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Spatio-temporal patterns and environmental controls of small pelagic fish body condition from contrasted Mediterranean areas

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ABSTRACT

Small pelagic fish are among the most ecologically and economically important marine fish species and are characterized by large fluctuations all over the world. In the Mediterranean Sea, low catches and biomass of anchovies and sardines have been described in some areas during the last decade, resulting in important fisheries crises. Therefore, we studied anchovy and sardine body condition variability, a key index of population health and its response to environmental and anthropogenic changes. Wide temporal and spatial patterns were investigated by analyzing separately data from scientific surveys and fisheries in eight Mediterranean areas between 1975 and 2015.

Results showed that anchovy and sardine body condition as well as maximum size in some areas sharply decreased in most Mediterranean areas along years (except in the Northern Alboran Sea). Despite this general pattern, well-marked environmental differences between sub-regions were highlighted by several analyses and variations in body condition were not found to be homogeneous over all the Mediterranean Sea. Further, other analyses revealed that except for the Adriatic where major changes towards a lower body condition were concomitant with a decrease in river runoffs and chl-*a* concentration, no concomitant environmental regime shift was detected in other areas.

Together, these analyses highlighted the current poor body condition of almost all small pelagic fish populations in the Mediterranean. Yet, global environmental indices could not explain the observed changes and the general decrease in condition might more likely come from regional environmental and/or anthropogenic (fishing) effects. A prolonged state of poor fish body condition, together with an observed reduced size and early age-at-maturity may have strong ecological, economic and social consequences all around the Mediterranean Sea.

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1. Introduction

Ocean systems are currently going towards changing environmental conditions especially due to the impact of anthropogenic climate change (Hoegh-Guldberg and Bruno, 2010). In particular, the Mediterranean Sea has been identified as one of the most responsive regions to climate change (Giorgi, 2006), as well as to direct human impacts such as pollution (Halpern et al., 2008). Specifically, recent studies using climate models already highlighted the warming of this sea (both at the surface and in deep waters) and the increasing frequency of extreme events (Bethoux et al., 1990; Theocharis, 2008; Vargas-Yáñez et al., 2008, 2010). Large scale perturbations, such as climate change, are known to affect all biological levels, directly (e.g. by affecting physiological thresholds) and/or indirectly (e.g. by modifying food resources; Jørgensen, 1992), resulting in spatio-temporal changes in the abundance of exploited fish in the Mediterranean Sea (see e.g. Lloret et al., 2015) and elsewhere (see e.g. Drinkwater et al., 2010).

Pronounced small pelagic fish population fluctuations are observed all over the world, especially in the upwelling areas (Baumgartner et al., 1992; Chavez et al., 2003). In the Mediterranean, those variations have been linked to recruitment (Martín et al., 2011), spawning (Agostini and Bakun, 2002; Basilone et al., 2013) or larval survival (Garcia et al., 1998). Such major population changes can have important impacts on the dynamics of marine ecosystems, as these forage fish represent an important biomass at mid-trophic levels, making them a key-component of the ecosystem (Cury et al., 2000; Coll and Libralato, 2012). Thus, the dynamics of this functional group are important both to maintain the integrity of the marine ecosystem, and for socioeconomic stability in the region. The main reason for the renowned population fluctuations of small pelagic is their short life span, as well as their susceptibility to environmental variability (Cushing and Dickson, 1976). Importantly, these characteristics make them excellent indicators of climate-driven environmental changes in marine systems (Drinkwater et al., 2010; Peck et al., 2013). The two most abundant small pelagic fish species in the Mediterranean Sea, the European sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*), have been exploited for a long time (Lleonart and Maynou, 2003) and are still intensely exploited, accounting for 35–50% of the reported catch in this area (GFCM, 2014). In recent years, a general decreasing trend has been observed in the landings of the small pelagic fish stocks in different parts of the Mediterranean Sea (GFCM, 2012; Vasilakopoulos et al., 2014), leading to an important fisheries crisis. In addition to this, alarming biological signals also appeared, such as a decrease in growth and body condition of small pelagics in the Gulf of Lions (Van Beveren et al., 2014), and a higher risk of recruitment failure with increasing temperature in the Northern Spain area (Maynou et al., 2014).

