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 data about zooplankton taxonomy, abundance and biomass, 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 area off the northwest African coast. High chlorophyll and primary production normally observed in coastal waters due to upwelling, decrease rapidly towards the ocean. Therefore, the sharp gradient from the permanently stratified waters of the subtropical gyre to the coastal upwelled waters makes this area of great oceanographic interest. Mesoscale phenomena are of importance in this region as besides upwelling filaments, the complex eddy system shed from the Canary Islands is unique in comparison with other similar systems such as the Humboldt, California and Benguela. The Canarian Archipelago extends over 600 km perpendicular to the general flow of the Canary Current. Therefore, the physical setting is quite different due to the mesoscale variability imposed by the islands (Barton and Arístegui, 2004).

Biological consequences of these perturbations are important for the upper trophic levels. Zooplankton and fish larvae drift with currents and are influenced by the eddy field. Zooplankton show low values of biomass in relation to cyclonic eddies due to the outward movement of the water and an accumulation around anticyclonic ones due to the inward effect (Hernández-León *et al.*, 2001a). Ichtyoplankton surveys around the islands also show a tendency of larvae to concentrate in two stagnation points upstream and downstream of the island (Rodríguez *et al.*, 2001).

The coupling of production in the coastal area off northwest Africa with the oceanic zone through filaments and eddies topographically formed in the coast or shed by the islands promotes a continuous transport of organic matter towards the deep ocean. In the Canaries region, filaments are recurrent structures shed from the African upwelling, between Cape Juby and Cape Bojador. They transport upwelled waters rich in chlorophyll (Fig. 1; Pacheco and Hernández-Guerra, 1999), zooplankton (Hernández-León *et al.*, 2002) and fish larvae (Fig. 2; Rodríguez *et al.*, 1999).

The fish larvae community was poorly know in the Canaries and a special effort was made during the last years to describe the taxonomical composition along the annual cycle. Of particular interest were the clupeiform larvae due to its important

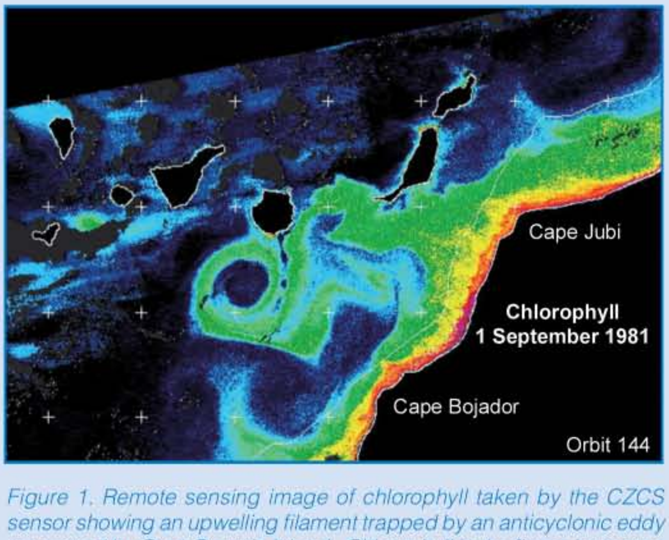

Figure 1. Remote sensing image of chlorophyll taken by the CZCS sensor showing an upwelling filament trapped by an anticyclonic eddy generated by Gran Canaria Island. Chlorophyll in the figure increases from blue to red. From Pacheco and Hernández-Guerra (1999).

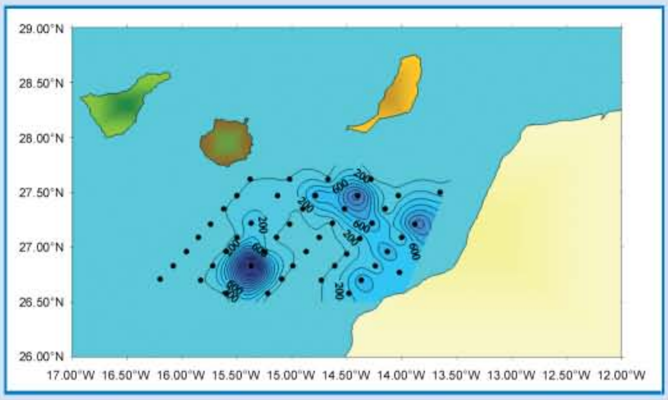

Figure 2. Abundance of Sardina pilchardus along an upwelling filament off Northwest Africa. Redrawn from Rodríguez et al. (1999).

economical and ecological value. *Sardinella aurita* (round sardinella) were the most common species of this group in the last decade, in contrast to *Sardina pilchardus* (pilchard), which used to be so in the early 1990s. Concentration and retention processes are typical of upwelling filaments. These effects were observed for African neritic fish larvae (Rodríguez *et al.*, 2004). A quasi-permanent cyclonic eddy, located near the upwelling zone, represented a nursery area for some clupeiform larvae, enabling them to overcome the negative effect of the Ekman transport. Neritic fish larvae transported offshore in these filaments sometimes reach the eastern coasts of the Canary Islands, as shown by Bécognée *et al.* (2006) and Moyano *et al.* (in prep.). Some clupeiforms, as the pilchard, round sardinella and European anchovy appeared to be good tracers of these structures. In particular, the case of pilchard is of interest to study the long-term climate changes. As deduced by biometric studies, this species is not reproducing in the Canary Island waters. However, early stages are found in the ichtyoplankton samples around the islands. The presence of this larvae coinciding with the strike of upwelling filaments with the islands were confirmed in the study of different annual cycles, suggesting that this transport is a common dispersal process.

