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Nile damming as plausible cause of extinction and drop in abundance of deep-sea shrimp in the western Mediterranean over broad spatial scales

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ABSTRACT

Greatly increased retention of flow in Nile River reservoirs was initiated in 1964, after completion of the Aswan High Dam, which induced important oceanographic changes in the Mediterranean Sea, including deep waters (below a depth of 150 m). Based on an analysis of data series starting in the 1940s/1950s, the giant red shrimp *Aristaeomorpha foliacea* has become locally extinct off of the Catalonian coasts (and elsewhere in the northwestern Mediterranean) at depths of 400–900 m, with a simultaneous and significant drop in the catches of red shrimp, *Aristeus antennatus*, in the second half of the 1960s. The extinction and sharp decline of deep-shrimp populations off Catalonian coast (at *ca.* 3200 km westwards from Nile Delta) followed the 1964 drop in Nile discharge with a delay of *ca.* 3–5 yrs (breakpoint analysis applied to data series). The breakpoints detected in the second half of 1960s both in Nile runoff and shrimps' abundance were independent of climatic events in the study area (e.g. changes in NAO) and occurred before the increase in fishing effort off Catalonian coasts (breakpoint in 1973–1974). The Levantine Intermediate Water (LIW), inhabited by *A. foliacea* in the western Basin, had significant temperature (T) and salinity (S) increases in the 1950–1970 period, and Nile damming has contributed about 45% of the total S increase of Western Mediterranean deep-water masses from the 1960s to the late 1990s (Skliris and Lascaratos, 2004). This had to increase, for instance, LIW salinity at its formation site in the eastern Mediterranean. Nile damming was probably a triggering factor for the extinction/drop in abundance of deep-sea shrimp off Catalonian coasts.

1. Introduction

Climate oscillations are known to influence the dynamics of marine ecosystems in diverse regions like the North Pacific (Hare and Mantua, 2000), North Atlantic (Dulvy et al., 2008) and NW Mediterranean (Rixen et al., 2005; Molinero et al., 2007), with shifts linked to changes in oceanographic conditions. Knowing the extent to which human activities influence marine dynamics is crucial for correct interpretations of natural variability and climatic change. Climate-related changes mainly have been identified among communities dwelling on neritic waters and the continental shelf, though some long-term changes have also been found recently in deep-sea environments (Ruhl and Smith, 2004; Bailey et al., 2006; Maynou, 2008; Cartes et al., 2009).

Long-term variability in marine, including deep-sea, communities can be attributed to climate oscillations. Climatic indices, among which the North Atlantic Oscillation (NAO) is the most widely used (Hemery et al., 2008), have shown correlations with biological changes. In the western Mediterranean the persistence of positive NAO phases corresponds to periods of increased drought and low rainfall (Mariotti et al., 2002). Off Catalonian coasts (Balearic Basin, western Mediterranean), low/negative NAO phases enhance precipitation and river runoff, which in turn may increase (via submarine canyons) food input to deep benthos and increase stocks of bottom-feeding species such as the red shrimp *Aristeus antennatus* (Cartes et al., 2009). Relationships between climatic indexes and catches of deep water species have been previously established off Catalonia (Maynou, 2008) and neighbouring areas (e.g. the Balearic Islands), based on NAO and other mesoscale indexes (Massutí et al., 2008).

The deep Mediterranean can be considered a natural laboratory because of its relatively high thermohaline stability (practically constant conditions of temperature and salinity through the year: 13 °C, 38 psu) in the water column below 150 m (Margalef, 1985), making it good place to study long-term changes and possible effects on fauna, induced for instance by human activities. The historical oceanographic data available in the Mediterranean indicate a progressive warming of deep waters (between 150 and 2600 m) in the western Mediterranean Basin, where temperature and salinity have increased in the deepest layers by 0.12 °C and 0.03 psu from 1959 to 1988–1989 (Béthoux et al., 1990; Rixen et al., 2005). Temperature changes in the Levantine Intermediate Water (LIW) and Western Mediterranean Deep Water (WMDW) distinctly accelerated starting about 1955. Since the 1950s intermediate waters experienced decadal oscillations in T, with a

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progressive increase in S (Rixen et al., 2005; Vargas-Yáñez et al., 2009). LIW and WMDW are distributed respectively at *ca.* 150–600 m and from 600 m to the bottom in the western Mediterranean (Rixen et al., 2005). The warming trend in WMDW may well be associated with the salinity increase imported from the eastern Mediterranean by inflowing LIW (Rohling and Bryden, 1992). These changes in water masses have been suggested to be linked to general climatic change (Williams, 1998). However, the damming of major rivers, reducing freshwater discharges into the Mediterranean has also been implicated (Rohling and Bryden, 1992; Béthoux and Gentili, 1999), with particular attention to the influence of Aswan Dam construction (reservoir filling starting in 1964) on Nile discharge and LIW formation in the Eastern Basin (Skliris and Lascaratos, 2004). Such anthropogenic effects, derived from continental human activities, have not been considered to date in deep sea ecology. Determining the relative influence of different factors, both natural and human-induced, in climate change remains a major challenge for the study of oceans and marine diversity.

