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Assessing the importance of nursery areas of European hake (*Merluccius merluccius*) using a body condition index

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ABSTRACT

In this study, we analysed the variability of reserve storage in juvenile European hake (*Merluccius merluccius*) off the western coasts of Italy (Central Mediterranean Sea). Reserve storage was measured by the hepatosomatic index (*HSI*), in relation to environmental and population covariates. *HSI* has been proved to be a consistent measure of energy storage in gadoids, thus reflecting quantity and quality of food availability for growth. Generalized Additive Models for Location, Scale and Shape (GAMLSS) were used to model the effect of depth, bottom temperature, bottom currents, fish density and fish body size on *HSI* of juvenile European hake. The results revealed that reserve storage in the liver appears to be maximized for juveniles living on the shelf break, between 120 and 170 m depth, with bottom temperature and current speed not exceeding 14 °C and 0.04 m s^{-1} respectively. Furthermore, *HSI* significantly increased with fish density up to about 6000 individuals per km^{-2} and decreased at higher densities indicating that reserve accumulation in the liver might be subject to density-dependent mechanisms (e.g. competition for food) as well. These findings suggest that the use of density as measure of nursery importance need to be further investigated. Finally, we found that *HSI* increased with fish size up to about 14 cm total length. Based on these results, *HSI* appears a reasonable index to indirectly measure the quality of habitats where juvenile European hake aggregate after their settlement on the bottom, and to potentially monitor habitat suitability as nursery across the spatial-temporal gradient.

1. Introduction

Protecting recruitment habitats is a key conservation measure to enhance productivity of exploited fish and shellfish populations (Beck et al., 2001; Dahlgren et al., 2006). Juvenile fish congregate in habitats often exposed to direct and indirect impacts of human activities. Degradation and loss of such habitats can severely threaten fish stocks reducing the survival of recruits (Hall, 1999). Trawling and dredging can physically destroy biogenic constructions such as coral reefs, seagrass meadows and other three-dimensional benthic habitats, which are known to serve as nurseries for many different organisms (De Juan et al., 2011; Clark et al., 2016). Moreover, pollution, shifts in sediment flow, modification in circulation patterns and other human-driven effects, including climate change, can substantially alter the quality of fragile nursery habitats, with a negative effect on the recruitment processes (Airoldi and Beck, 2007). Annual recruitment success is strictly related to the size and quality of habitats used for settlement (Auster et al., 2001; Cook and Auster, 2005).

Therefore, understanding the role of different nursery habitats is crucial for setting conservation priorities. Several metrics have been proposed to quantify the importance of nursery habitats in a conservation perspective, including the contribution of each area or portion of area to the adult population (Beck et al., 2001; Dahlgren et al., 2006), exclusivity in the habitat use (Fiorentino et al., 2003), juvenile density and persistence of density hot-spots (Ardizzone and Corsi, 1997; Colloca et al., 2009, 2015). In particular, recruit density and persistence over time have been commonly used in the Mediterranean Sea as criteria for nursery identification assuming density as a direct measure of habitat suitability: i.e., the denser the patch of recruits the higher its contribution to the adult population is. In the case of the European hake, recruits show a patchy distribution along the shelf-break with stable density hot-spots (Colloca et al., 2009, 2015; Garofalo et al., 2011). Such temporal stability in the distribution pattern of hake recruits was assumed as the likely effect of adaptation processes of local

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populations to the predominant water circulation pattern (Abella et al., 2008; Colloca et al., 2009).

Life-history theory predicts that organisms have limited energy budgets (Kozłowski and Teriokhin, 1999). Thus, individuals allocate resources among competing demands for different vital functions such as growth and storage (Perrin and Sibly, 1993; Stallings et al., 2010). Since the main sources of juvenile fish mortality are predation and starvation, it is fundamental they achieve both high somatic growth, reducing vulnerability to size-dependent predation, and store enough energy to overcome periods of low food availability (Post and Evans, 1989; Post and Parkinson, 2001; Taylor et al., 2007).

Storing resources is a key strategy to improve the probability to survive in fluctuating environments. European hake accumulates lipids in the liver which is the main energy storage and has also been demonstrated to be a key mechanism for ovary development and egg quality (Lloret et al., 2008). The few studies conducted in the Mediterranean on this subject have shown that a significant spatial and temporal variability in lipid storage and body condition can occur in juvenile European hake (Ferraton et al., 2007; Hidalgo et al., 2008; Sartor et al., 2013).

In this study, we used the hepatosomatic index (*HSI*) of juvenile hake off the Western coast of Italy as a measure of energy storage, with the objective to evaluate its usefulness as an index to measure the suitability of nursery habitats. Our assumption is that the higher the body condition of juveniles, as measured by the *HSI* index, the higher their survival probability and in turn the contribution to the parental stock. Generalized Additive Models for Location, Scale and Shape (GAMLSS, Rigby and Stasinopoulos, 2005) were used to model the effect on *HSI* of density, body size and environmental parameters, such as bottom temperature, bottom current speed and depth. The potential use of this index in conservation framework aimed at protecting fish juveniles habitats is also discussed.

