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Small pelagic fish in the NW Mediterranean Sea: an ecological review

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In the NW Mediterranean Sea, anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) are the most important small pelagic fish in terms of biomass and catch. Round sardinella (*Sardinella aurita*) and sprat (*Sprattus sprattus*) are also present in this region. A review of the information available on their biology and ecology has been done (Palomera *et al.*, 2007) to point out the gaps in current knowledge necessary to understand the dynamics of small pelagic fish in the region and to progress towards a precautionary and adaptive management. The commercial exploitation of small pelagics in the NW Mediterranean has been significant since the early 1940s. Although sardine makes up the largest share, anchovy reaches a higher price in the market and is thus more important and subject to heavier fishing pressure.

Data obtained from different studies in the NW Mediterranean allowed us to characterise the spawning habitats of sardine, anchovy and round sardinella by temperature and salinity. Egg abundance superimposed on T-S plots (Fig. 1) clearly defines the spawning habitats of the three species based on water mass characteristics. Anchovy eggs in the region are mainly found in warm waters, between 17 and 23°C, a temperature range that is located between that of the other two species. Moreover, anchovy is the only species that spawns in a wide salinity range, including waters of continental origin. Cold waters (12-14°C) are preferred by sardine to spawn, although spawning also occurs up to 19°C (Fig. 1). The opposing trend is shown by round sardinella, which may spawn at an SST higher than 23°C. The reproductive period of round sardinella in the NW Mediterranean stretches over the warmest period of the year, from July to October in accordance with its tropical origin.

According to their spawning periods, the increase in temperature and day length must trigger anchovy spawning, while the decrease in temperature and day length is the trigger in sardine. Nevertheless, the processes involved in the homogenisation of the water column and the considerable decrease in temperature

are much more variable than those leading to the increase and stratification of the water column. This implies that the processes to reach optimum spawning conditions for sardine are longer and more variable than for anchovy. Larval distribution is also related to major productivity mechanisms of the respective spawning seasons. In spite of the different thermal regimes that anchovy and sardine experience during the early larval stages, growth rates for the two species are within similar ranges (Fig. 2). Taking into account that metabolic rates should be lower in colder waters, this suggests that other factors like food quality or assimilation efficiency could have a more important role as a compensatory factor in sardine larval growth processes.

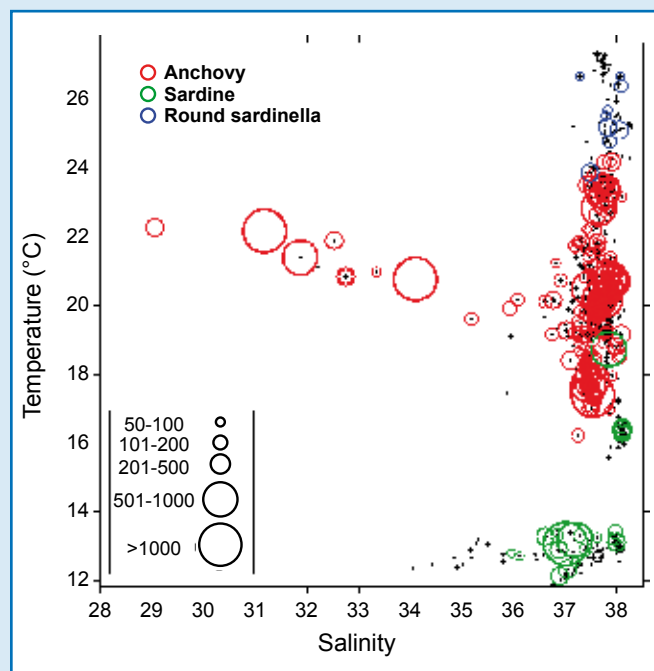


Figure 1. Surface temperature-salinity plots for anchovy, sardine and round sardinella eggs from surveys carried out in northwestern Mediterranean waters (only abundances >50 egg m⁻² are drawn).

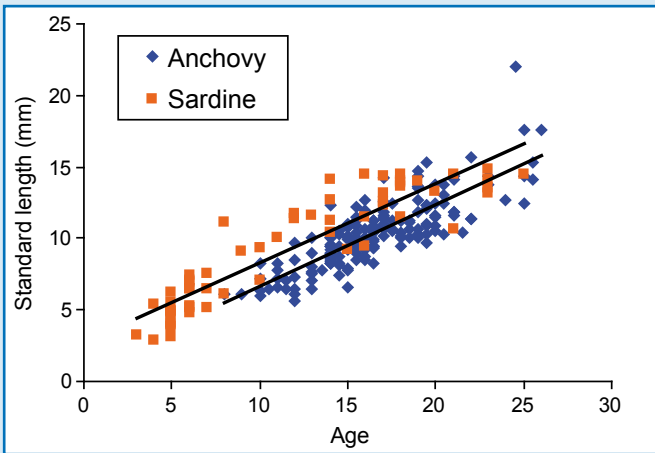


Figure 2. Age-length relationship of sardine ($y = 0.5518x + 2.7806$) and anchovy ($y = 0.5588x + 1.1399$) larvae sampled in February 1999 and June 2001, respectively

