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Energy density of zooplankton and fish larvae in the southern Catalan Sea (NW Mediterranean)

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A B S T R A C T

In marine communities, energy of small planktonic organisms is transferred to their predators through feeding. The energy accumulated as organic substances by the different plankton organisms (Energetic Density content, E_D) has been analysed in high latitudes and tropical areas, but not in the Mediterranean Sea. In this study, we approach this type of investigation for Mediterranean plankton through measures of total calorimetric content using an oxygen bomb calorimeter. We examined the spatiotemporal variation in the E_D of microplankton (50–200 μm) and mesozooplankton (200–2000 μm), and two plankton-consumers, sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) larvae. The study was carried out during the winter and summer of 2013 off the Ebro River Delta (NW Mediterranean Sea). Both plankton fractions showed a more coastal distribution and higher biomasses during winter, the period of sardine larvae occurrences, in front of a wider cross-shelf distribution and lower biomasses in summer, when anchovy appeared. E_D values increased with the size of each plankton component, i.e., microzooplankton < mesozooplankton < fish larvae. A tendency for higher plankton E_D in the winter period was observed, although being only significant for coastal zone, associated to the more productive waters there. Sardine and anchovy larvae showed an increasing trend in the amount of energy during development, with significantly lower E_D between early larvae (6–10 mm standard length) and late postflexion stages (16–20 mm standard length). Small larvae of both species departed from a similarly low E_D content, but in the next two size classes sardine larvae showed higher E_D values than anchovy, being significantly higher in the 16–20 mm size class. Information on larval feeding patterns and larval growth rates for each species were used to discuss differences in energy allocation strategies.

1. Introduction

Zooplankton has a key trophic role in marine pelagic systems, because it constitutes the connecting link between primary producers and the upper trophic levels, from fish larvae to mammals. Nevertheless, the simple approach phytoplankton-zooplankton-upper predators is nowadays acknowledged to be more complicated, and small heterotrophs have been recognized as potential prey for zooplankton (Calbet and Landry, 2004; Saiz et al., 2007) and may even be included in the fish larval diet (Rossi et al., 2006; Govoni and Chester, 1990). Plankton accumulates energy as organic substances, and their consumers, in turn, feed upon these energetic substances; thus, each of the members in a community depends upon the preceding level as a source of energy (Lindeman, 1942). For this reason, information on the energy content of plankton species and their consumers are important for understanding the distribution, seasonal variations and transfer of matter and energy in marine communities (Percy and Fife, 1981). Moreover, this type of data can be used in a variety of ecological applications, such as models of ecosystem function, energy flow, physiology and trophodynamic studies to estimate fishery resources (Nageswara and Kumari, 2002; Politikos et al., 2011; Davies et al., 2012).

Research on plankton energetic density has been undertaken in Arctic and North Atlantic regions, where zooplankton is exposed to important fluctuations in food availability, and where suitable adaptations to store energy as lipids during periods of food shortage have been shown (Percy and Fife, 1981; Norrbin and Bamstedt, 1984; Lee et al., 2006). Stored lipids provide energy for reproduction, for withstanding periods of low supply, to sustain expensive expenditure activities such as swimming to catch prey or escape predators, and for vertical migration (Lee et al., 2006; Kiørboe, 2008). However, in tropical regions where low food concentrations are available year round, there is no evidence that plankton accumulates lipids as an energetic store; rather it accumulates proteins holding lower energy content than in higher latitudes (Goswami et al., 1981; Lee et al., 2006; Kumar et al., 2013). There are no studies that examine the energetic density (E_D) of

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the plankton of temperate regions, such as the Mediterranean Sea, so the strategy of energy accumulation is unknown.

In spite of the general oligotrophy of the Mediterranean Sea, the north western sector is a comparatively productive area. Within the continental shelf winter mixing processes involve the whole water column and supply nutrients to the epipelagic layers, which is reflected in the generally highest primary production levels in this period (Estrada, 1996), and in the development of phytoplankton and later zooplankton blooms (Alcaraz et al., 2007). The mesoscale hydrographic features associated to the shelf-break frontal system contribute to the fertilization processes during the warmer and stratified summer season, ending up in the development of a Deep Chlorophyll Maximum (DCM), and the associated zooplankton maximum in the shelf break zone (Alcaraz, 1985; Saiz and Alcaraz, 1990). In the region off the Ebro river delta, freshwater run-offs during the stratified periods are also an important contributor to surface productivity in summer (Salat, 1996; Salat et al., 2002), associated with high phytoplankton and microzooplankton abundances (Sabatés et al., 2007). Abundance of zooplankton in the region has high spatial and temporal variability. Among microzooplankton dinoflagelates and copepod nauplii dominated summer samples, while diatoms, tintinids and copepod nauplii dominated in winter (Gómez and Gorsky, 2003; Villate et al., 2014). Copepods dominate mesozooplankton through the year, while items like cladocerans and appendicularians occur mainly in summer (Calbet et al., 2001; Fernandez de Puelles et al., 2003).

