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Temporal trends in nutrient ratios: chemical evidence of Mediterranean ecosystem changes driven by human activity

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Abstract

Over the last few decades, the Mediterranean ecosystem has experienced changes in biodiversity due to climatic and environmental change or to accidental inputs of exotic species. But the plankton community, which is the base of the food chain and remains only partly described, is also probably experiencing a drastic change. Observed changes in nutrient concentrations and ratios in the deep waters of the western Mediterranean, as well as differences between the eastern and western Mediterranean, suggest that shifts have occurred in the relative distribution of nutrients and therefore probably phytoplankton species over the whole sea. A shift from a diatom-dominated ecosystem to a non-siliceous one (as already observed in some coastal areas, with increasing algal blooms and eutrophication events) may involve the whole Mediterranean Sea and have consequences for fishery and tourism activities.

1. Introduction

In the last few decades, the Mediterranean ecosystem has experienced changes in biodiversity due to the effect of human activity: e.g., (i) in the eastern basin more than 300 new species entered as Lessepsian migrators from the Red Sea (Galil, 1993), such invasion began with the opening of the Suez Canal in 1869, but increased in the early 1970s due to the deepening and widening of the canal and the closing of Aswan High Dam, which together have eliminated the salinity differences along the route between the Red and Mediterranean Seas; (ii) in the western basin, the colonization of coastal areas by the green alga *Caulerpa taxifolia* (Chisholm et al., 1995), a probable accidental input and (iii) the appearance of tropical species (fish, algal and urchin) (Francour et al., 1994), probably due to climatic and environmental changes, as evidenced by the continuous increases in temperature and salinity of Mediterranean waters since the 1960s (Bethoux et al., 1998a).

Since the classic work of Redfield et al. (1963), nutrient elemental ratios in plankton and in seawater may be used to identify peculiarities in ecosystem dynamics and functioning (e.g., Fanning, 1992), and to model biogeochemical

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processes (Karl et al., 2001). Changes in elemental ratios with time may be related to changes in the surface inputs of nutrients and in the marine cycling of organic matter (Pahlow and Riebesell, 2000). In the Mediterranean Sea, nutrient ratios P:Si:N are different from those in the Atlantic Ocean, indicating differences in nutrient inputs and the ecosystem. Furthermore, a difference in nutrient ratios between eastern and western Mediterranean deep waters signifies an environmental change. Consequently, it is probable that plankton assemblages are experiencing major changes in composition. Such changes are difficult to verify due to the complexity of the trophic interactions among different levels of the food web and to the current limitations in monitoring species diversity and abundance.

2. Mediterranean characteristics

2.1. Circulation and residence times

The western Mediterranean (mean depth ca 1600 m) consists of two deep basins, the Algero–Provençal basin (hereafter named AP basin) and the Tyrrhenian Sea, separated from the eastern Mediterranean by the Strait of Sicily. The eastern Mediterranean includes the Ionian, Adriatic and Aegean Seas and the Levantine basin (Fig. 1). The circulation of this semi-enclosed sea is mainly driven by a freshwater deficit of $0.9\,\mathrm{m\,yr^{-1}}$ due to a continental climate. In the Strait of Gibraltar (300 m depth), there is an Atlantic inflow of surface water in the upper part and a deep outflow of Mediterranean waters in the lower part of the strait, each being $\cong 20$ times the water deficit. Across the Strait of Sicily (400 m depth), there is a similar scheme of superposed flows. Flows across the two sills, estimated as 1.6 Sv ($1.6 \times 10^6\,\mathrm{m^3\,s^{-1}}$) at Gibraltar (Bethoux and Gentili, 1999) and 1.2 Sv across the Strait of Sicily (Astraldi et al., 1996), determine the mean residence time of deep water in the AP and eastern basins, at 16 and 50 yr, respectively. They are much shorter than typical oceanic residence times (for instance ca 250 yr for the deep North Atlantic Ocean). Inflowing Atlantic surface waters are progressively transformed into Mediterranean surface, and then deep waters by the increase of salinity (the effect of the freshwater deficit), and nutrient concentrations are changed by atmospheric and terrestrial inputs (hereafter named ATI) and biological activity. Inputs of nutrients, phosphate, nitrate and silicate, together with carbon and some trace elements (notably iron), allow the photosynthetic

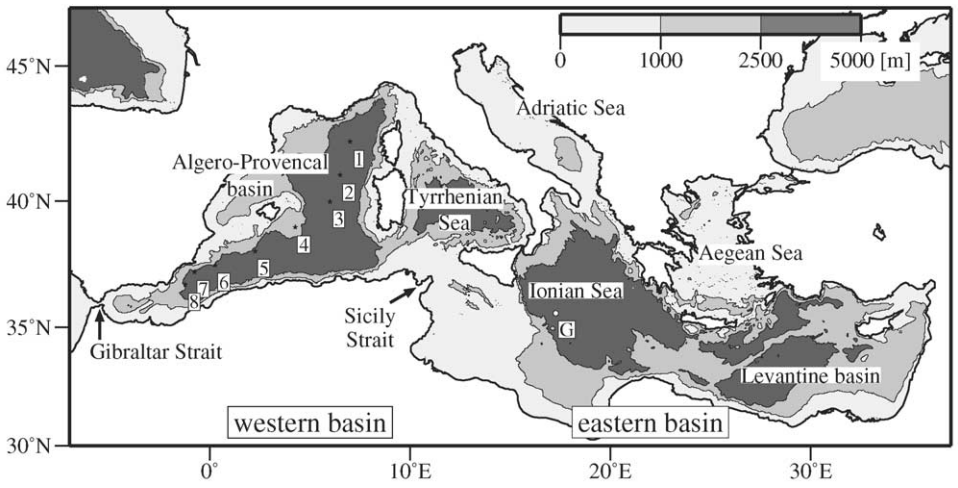

Fig. 1. Mediterranean regions and general bathymetry. 1,…, 8: hydrological stations occupied during SEMAPHORE 1994 cruise in the Algéro-Provençal basin. G: GEOSECS station 404 in the Ionian Sea in 1977.