Because adults and larvae of sardine and anchovy feed on plankton, recruitment of these species in the highly variable NW Mediterranean will be determined by variations in environmental processes. An increase in planktonic production during the spawning period (e.g. by increasing nutrient availability mediated through river runoff or wind mixing) may affect these species rapidly. Linear transfer function models between landings and environmental variables during the spawning season of anchovy and sardine revealed the importance of Ebro River discharges for anchovy production, and of wind mixing for sardine production. Results indicated significant and positive correlation between spawning of anchovy and sardine with river flow and wind mixing, respectively (Lloret *et al.*, 2004). This is in agreement with the reproductive behaviour of both species. Spawning of anchovy is restricted to the surface

and larvae remain above the thermocline (Palomera, 1991). Thus, an increase in surface primary productivity in the enriched continental waters enhances production of zooplankton, the main food for anchovy larvae (Tudela *et al.*, 2002). The only source that may contribute to surface productivity is nutrient input from river outflow (Salat, 1996). Sardine spawns during autumn-winter, when the water column is vertically homogeneous and relatively cool. At that time, vertical mixing partly associated with wind regimes will affect the entire surface layer, carrying nutrients to the entire euphotic zone. Sardine larvae exhibit deeper vertical distribution than anchovy, with preferred levels above 50 m depth (Olivar *et al.*, 2001). Survival of sardine larvae is therefore closely related to vertical mixing and, consequently, to wind stress as a contributing mechanism.

Trophic behaviour studies of adult anchovy carried out during the spawning season in the Catalan Sea and the Gulf of Lions evidenced that this species feeds on small zooplankton, mostly copepods, and to a lesser extent on molluscs, cladocerans, other crustaceans and appendicularians (Tudela and Palomera, 1997; Plounevez and Champalbert, 2000). The main prey species for anchovy are *Centropages typicus*, *Temora stillifera*, *Microsetella rosea* and *Oncaea* spp. The daily ratio of food ingested by anchovy in the NW Mediterranean Sea was 4% of individual weight (34.1 cal g^{-1}). In the Catalan Sea, the consumption of adult anchovy was estimated to represent as much as 20% of the total zooplankton production accessible to anchovy aggregations. These results evidence the important role of this species in channelling energy from the pelagic food webs to higher trophic levels. Because sardine is more abundant than anchovy in the NW Mediterranean, combined predation of both anchovy and sardine may account for consumption of a large proportion of zooplankton production in the region.

