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Benefits of frontal waters for the growth of *Engraulis anchoita* larvae: The influence of food availability

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ABSTRACT

We studied the abundance, size and growth rates of *Engraulis anchoita* larvae during the end of the species' spawning season in relation to environmental variables. Two sampling transects, one in Península Valdés (northern transect: NT) and the other in Isla Escondida (southern transect: ST), with four stations each, were established in late summer. Both locations are characterized by high concentrations of *E. anchoita* larvae in spring, strongly associated with the presence of frontal waters, at the beginning of the species' spawning season. Zooplankton and ichthyoplankton were sampled, and temperature profiles and chlorophyll-*a* satellite images were analyzed for each sampling station. Zooplankton samples were divided in size fractions, and composition and abundances were estimated. Standard length (SL), ontogenetic stages, and abundance (including eggs) were estimated. Additionally, age and growth rates were determined by otolith analysis. Two different scenarios were observed in both transects. In the NT, a frontal structure was found, while at the ST, the water column was completely homogeneous. Total zooplankton abundance was maximum at frontal waters, with 22,195 ind. m^{-3}, being the small size fraction (< 200 µm) the most abundant, mainly composed of nauplii (9000 ind. m^{-3}) and cyclopoid copepodites (4000 ind. m^{-3}). The NT showed higher abundance (mean of 126.5 ind. m^{-2} per station in NT; 29.75 ind. m^{-2} in ST), faster growth rates of *E. anchoita* larvae (NT: 0.45 ± 0.04 mm day^{-1}; ST: 0.34 ± 0.09 mm day^{-1}; n = 90), and higher mean SL at frontal waters (7.57 ± 1.52 mm SL) than the ST. In the NT, *E. anchoita* growth rates were constant in time, whereas in the ST, they decreased with age. Our results support the classical theory, which states that frontal waters provide advantageous environmental conditions for fish larvae feeding, growth and, thus, survival.

1. Introduction

Frontal waters are characterized by circulations that are a consequence of differential densities between two water masses, which generate a convergence at the surface or bottom boundary (Largier, 1993; Mann and Lazier, 1996). Oceanographic characteristics of seasonal fronts such as nutrition enrichment and water stratification generate favorable conditions for the development of phytoplankton, zooplankton, ichthyoplankton and top predators (Bakun et al., 2010; Mann and Lazier, 1996). According to the hypothesis of Bakun (1996), the "Bakun's Fundamental Triad", frontal areas have three essential characteristics that enhance survival and recruitment of pelagic fish during their early stages: i) the enrichment of surface water layers caused by the rise of deeper water rich in nutrients; ii) the concentration of planktonic organisms that constitute food items for fish larvae and iii) the retention of fish eggs and larvae in favorable areas.

A conspicuous feature in the Patagonian coastal area is the development of the tidal thermal front of Península Valdés during spring and summer (Fig. 1). When the frontal system is fully formed, it extends between 41° and 45°S, following the 75–80 m isobath (Sabatini et al., 2004). High tidal dissipation rates generate strong vertical mixing in near shore waters, which homogenizes the entire water column. Wind

