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3.3. Controls of phytoplankton dynamics in the Catalan Sea

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The Mediterranean Sea can generally be considered as oligotrophic although it has a suite of fertilization mechanisms at various spatial and temporal scales that are responsible for hotspots of phytoplankton biomass and production. In this essay, we review some of these mechanisms in the Catalan Sea.

Drivers of fertility in the Catalan Sea

The marine currents in the NW Mediterranean flow from the NE to the SW along the Catalan coast and return towards the NE near the Balearic Islands. This cyclonic gyre leaves a divergence zone in the middle, separated from the coastal waters by shelf-slope fronts.

In winter, cooling of the surface layers facilitates mixing of the water column and the input of nutrients from deeper waters into the euphotic zone. In the Liguro-Provençal Basin, at the northern boundary of the Catalan Sea, the doming of the isopycnals, in combination with heat loss and evaporation caused by strong and dry northerly winds, may lead to deep convection and vertical mixing down to the bottom, with introduction of nutrients into the upper layers and formation of deep water that spreads around the basin. Deep convection is an important driver of the phytoplankton dynamics and production not only locally but also in distant zones of the basin. For example, on 25 March 2005, surface chlorophyll *a* reached 7 mg m^{-3}, among the highest values measured in the region, and on 22 March 2009, with 2.3 mg m^{-3} of surface chlorophyll *a* (Figure 1B), vertically integrated (0–80 m) primary production attained 1800 mg C m^{-2} d^{-1} (Estrada *et al.* 2014).

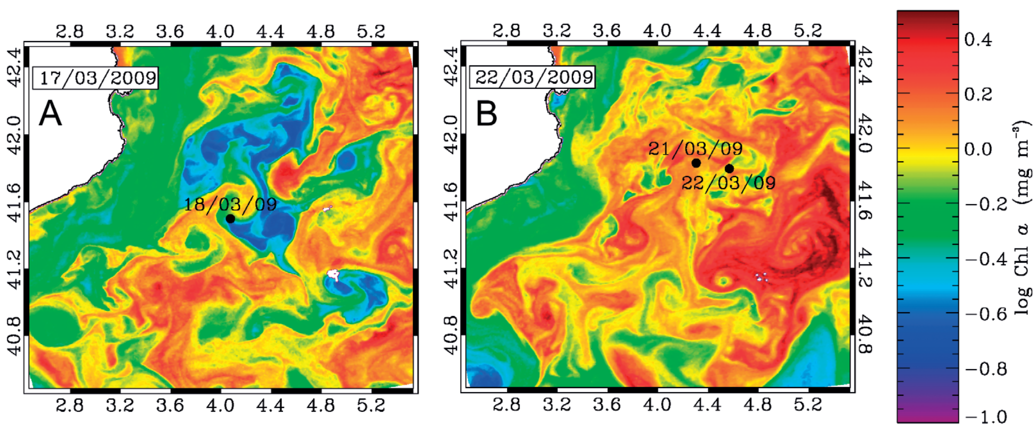

Figure 1. Remote sensing-derived images of chlorophyll *a* distribution in the NW Mediterranean on 17 (A) and 22 March 2009 (B). Note the increase in chlorophyll *a* concentration from 17 to 22 March. The low chlorophyll *a* (blue) area on 17 March is a result of deep convection. The black dots indicate station positions during the Famoso 1 cruise. Reprinted from Estrada *et al.* (2014), with permission.

Between late winter and early spring, the increase in irradiance and the start of thermal stratification induce the growth of an intense phytoplankton bloom in the surface waters. Later on, stratification intensifies and a steep vertical density gradient (the pycnocline) develops between the upper mixed layer and the deeper waters. The growth of phytoplankton depletes the nutrients (such as nitrate, phosphate and silicate) in the upper, illuminated part of the water column. Under these conditions, the balance between nutrients diffusing from below the pycnocline and light availability from above leads to the appearance of a deep phytoplankton and chlorophyll maximum, accompanied by accumulations of zooplankton (Estrada *et al.* 1993, Alcaraz *et al.* 2007). In the divergence region, the pycnocline is shallower and the higher light availability enhances phytoplankton growth in the deep maximum. In turn, the shelf-slope fronts bordering the gyre feature eddies, meanders and filaments, which together with the ageostrophic circulation (Estrada *et al.* 1999) can generate fertilization events. Often, a phytoplankton peak occurs in autumn, when cooling of the surface water breaks the pycnocline.

Other important contributions to nutrient enrichment in the Catalan Sea originate from continental water inputs and from atmospheric deposition. In the NW Mediterranean, the most influential rivers are the Rhône and the Ebre; however, discharges from smaller rivers and wastewater overflows may also be locally prominent, in particular after storms.

The phytoplankton succession

The fluctuations of phytoplankton biomass during the seasonal cycle are associated with marked changes in the composition of the community. The succession of dominant groups from the winter-spring peak to summer stratification was characterized by Ramón Margalef as a function of water turbulence intensity and nutrient availability (see Alcaraz and Estrada 2022). Fast-growing groups such as diatoms dominate when turbulence and nutrient concentration are high, while in stratified and nutrient-poor waters dinoflagellates, which are motile and can migrate up and down in the water column, are more abundant. Coccolithophores tend to thrive in intermediate situations. In the last few decades, new methodologies for phytoplankton categorization based on pigment markers or on molecular genetic techniques have provided information on the distribution of taxa such as cyanobacteria and many flagellates, which, owing to their small size or lack of distinctive morphological features, had not been suitably quantified in earlier studies.

