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Trends in the size of mesozooplankton during the last 25 years at A Coruña (N Spain)

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Summary: Temporal changes in the mean individual size and in the abundance of taxonomical groups of different size of mesozooplankton (200-2000 μm) were investigated in samples collected in the shelf waters of A Coruña (N Spain) since 1988. An overall decreasing trend in the average size of individuals, indicated by the biomass (dry weight) to abundance ratio was observed. Most of this decrease can be attributed to the increase in the dominance of copepods of small size (< 1 mm) while no significant decreases in the abundance of species of large size (> 1 mm) were found. Indeed, some species of large size showed increasing trends in abundance during the study period. Nevertheless these trends were small at linear scales and most species did not show significant linear trends during the study period. The observed trends in zooplankton were related to weak changes in sea surface temperature and upwelling intensity during the studied period. This suggests that the effects of the general warming of the surface ocean on plankton are weakened in regions of coastal upwelling.

Introduction: Temperature has been recognized as one of the main factors affecting body size of aquatic ectothermal organisms at the level of communities, species and populations, with a general reduction in size at high temperatures (Daufresne et al., 2009). Smaller plankton size affects the entire food web, because of the adaptation to consumers to certain sizes of prey but also the sequestration of biologically-fixed carbon in the deep ocean by the sedimentation of large particles (Legendre and Rassoulzadegan, 1996). The nature and rate of changes in plankton size, however, can vary in the different ocean regions where warming is modulated by different factors. Coastal upwelling affects the warming trends because the input of cold waters to the surface. The result are differential trends in surface temperature between the coast and the open ocean (Mendelssohn and Schwing, 2002; Santos et al., 2012). In the NW coast of the Iberian Peninsula, upwelling has been related to changes in plankton biomass, production and species composition (Bode et al., 2009; Pérez et al., 2010; Bode et al., 2011). In this study we examine the reduction in the individual size of zooplankton in the last 25 years from a coastal upwelling site in the NW Iberian coast, to ascertain if the changes are due to an increase in the abundance of species of small size or to a decrease in those of large size. In addition we explored the relationships between the changes in size and abundance to changes in water temperature and upwelling intensity.

Materials and methods: Zooplankton abundance and biomass data were obtained from monthly samples collected between 1988 and 2013 at Station 2 of A Coruña (Spain), from the time-series project RADIALES (http://www.seriestemporales-ieo.com/) (Bode et al., 2009). Several series of zooplankton groups representative of small (<1 mm) or large body size (>1mm) as well as the ratio small:total copepods and the mean body weight of zooplankton as the ratio biomass:abundance, were analysed in detail. Sea surface temperature (SST, ^{0}C) was obtained with CTD casts and upwelling intensity was represented by the Ekman transport ($m^3\ s^{-1}\ km^{-1}$) (http://www.indicedeafloramiento.ieo.es/). Time-series of zooplankton and environmental data were decomposed by an additive model including: mean, linear, periodic components and autocorrelation terms (e.g. Bode et al., 2011). The residual variance of the model for each series was employed to study the relationships between series by means of correlations at different time-lags.

Results and discussion: Total abundance and biomass showed an increasing linear trend between 1988 and 2013 but the increase in abundance was larger than the increase in biomass, with the result of a negative trend in mean body size. This result agrees with the expected reduction in body size with warming (Daufresne et al., 2009; Beaugrand et al., 2010). There was an increase in the relative abundance of small zooplankton, but only some groups (*Acartia* and *Oithona*) showed significant trends while others did not show significant changes (*Oncaea,* Cladocera). These results indicate that the change is leaded by a few opportunistic groups, as *Acartia* (Bode et al., 2009, 2011). In contrast, there were no significant decrease in most large zooplankton, and some groups even increased (*Candacia,* Appendicularia, Euphausiacea). Therefore the decrease in mean body size is not caused by a decrease in the abundance of large zooplankton.

Neither SST or upwelling intensity showed significant trends during the study. Otherwise our series revealed mean changes in SST of +0.01 ^{0}C yr^{-1} and -2.23 m^{3} s^{-1} km^{-1} yr^{-1} in the upwelling index which are of similar magnitude to those reported for this region (González-Pola et al., 2005; Pérez et al., 2010; Santos et al., 2012). Besides, SST resulted negatively correlated with the upwelling index, stressing the dominant effect of upwelling. This caused that only a few zooplankton series showed significant effects of warming while most series were affected by upwelling.

Our results support a general decrease of individual zooplankton body size in the study zone in the last 25 yr because an increase in the dominance of some small copepods (as *Acartia* and *Oithona*). The changes are only partly explained by warming of surface waters, as the seasonal coastal upwelling interacts with the general warming of the ocean in the region. As a result, no significant trends in SST or upwelling were found, and the effect of upwelling on mesozooplankton size dominated over warming with changes in the later delayed between 2 and 6 months.

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