The energetic density of fish larvae has seldom been measured (Kimata, 1982; Quantz, 1985; Harris et al., 1986; Yufera et al., 1999). In the case of the western Mediterranean Sea the Fulton's index has been used to approach energy larval storage (García et al., 2006). The present study is addressed to analyse the energy density of the larvae of sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*), and that of their plankton resources from the northwestern Mediterranean Sea. These two species are the most important small pelagic fish, both in terms of economic and ecological aspects (Coll et al., 2006). The sardine shows a coastal distribution and prefers cold waters (12–14 °C) during the autumn - winter spawning period (Palomera et al., 2007; Olivar et al., 2010). Anchovy spawning period begins at the end of spring, when the water temperatures start to increase, and lasts until the beginning of autumn, being particularly important in areas with an influence of continental waters (Palomera, 1992; Palomera et al., 2007). A recent investigation on energetic density of adults of these species showed different energy allocation strategies between them, i.e., sardine accumulates energy in the months previous to reproduction while anchovy uses the food intake for reproduction directly (Albo-Puigserver et al., 2017).

Larvae of both species are direct consumers of plankton, feeding on microplankton and mesozooplankton, with some differences between species and through their ontogeny; with a general major contribution of small prey items of the microplankton in the diet of sardine larvae (Tudela et al., 2002; Morote et al., 2010; Costalago et al., 2012; Caldeira et al., 2014; Costalago and Palomera, 2014; Intxausti et al., 2016). Our hypothesis is that the important environmental differences between winter and summer in the NW Mediterranean Sea are likely reflected in E_D of plankton of each period and therefore in the organisms feeding upon them. Thus, the main objective of the present study was to relate the energetic density of microplankton and mesozooplankton in these two contrasting periods, and that of sardine and anchovy larvae, which have important differences in their spatial and temporal occurrences in the plankton.

2. Material and methods

2.1. Study area and sampling procedure

The study area was located in the NW Mediterranean Sea, covering the entire continental shelf associated with the Ebro River Delta

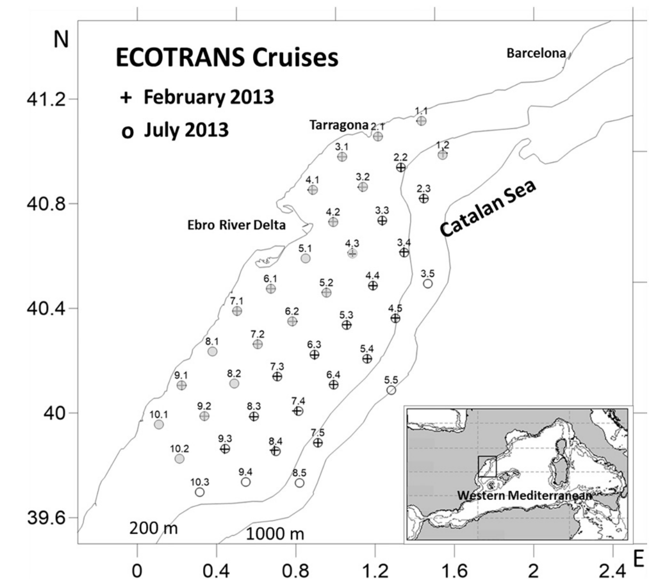

Fig. 1. Study area of the two surveys carried out in the southern Catalan Sea (NW Mediterranean). Coastal stations depicted in grey and offshore stations in white. Inset map shows the Western Mediterranean basin and the box denotes the studied area.

(Fig. 1). This region is characterized by a great seasonal variability. Sea surface temperatures oscillate from 13 °C in the winter to > 27 °C in the summer (Millot, 1999). As for the vertical structure, it is characterized by the presence of a very marked thermocline from the beginning of the spring until autumn, whereas in winter almost the entire water column is homogeneous (Salat et al., 2002). Moreover, there are significant differences in planktonic production in the area with period of the year, with maximum values in April and May and the lowest at summer (Arin et al., 2005; Champalbert, 1996).

Two 15 days' surveys, in February and July of 2013, were conducted to identify winter and summer situations, within the peak of the spawning of the objective species, winter for sardine and summer for anchovy (Palomera et al., 2007). Stations were placed in a regular grid from ca. 50 m to the shelf-break 500–1000 m, with a distance between them of 10 miles (Fig. 1).

In each station a vertical cast with a Conductivity, Temperature and Depth profiler (CTD Sea Bird 25) from surface to the sea-bottom was made to obtain vertical profiles of temperature, salinity and fluorescence. Microplankton and mesozooplankton samples were obtained at each station through vertical hauls from 100 m depth to the surface using a CalVET net (25 cm diameter, fitted with 53 μm meshes) for the microplankton, and a WP2 (58 cm diameter, with 200 μm mesh size) for the mesozooplankton. Fish larvae were sampled by means of oblique hauls, with a Bongo net (57 cm diameter, with 300 μm mesh size) at ship speed of 2 knots, from a maximum depth of 200 m to the surface. All the nets were equipped with a flowmeter to determine the volume of water filtered.

2.2. Sample processing

On board, CalVET and WP2 samples were filtered through sieves of 200 and 2000 μm, respectively, to obtain the two groups for the study of micro- and mesozooplankton (53–200 μm and 200–2000 μm, respectively). Plankton samples were split in two with a subsampler, and stored in liquid nitrogen. One of the subsamples from the CalVET and one from the WP2 were used to estimate the biomass (dry weight/m^3) and the caloric content, the second one was not used in the present study and kept frozen for isotopic analysis. Anchovy and sardine larvae from one of the Bongo nets were sorted on board and frozen in liquid nitrogen. The sample from the second Bongo net was preserved in 5% buffered formalin and fish larvae were sorted out in the laboratory for