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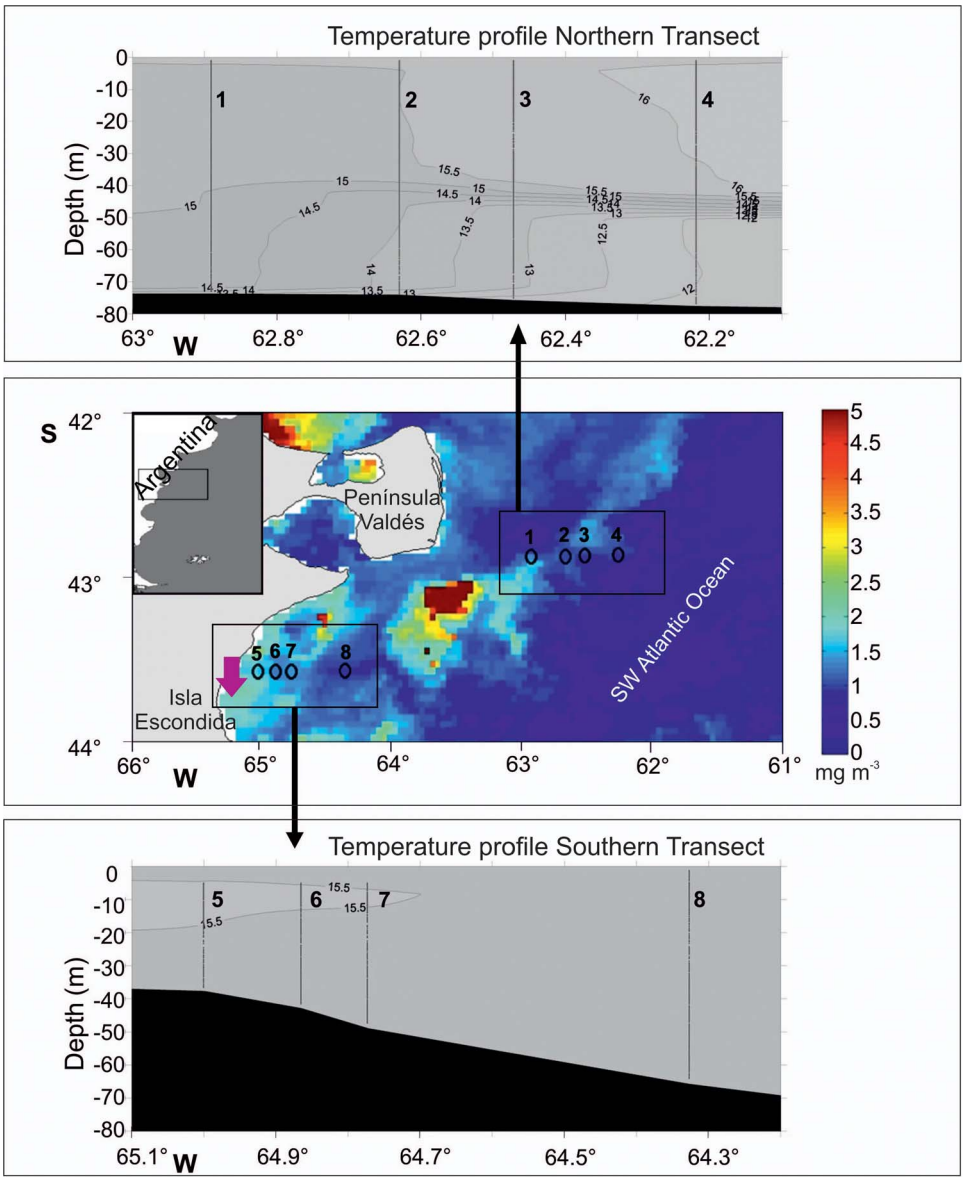

Fig. 1. Position of transects and distribution of stations with mean surface chlorophyll-*a* values (mg C m^{-3}) calculated as an average of eight days centered on April 3rd, 2013 (center). Detail of temperature profiles (°C) of the northern and southern transects (above and below, respectively). The purple arrow indicates the location of Isla Escondida.

pressure on the surface layer also contributes to forming and maintaining the homogeneity near the shore. On the other hand, seasonal surface warming induces a strong stratification of the shelf waters. As a consequence, a clear separation can be observed between highly mixed coastal and stratified offshore waters (Tonini et al., 2013). Between the homogeneous and stratified waters, there is a transitional zone, with a weaker thermocline, which constitutes the frontal area (Carreto et al., 1986; Glorioso, 1987). This structure is maintained until autumn, when the stratification is weakened due to the wind effect and decreasing solar heating (Acha et al., 2004).

The Península Valdés tidal front is important to several fish resources that are subject to commercial fishery, e.g. the hake, the southern blue whiting, the Argentine shortfin squid, the mackerel and the patagonic Argentine anchovy (Alemany et al., 2014; Brunetti et al., 1998). The latter, *Engraulis anchoita* (Hubbs and Marini, 1935), is a small pelagic fish, important in the food web of the Argentine Sea, being in the dietary base of several commercially exploited species. *Engraulis anchoita* represents one of the most important fish resources in terms of biomass in the Southwest Atlantic Ocean (Hansen and Madirolas, 1996; Madureira et al., 2009; Pájaro et al., 2009). The patagonic stock of *E. anchoita* spawns between 41° and 47°S from austral spring to autumn, with a maximum spawning peak in December, from the coast to 150 km offshore. Each female lays eggs multiple times during the entire spawning season, forming areas with large concentrations of larvae. Two main areas of larval concentration have been previously detected: one near Península Valdés and the other a few kilometers south, in the area of Isla Escondida (Sánchez, 1995; Sánchez and Ciechomski, 1995). *Engraulis anchoita* is a zooplanktivorous species throughout its life cycle, being a key component of the dynamics of pelagic ecosystems, performing a "wasp-waist" type control (Bakun, 2006; Cury et al., 2000; Hunt and McKinnell, 2006). Thus, variations in the adult biomass of *E. anchoita* could generate drastic changes at both higher and lower trophic levels.

Ciechomski (1966) and Ciechomski and Weiss (1974) reported that larval stages up to around 38 mm of standard length feed mainly on small organisms, mostly copepod eggs, nauplii and small copepodites (Sabatini, 2004; Sánchez and Manazza, 1994; Sato et al., 2011; Viñas and Ramírez, 1996). Copepod ontogenetic stages have been related to the degree of water stratification. Previous studies in the frontal system of Península Valdés have reported the highest abundance value of