Body condition is an important individual physiological trait of marine organisms, influencing other life history traits, such as growth, reproduction (e.g. egg size and number, age at first maturity) and mortality (Lloret et al., 2014; Brosset et al., 2016a). Specifically, body condition indices are proxies of the quantity of stored energy, evaluating individual's health status and fitness (Schulte-Hostedde et al., 2001; Wilson and Nussey, 2010). For example, survival, growth and reproductive success are theoretically higher for individuals in better condition (Millar and Hickling, 1990), resulting in an important link between average population body condition and future population success (Jakob et al., 1996; Adams, 1999). Recently, more evidence emerged showing that variations in body condition can affect ecological processes at scales ranging from individuals to ecosystems (Rätz and Lloret, 2003; Lloret et al., 2014; Van Beveren et al., 2014). Consequently, fish body condition can in part determine ecosystem functioning and fisheries yield, so that this factor can constitute a valuable tool in stock assessment and management (Lloret et al., 2012). Furthermore, condition indices can be computed easily from collected length and weight data, available in numerous areas and at large temporal scale. It has already been demonstrated that environmental factors, such as temperature, food availability (Brosset et al., 2015b) or parasitism (Ferrer-Maza et al., 2016) influence fish condition through direct and/or indirect effects. For example, a decrease in body condition due to a lack of food or an increase of metabolic costs under higher temperature has already been advocated in several studies (see e.g. Pörtner and Knust, 2007; Brosset et al., 2015b). Changes in water stratification and currents are known to strongly influence plankton productivity and could thus indirectly act on the body condition of planktivorous small pelagic fish (Costalago et al., 2014; Le Bourg et al., 2015; Brosset et al., 2016b). Furthermore, these effects are easily visible because of the fast response of fish condition to environmental changes (Peck et al., 2013).

However, to our knowledge, a large scale study focusing on small pelagic fish body condition has never been realised in the Mediterranean Sea, so that at present it is still unclear if the recent decreases described in a few areas are truly a common issue. In this study, data of anchovy and sardine body condition from eight Mediterranean areas were compiled for the first time to compare the temporal trend in body condition of the different studied stocks and to assess whether a general decline took place. We also focused on the environmental (including climatic) factors that could potentially affect fish condition, taking into account spatial factors. A dataset of morphometric (i.e. length and weight) variables of more than 250,000 individuals analysed from 1975 to 2016 enabled us to compute the individuals' morphometric condition index, which assumes that for a given length a heavier fish is in better condition.

2. Material and methods

2.1. Study areas

Mediterranean sub-areas (GSA) were selected following the General Fisheries Commission for the Mediterranean (GFCM) delimitations adopted for stock assessments from the westernmost Alboran Sea to the Black Sea in the East (Fig. 1). The Mediterranean Sea is known to be oligotrophic, even if an important variability in productivity is visible with a West to East gradient and enhanced primary productivity areas due to strong river discharge as in the North Western Mediterranean, with the Rhone in the Gulf of Lions and the Ebro in the Catalan Sea, or the Po river in the Northern Adriatic Sea.

In the North Western part of the Mediterranean Sea the Gulf of Lions is the most productive area and covers about 20,400 km^2 (Bănaru et al., 2013). This area has a wide continental margin (>60 km) and productivity depends on strong mixing events induced by NW and N winds and Rhodanian inputs which create a gradient of nutrients from East to West (Darnaude et al., 2004). Also, local upwellings support the high productivity (Millot, 1990). The Northern Spain area, grouping the Catalan Sea and the Gulf of Valencia, is oceanographically connected with the Gulf of Lions through the Northern current flowing to the south-west which enhances the production in the north Catalan Sea. Models have indeed highlighted larval connectivity between the northern spawning grounds of anchovy in the Gulf of Lions and the Catalan Sea due to the hydrodynamic characteristics in the area mediated by the North current and the filament transport in mesoscale eddies (Ospina-Alvarez et al., 2012). The north Catalan Sea has a narrow shelf that widens in front of the Ebro river delta (>60 km