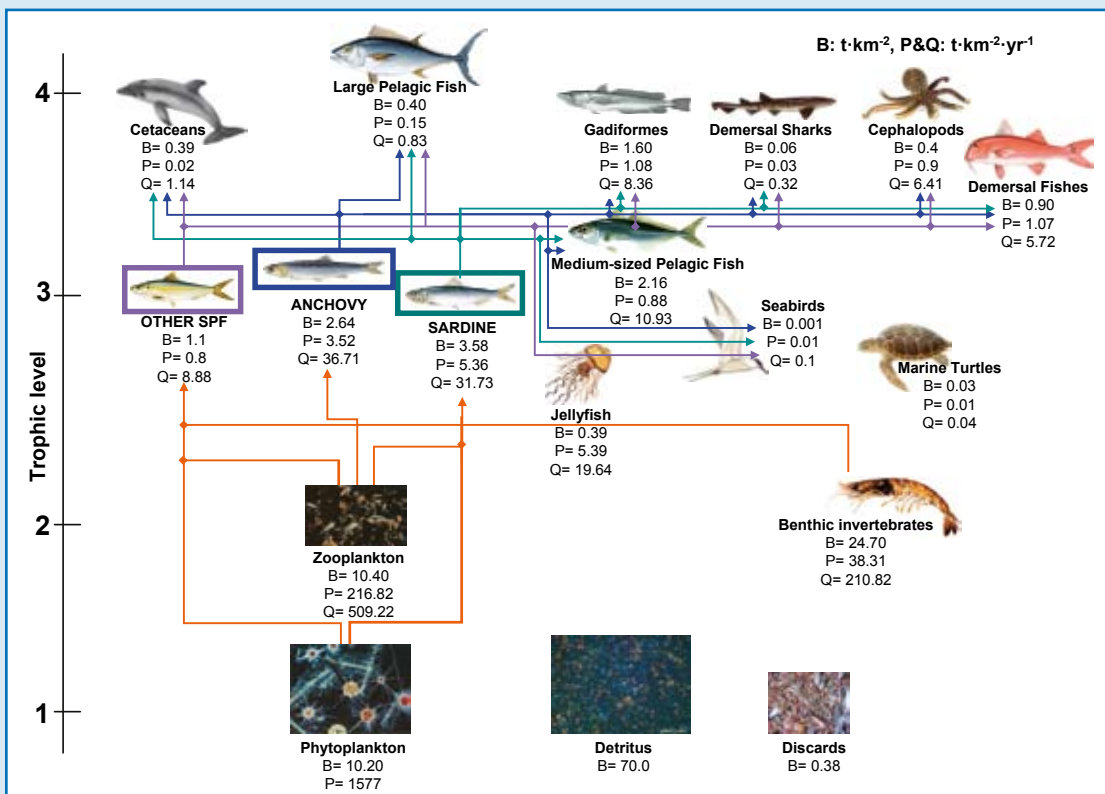


Figure 3. Schematic representation of the South Catalan Sea continental shelf food web, where the trophic role of small pelagic fish is highlighted.

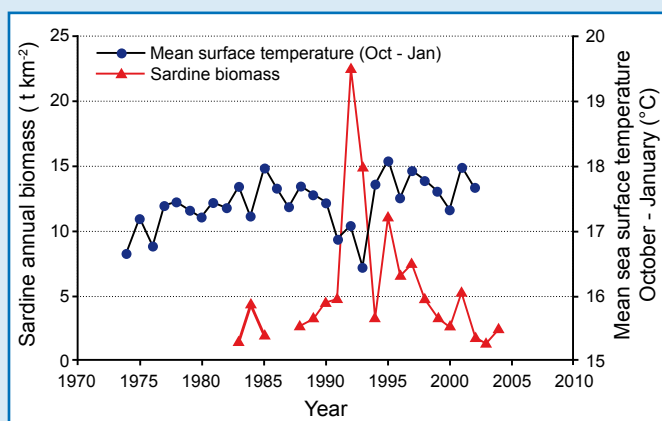


Figure 4. Time series of sardine biomass (t, km^{-2}) and yearly mean sea surface temperature (SST, $^{\circ}C$) during the spawning months in the South Catalan Sea area.

Modelling the exploited continental shelf and upper slope ecosystem associated with the Ebro River Delta (in the South Catalan Sea; Coll *et al.*, 2006) using the Ecopath with Ecosim software highlighted the role of small pelagic fish in the NW Mediterranean (Fig. 3). Analysis of the biomass, production, and consumption of production highlighted the importance of sardine and anchovy within the system: anchovy consumed 22% of system production, while sardine consumed 25%. Dynamics of biomass and catch related to anchovy and sardine were successfully reproduced over time, demonstrating a decrease in biomass and catches of anchovy and sardine in the ecosystem from the late 1970s to the present. In addition, the intense decrease in sardine biomass had a slight positive effect on anchovy, probably due to partial competition for trophic resources.

Sardine was identified to be involved in wasp-waist flow control situations (controlling both the prey and the predators), while anchovy and the other small pelagic fish group were identified as important bottom-up flow control groups (controlling predators). Dynamic modelling which enabled prediction of an environmental function related to the primary production dynamics. The environmental function decreased with time, while there was an increase in both temperature and NAO index

related with warmer and drier time periods in the Mediterranean region. Because there is no evidence of a decrease in the primary production in the area, this environmental function is suggested to be related to sardine biomass dynamics, where there is a negative relation of sardine biomass in the South Catalan Sea area and the mean SST per year during the spawning months (Fig. 4).

Small pelagic fish have therefore been shown to be key mid-trophic levels in the NW Mediterranean Sea. Both internal features of the food web (e.g. flow control and trophic interactions) and external features (e.g. fishing activity and environmental factors) are significant drivers of small pelagic fish dynamics in the NW Mediterranean Sea over time.

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The coastal-ocean transition zone in the Canary Current system

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During the last decade, the institutions engaged in marine science in the Canary Islands have collaborated in the development of a science strategy related to GLOBEC. The objectives attained were 1) the retrospective analysis of zooplankton taxonomy, abundance and biomass data, 2) the development of new methods for the study of zooplankton growth and metabolism, 3) the study of the role of the deep scattering layers in the structure of the pelagic ecosystem in oceanic waters, 4) the mesoscale variability due to the effect of eddies shed by the Canary Islands and their effect in the

accumulation of zooplankton and fish larvae, 5) the effect of upwelling filaments in the transport of zooplankton and fish larvae from the northwest African shelf to the islands, 6) the distribution and evaluation of fish biomass using acoustics around oceanic islands, and 7) the interplay between the physical variability and predation by the deep scattering layers and fish on the development of fish stocks in the area.

The Canary Current is the easternmost branch of the North Atlantic subtropical gyre flowing southward. The most important characteristic of the region is the presence of the large upwelling