2. Materials and methods

2.1. Study area

The study was carried out off the central-western coast of Italy, from the North Tyrrhenian to the South Ligurian Sea (FAO Geographical Sub-Area 9: GSA 9, Fig. 1) where some of the most important nursery of European hake in the Mediterranean are located (Orsi-Relini et al., 2002; Colloca et al., 2009, 2015; Murenu et al., 2010). The Tyrrhenian Sea is a semi-enclosed basin between three islands (Corsica, Sardinia and Elba) and the mainland (Italy). This basin is separated from the rest of the western basin by a channel of moderate depth. Therefore, it can be considered as a distinct system within the central-western Mediterranean basin (Artale et al., 1994; Gasparini et al., 2005). The circulation is organised in a series of cyclonic (anti-clockwise) and anticyclonic (clockwise) gyres driven by the wind and undergoes to significant seasonal changes. In particular, the central anticyclonic gyre spreads over most of the basin in spring and summer and almost disappears in autumn and winter (Artale et al., 1994). Wind-driven upwelling enriches the upper layer with nutrients giving to the Tyrrhenian Sea a relatively high concentration of nutrients within the Mediterranean basin (Nair et al., 1992; Nezlin et al., 2004). The Ligurian Sea is situated in the north-east corner of the western Mediterranean. This area is tightly connected with the Gulf of Lions, which is subject to periodic intrusions of the northerly winds from the Rhône valley. These winds generate very energetic weather conditions, particularly severe in winter. The major large scale hydrodynamic feature (Artale et al., 1994) is a well-defined cyclonic circulation, which helps to maintain the mean surface temperature lower than the adjacent basins, in particular of the Tyrrhenian Sea. The modified Atlantic water and Levantine intermediate water enter in the Ligurian Sea northward flowing along the east and west coasts of Corsica and converging just north of the island mixing into the Ligurian current (Astraldi and Gasparini, 1992).

2.2. Biological data

Data on juvenile hake were collected during the MEDITS bottom trawl survey carried out in May 2011. Information about the sampling protocol and methodologies can be found in Bertrand et al. (2002). For the aim of this study, 21 trawl stations from 62 and 251 m depth were selected in order to cover the main range of spatial distribution of juvenile hake in the study area (Fig. 1). The main characteristics of the

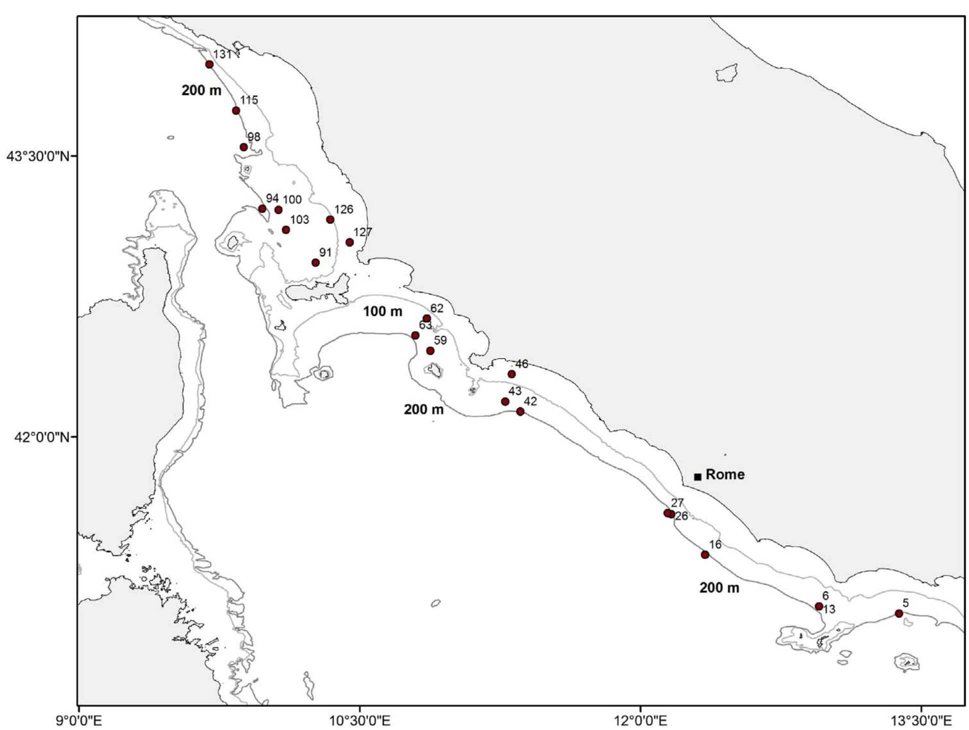

Fig. 1. Study area and sampling stations. Stations code are as in Table 1.