An important component of the pelagic fauna, unfortunately scarcely studied, are the organisms inhabiting the Deep Scattering Layers (DSLs). In the Canary Current this layer is quite enhanced due to the influence of the coastal upwelling and is located between 400 and 600 m depth almost permanently (Boden and Kampa, 1967). A portion of these organisms are interzonal diel vertical migrants. A high percentage of this fauna predate upon epizooplankton and the consequences of their migration to the upper layers of the ocean at night are now being understood. In the study of an annual cycle of epipelagic copepods around the Canary Islands, Hernández-León (1998) observed an important variability in their abundance. Curiously, a succession of peaks was found coinciding with the full moon days. This variability showed a sharp similarity with the zooplankton lunar cycle described by Gliwicz (1986) in African lakes. Historical data review of zooplankton abundance (Hernández-León, 1998; Hernández-León *et al.*, 2001b) and later field studies (Hernández-León *et al.*, 2002, 2004, in prep.) showed the presence of a lunar cycle in epizooplankton due the

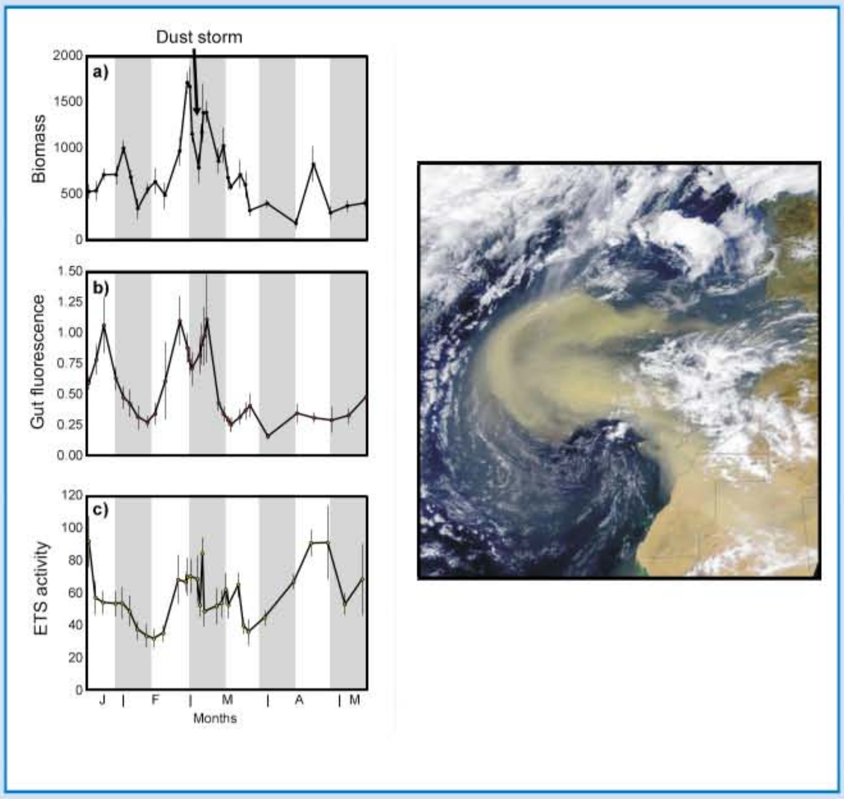

Figure 3. A) Total zooplankton biomass (mg dry weight·m^{-2}) and average (±standard error) specific gut fluorescence (B, µg pigment·mg^{-1} protein) and specific ETS activity (C, µlO_2·mg^{-1} protein·h^{-1}). Note the increase in specific gut content and ETS activity before the increase in biomass. Shaded areas correspond to the periods from waning to crescent moon. Observe the increase in mesozooplankton biomass during the illuminated period of the moon cycle and the sharp decrease during the dark period. The dust storm observed in the photograph (see information in http://visibleearth.nasa.gov/cgi-bin/ viewrecord?22352) was generated in the date indicated by the arrow. A sharp increase in chlorophyll (not shown) preceded the increase in mesozooplankton biomass and gut fluorescence coinciding with the dark phase of the moon. Redrawn from Hernández-León et al. (2004).

predatory pressure of diel vertical migrants. These organisms do not reach the upper layers of the ocean during the full moon to avoid predation by oceanic fish allowing the zooplankton community to grow. In the annual cycled studied during 2001 (Bécognée *et al.*, 2006), abundance of *Sardinella aurita* larvae during full moon was 38% of the one found during new moon, also suggesting a coupling with the lunar cycle observed in zooplankton.

Finally, the interplay between the physical frame, promoting the biological response and the effect of predation by diel vertical migrants seems of interest to disentangle the fate of carbon in this area. Vertical mixing during winter promotes a slight nutrient enrichment in the euphotic zone, which enhance phyto-and zooplankton growth (Fig. 3). Dust storms also promote large-scale fertilisation in the area. However, the increase in mesozooplankton biomass promoted by the dust storm is transported downward due to predation by diel vertical migrants in the shallower layers during new moon, sequestering this carbon into the mesopelagic zone. Zooplankton and fish larvae transported by upwelling filaments are also influenced by migrants and the lunar cycle. The active flux promoted and the effect on fish larvae and fisheries deserve further research.

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