What can we learn from long-term series?

As happens on land, there are strong interannual fluctuations in the patterns of phytoplankton succession over a seasonal cycle. In addition, global anthropogenic change may interact with natural variability in ways that we do not yet know. Therefore, ascertaining drivers of change and identifying long-term trends requires the collection of long time series of environmental and biological ecosystem variables at appropriate resolution.

As a contribution to these goals, the Institut de Ciències del Mar (ICM-CSIC) maintains several temporal series in Catalan Sea waters. In the littoral of Barcelona, the Coastal Ocean Observatory (https://coo.icm.csic.es/ca) measures several parameters in real time and, since March 2002, has carried out monthly surveys assessing environmental and biological variables. This long-term series has given important insights into the functioning of the coastal planktonic ecosystem of the Catalan Sea. For example, Arin *et al.* (2013) found that river runoff was the main source of nutrients for the winter-spring maxima of 2003 and 2004, while fertilization episodes fuelling the phytoplankton blooms of 2005 and 2006 were due to the intrusion of offshore waters associated with the strong mixing events of the unusually cold and dry winters of these two years (Figure 2). In the Bay of Blanes Observatory series (http://bbmo.

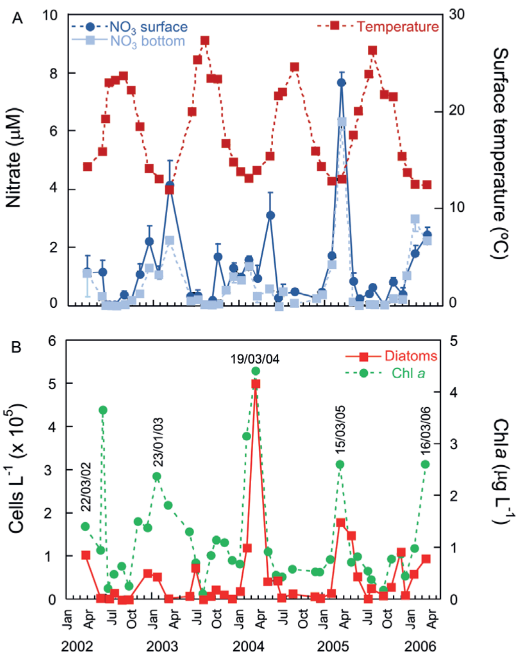

Figure 2. A, surface and bottom nitrate concentration (median + median absolute deviation) from eight sampling stations of the Coastal Ocean Observatory off Barcelona (March 2002 to March 2006) and surface temperature showing the annual cycle; B, surface chlorophyll *a* (Chl *a*) and diatom abundances from the same period at a representative station.

icm.csic.es/), the study of 14 years (2000–2014) of samples was used to characterize the seasonal cycle of the main phytoplankton groups and showed that, superimposed on the general pattern, diatoms and prasinophytes (a group of flagellates) proliferated in response to fertilization from storm runoff (Nunes *et al.* 2018). This series also revealed a decreasing trend in chlorophyll *a* concentration that could be attributed to a reduction of nutrient availability due to improvements in the wastewater treatment in the zone.

Concluding remarks

The Mediterranean has been considered as a reduced and more accessible model of the world's oceans. In a similar way, the Catalan Sea concentrates many of the ecological and socio-economic processes occurring in the whole Mediterranean. Information from oceanographic surveys and time series in the Catalan Sea and other marine areas around the world helps to reveal how interactions between natural and anthropogenic variability influence the pelagic ecosystem and highlights the importance of long-term monitoring for improving future projections and management decisions.

References

Alcaraz M., Calbet A., Estrada M., *et al.* 2007. Physical control of zooplankton communities in the Catalan Sea. Prog. Oceanogr. 74: 294–312.

Alcaraz M., Estrada M., *et al.* 2022. Turbulence and plankton dynamics in a warmer ocean. In: Pelegrí J.L., Gili J.M., Martínez de Albéniz M.V. (eds.), The ocean we want: inclusive and transformative ocean science. Institut de Ciències del Mar, CSIC, Barcelona, pp. 139–141.

Arin L., Guillén J., Segura-Noguera M., Estrada M. 2013. Open sea hydrographic forcing of nutrient and phytoplankton dynamics in a Mediterranean coastal ecosystem. Estuar. Coast. Shelf Sci. 133: 116–128.

Estrada M., Marrasé C., Latasa M., *et al.* 1993. Variability of deep chlorophyll maximum characteristics in the Northwestern Mediterranean. Mar. Ecol. Prog. Ser. 92: 289–300.

Estrada M., Varela R.A., Salat J., *et al.* 1999. Spatio-temporal variability of the winter phytoplankton distribution across the Catalan and North Balearic fronts (NW Mediterranean). J. Plankton Res. 21: 1–20.

Estrada M., Latasa M., Emelianov M., *et al.* 2014. Seasonal and mesoscale variability of primary production in the deep winter-mixing region of the NW Mediterranean. Deep-Sea Res. Pt I. 94: 45–61.

Nunes S., Latasa M., Gasol J.M., Estrada M. 2018. Seasonal and interannual variability of phytoplankton community structure in a Mediterranean coastal site. Mar. Ecol. Prog. Ser. 592: 57–75.

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