Human impacts at broad spatial scales are well known in coastal marine systems (e.g. the opening of Suez Channel allowing Lessepsian invaders into the Mediterranean from the Indian Ocean and the Red Sea), whilst effects on the deep and relatively stable marine environment mostly remain unobserved. Effect of fisheries exploitation on deep-sea stocks is well-known, e.g. the case of the orange roughy *Hoplostethus atlanticus* in the south Pacific (Koslow et al., 2000), which was rapidly overexploited due to the assumed slow growth rates of this deep-sea species and the high vulnerability of deep-sea ecosystems in general to trawl and other damage. In the Mediterranean, deep-sea species have also suffered important drops in abundance (see below), and there have even been local extinctions such as that of the shrimp *Aristaeomorpha foliacea.* It was abundantly caught by trawlers off Catalonian coasts until the end of the 1960s (Zariquiey-Alvarez, 1968). The shrimps *A. foliacea* and *A. antennatus* are among the dominant species in Mediterranean deep-sea communities and, together with the Norway Lobster (*Nephrops norvegicus*), they are the most important target species in regional deep fisheries. Both species of shrimp have wide geographical distributions (Zariquiey-Alvarez, 1968), coexisting in the western Atlantic (from the Bay of Biscay to South Africa in the case of *A. foliacea*, from Portugal to Cape Verde Islands in that of *A. antennatus*) and the Mediterranean. *Aristaeomorpha foliacea* is also distributed along the Atlantic coasts of the USA, Japan and Australia. The deep Mediterranean is probably the only place where the two species coexist across extensive parts of their depth ranges under similar conditions of temperature and salinity: *A. foliacea* lives primarily at depths between 250 and 900 m and *A. antennatus* between 400 and >2200 m (Zariquiey-Alvarez, 1968; Ghidalia and Bourgois, 1961; Cartes, 1993). Hence the distribution of *A. foliacea* roughly overlaps with the LIW mass, whilst *A. antennatus* coincided with deep Mediterranean waters (Ghidalia and Bourgois, 1961). The particular characteristics of the Mediterranean, particularly the high physical stability of its deep-water masses (Margalef, 1985), allow us to examine environmental effects on and biological interactions among, deep-sea fauna under controlled conditions.

Using reconstructed long-term data series of abundance and landings of the two most important deep-sea shrimp species off Catalonia coasts (the red shrimp *A. foliacea* and *A. antennatus*), we have analyzed changes in their abundance in the deep Mediterranean. This revealed both a local extinction and a drop in commercial catches, suggesting a relationship to major changes in the discharge of the Nile River. We hypothesize that change in the thermohaline characteristics of the LIW directly related to changes in Nile river discharge have modified the continental slope environment in the western Mediterranean since the late 1960s. The result has been major changes in faunal communities. Due to the absence of long data series of faunal abundance estimates in the deep Mediterranean (and elsewhere in deep environments), we have employed CPUE/abundance indices of the main fishery resources, the two red shrimp species, in the deep Mediterranean as proxies to assess the impact of LIW changes on deep water habitats. In this context we further discuss other possible causes determining these changes. Climatic oscillations, related to the NAO climatic index have also been considered, while possible ecological (e.g. trophic) factors affecting the two species of deep shrimps are discussed. The Nile, the most important freshwater source to the Mediterranean, discharges into the Levantine Basin of the eastern Mediterranean Sea *ca.* 3200 km east of the Catalonian coast. Therefore, both climatic changes and anthropogenic impacts will for the first time be taken into account in a long-term study of a deep-sea ecosystem.

2. Materials and methods

In order to obtain a comparative picture of the depth and geographic distributions of *A. foliacea* and *A. antennatus* in the Mediterranean we have compiled and summarized such information from published sources and own data. We expressed this information from four areas (see Fig. 1) from references (and sources cited therein) giving information of wide areas in the western Mediterranean (Ghidalia and Bourgois, 1961; Maurin, 1962; Cau et al., 2002) and from more concrete areas (in the Catalonian coasts – Balearic basin – by Zariquiey-Alvarez, 1968; Cartes, 1993; Cartes et al., 2009; in the Sicily channel: Ragonese et al., 1994; in the Ionian sea: Politou et al., 2004).

2.1. Data collection for analyses

Annual landings and abundance data were compiled for the Catalonian coast from 1950 for *A. foliacea* and from 1946 for *A. antennatus*. The data came from different sources depending on the species:

For *A. antennatus* data came from:

(1) Fishery statistics provided by *Anuarios de Pesca Marítima* for the period 1946–1981 (catches in tons/yr: additional details in Bas et al., 1955; Tobar and Sardà, 1987) for Catalonia, complemented with catch data for the period 1982–1987 provided in Martín (1991).
(2) Monthly catch data since 1988, collected by the Fishers' Associations were provided to the authors in the framework of a routine fisheries landings monitoring programme for all ports of Catalonia with *A. antennatus* landings.

For A. foliacea (which is not often reliably reported in official statistics in the area) the data series (estimated in ind/ha) was constructed based on:

(3) Data (catches in kg/day) from port/fishing grounds sampling recorded by researchers of the *Institut de Ciències del Mar* (Dr. C. Bas, Institute of Marine Sciences) (ICM) of Barcelona in the period 1957–1965 (unpublished data exceptionally taken per vessel and fishing grounds at Blanes port, located *ca.* 58 km north of Barcelona);
(4) Abundance (ind/ha) from trawl survey monitoring projects of CSIC and the Spanish Institute of Oceanography (I.E.O., e.g. MEDITS-ES series: 1994–2008).
(5) Interviews with experienced (most of them retired) fishermen (skippers of fishery vessels) performed in 2008–2009 to establish the date of commercial extinction and to contrast the bulk of catches in the 1950s–1960s with later years. Within the project EVOMED (European Commission DG MARE, Ref. MARE/2008/11) established to compile historic