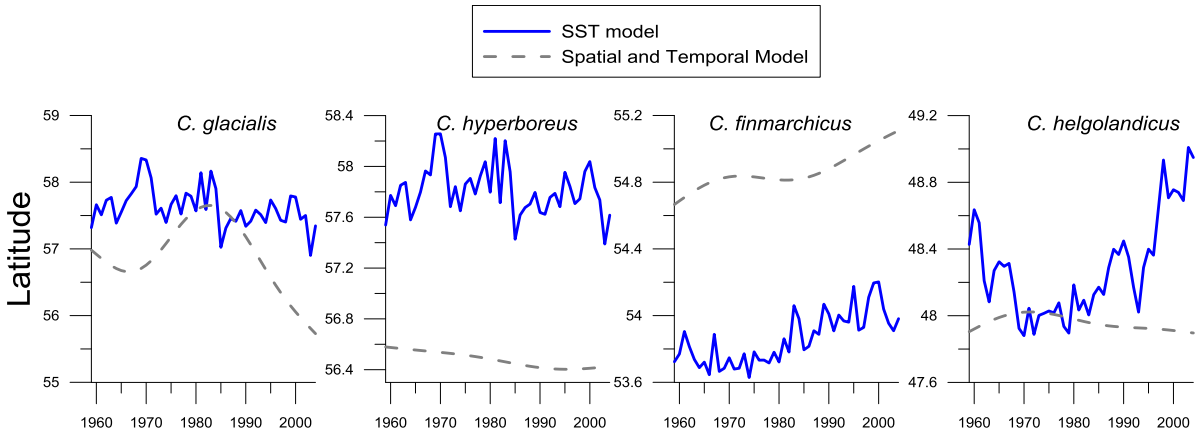

Figure 1. Shift in latitude of the gravity centre of *Calanus spp*. population habitat suitability models.

References

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