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"Effect of zooplankton prey on distribution and abundance of North Sea herring (Clupea harengus) larvae: A long term study."

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Summary

Recently, North Sea autumn spawning herring (*Clupea harengus*) has gone through consecutive years of low recruitment despite high spawning stock biomass. Although several mechanisms, such as reduced larval growth and high early larval mortality, have been identified as co-occurring during these years, the causes behind them have not been identified. In this study we analyse a long term dataset of larval distribution, from the International bottom trawl survey (IBTS), in relation to environmental factors and zooplankton abundances, obtained from the Continuous Plankton Recorder (CPR). These analyses assessed the potential influence of zooplankton on the reduced survival of larval stages. Generalized additive mixed models on 30 years of spatially defined data showed the abundance of the copepod *Pseudocalanus* sp. during winter to have an important effect on larval distribution and abundance. According to our models the direct effect of temperature on larval abundances was less than the effect of zooplankton abundances.

Introduction

North Sea herring (*Clupea harengus*) population consists of four stock components. Spawning starts around the Orkney and Shetland Islands in late August and continues southward to the Southern North Sea until January (Gröger et al. 2010). After hatching, larvae from go through a southerly drift towards the nursery areas along the south-east North Sea coast. Despite years of high spawning output in the last decade, recruitment of North Sea herring has decreased since 2002, producing successive weak year classes (ICES 2013). This low recruitment has been related to reduced survival during larval phases (Payne et al. 2009, Fässler et al. 2011), and also to atmospheric patterns such as North Atlantic oscillation (NAO) and Atlantic multidecadal oscillation (AMO, Gröger et al. 2010). Environmental changes related to multiannual patterns (NAO, AMO) also have affected plankton species composition and abundance (Alvarez-Fernandez et al. 2012). Some of these changes in plankton community could be connected to herring dynamics. Known zooplankton prey of herring larvae such as *Temora* sp. and *Pseudocalanus* sp have shown a sharp decline in the last decade (Alvarez-Fernandez et al. 2012). We studied the relationship between herring larvae and zooplankton prey in space and time via generalized additive mixed modelling, considering the potential effect of different plankton regimes in the North Sea, trying to discern the effect of food availability on the survival of herring larval stages.

Materials and Methods

Data on herring larvae (length 25-55mm) abundance were obtained from the MIK survey carried out during the IBTS in February. Abundance and spatial distribution (defined in a 1°Longx1°Lat grid) of larvae were analysed by Generalised additive models in relation to the zooplankton prey and temperature they encountered through their winter drift. The different relationships between larvae and prey represented in the models were allowed vary in space and time. Four different species, which are considered prey of herring larvae, were included: *Temora longicornis*, *Oithona* sp., *Pseudocalanus elongates* and *Acartia* spp.

Results and discussion

The best model included a non-linear predictor for Temperature which varies in space (Fig. 4a) , and linear predictors for *Pseudocalanus* sp. and *Temora* sp. which also vary in space (Fig. 4b, c). There was a negative relationship between temperature and PML abundance in the whole area except the English Channel (Fig. 4a). The relationship of zooplankton species to PML larvae is less uniform. *Pseudocalanus* shows a positive relationship with PML larvae in the northwest and southeast of the North Sea, and a negative relationship in the English Channel and the mouth of the Skagerrak (Fig. 4b). *Temora* sp. shows the opposite relationship (Fig. 4c).

Pseudocalanus sp. is an important prey of herring larvae for smaller sizes (< 20mm)(Blaxter 1965), which could be expected to be abundant during the months previous to the MIK survey. Therefore *Pseudocalanus* abundance during the winter months could influence abundance of PML in February-March. *Temora* sp. has been shown to be more important as prey for larval herring of larger size (>30mm) (Blaxter 1965), therefore, a different response of PML to each of these species could be expected. This could be explained competition between the two for food resources. As such, an increase in *Temora* sp. abundance could lower the body condition of Pseudocalanus sp. through competition for food.

The relationship of *Acartia* spp. and *Pseudocalanus* sp. with herring larvae was very similar, although the intensity of the relationship was less for *Acartia* spp. This similarity suggests that they both are prey of herring larvae during the period from October to February. *Acartia* spp. was already reported by Blaxter (1965) as prey for small herring larvae, which further confirms that our method is capturing the influence of zooplankton prey on the earlier stages of herring larvae. Together these results indicate the importance of winter abundance of small copepod species abundance, such as *Acartia* spp. and *Pseudocalanus* sp. on the survival of spawned herring larvae into the later stages.

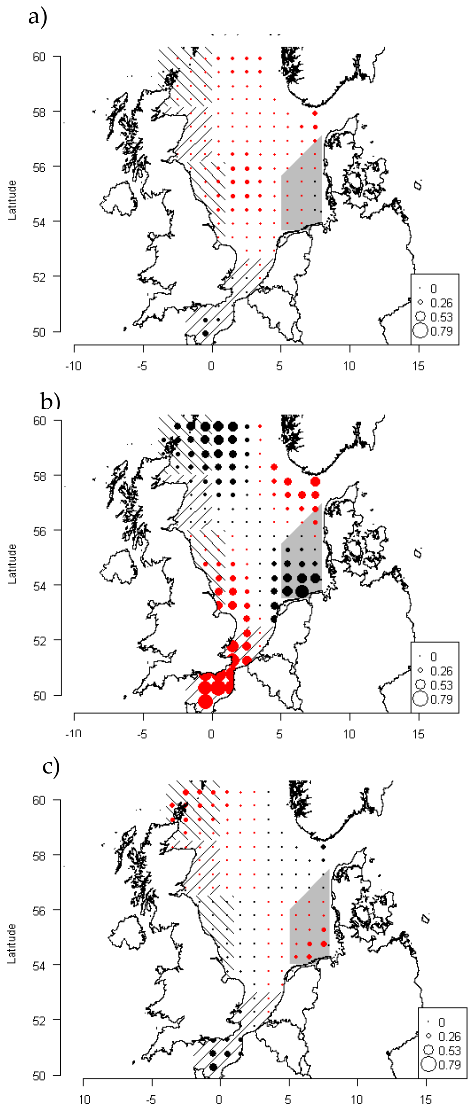

Figure 1. Change in the contribution of each parameter to the predicted PML abundance with an increase of: a) temperature, c) *Pseudocalanus* sp., and d) *Temora* sp. Red indicates a decrease while black indicates an increase.

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