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Common sole in the northern and central Adriatic Sea: Spatial management scenarios to rebuild the stock

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A B S T R A C T

The northern and central Adriatic Sea represents an important spawning and aggregation area for common sole (*Solea solea*) and provides for around 20% of the Mediterranean landings. In this area, this resource is mainly exploited with *rapido* trawl and set nets. The stock is not yet depleted and faces a situation of growth overfishing. The comparison between the spatial distribution by age of *S. solea* and the geographic patterns of the *rapido* trawl fishing effort evidenced an overlapping of this fishing activity with the area where juveniles concentrate (age groups 0–2). The majority of spawners inhabits specific offshore areas, here defined as 'sole sanctuaries', where high concentrations of debris and benthic communities make difficult trawling with *rapido*.

The aim of this study was to evaluate existing spatial management regimes and potential new spatial and temporal closures in the northern and central Adriatic Sea using a simple modelling tool. Two spatial simulations were carried out in order to verify the effectiveness of complementary methods for the management of fisheries: the ban of *rapido* trawling from October to December within 6 nautical miles and 9 nautical miles of the Italian coast. The focus of the simulation is that the effort of the *rapido* trawl is moved far from the coast during key sole recruitment periods, when the juveniles are moving from the inshore nursery area toward the offshore feeding grounds. The management scenarios showed that a change in selectivity would lead to a clear increase in the spawning stock biomass and an increase in landings of *S. solea* in the medium-term. The *rapido* trawl activity could be managed by using a different logic, bearing in mind that catches and incomes would increase with small changes in the spatial pattern of the fishing effort.

The present study highlights the importance of taking into account spatial dimensions of fishing fleets and the possible interactions that can occur between fleets and target species, facilitating the development of control measures to achieve a healthy balance between stock exploitation and socio-economic factors.

1. Introduction

The fishery resources of the Mediterranean Sea and in particular of Adriatic Sea are under considerable and increasing stress from human activities. In both basins, the combined effects of fishing mortality and habitat degradation have led to alarming reductions of many exploited stocks (Barausse et al., 2011; Coll et al., 2009; Colloca et al., 2013; Russo et al., 2013).

In the northern and central Adriatic Sea flatfish resources are highly vulnerable to certain fishing activities (e.g. *rapido* trawling; Pranovi et al., 2000) and to anthropogenic impacts, such as the presence of contaminants and disruption to sea-floor integrity (e.g. dredging for beach

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nourishment). Within the group of flatfish, the common sole, *Solea solea* (Linnaeus, 1758), is one of the most commercially important species in the Adriatic Sea, that contributes around 23% to the overall sole catch of the FAO-GFCM (Food and Agriculture Organization-General Fisheries Council for the Mediterranean) area (Mediterranean and Black Sea; FAO-FISHSTAT source). The majority of this contribution is provided by the northern and central parts of the Adriatic basin where around 64% of the common sole catch come from the Italian *rapido* trawl fleets, 33% from the Italian, Slovenian and Croatian set netters operating mostly within 3 nautical miles from the coast, and the remaining 3% from the Italian otter trawlers (Grati et al.,2013). In particular, approximately 80% of sole *rapido* trawl landings in the area occur during the fall season (Fabi et al., 2009).

Considering the problem from population dynamic and fishery management perspectives, the case of *S. solea* in the northern and central Adriatic Sea is clearly the expected result of a defective management. The young portion of the stock continues to be exploited at unsustainably high levels (Scarcella et al., 2012) particularly in areas where juveniles aggregate and the use of alternative catch strategies could result in greater revenues than those currently generated (Colloca et al., 2013). Multiple assessment approaches used to analyse the health of the sole stock indicated clear overexploitation with extremely high fishing mortality (Scarcella et al., 2012). In the last decade, international working groups (in the framework of EC-STECF and FAO-GFCM) have recommended reducing fishing mortality by 80% as well as the development of a management plan to achieve this reduction over time. Considering the extraordinary stresses on both the structure and function of the northern and central Adriatic Sea habitat and the large overcapacity of the Italian fishing fleet, new management approaches are required. In such view, Colloca et al. (2013), proposed a L_{opt} for sole, a target reference point for catches that avoids the risks of growth and recruitment overfishing, as in the classical formulation by Beverton and Holt (1957) and Beverton (1992). Furthermore, the truncated age structure of common sole stock that is the result of historical overfishing and the combined effect of high fishing pressure and low size selectivity [defined as the phenomenon of fishing effectiveness varying with the size of the fish (Beverton and Holt, 1957; Quinn and Deriso, 1999)] is well recognised. Actually, the catch composition of sole in the northern and central Adriatic Sea is dominated by ages 0 and 1-year specimens, with a low occurrence of large individuals (e.g. STECF, 2009). It is important to stress that the demographic erosion can increase the variability of sole-stock abundance due to the reduced ability of the population to successfully cope with environmental fluctuations (Anderson et al., 2008; Stenseth and Rouyer, 2008). Demographic erosion affects not only the spawning capacity of the stock but also the average market price and revenues from fishing activities.

The common sole stock in the northern and central Adriatic Sea has been considered and assessed inside a management unit defined by FAO-GFCM as Geographical Sub-Area 17 (Northern Adriatic Sea). Management units are commonly based on jurisdictional and management convenience instead of biological inference (Smedbol and Stephenson, 2001; Stephenson, 1999). Boundaries between stock management areas can often bisect subpopulations resulting in the inclusion of fish from a single sub-population in 2 separate stock assessments. However, tagging experiments using the traditional mark-and-recapture procedure showed that all of the soles caught in GSA 17 were recaptured in the sub-basin (Pagotto et al., 1979). Furthermore, the local currents, eddies, and geomorphological and oceanographic features of this sub-basin differ markedly from those of the southern Adriatic (FAO-GFCM GSA 18) and Ionian Sea (FAO-GFCM GSA 19; Artegiani et al., 1997) preventing high rates of exchange of adult spawners and mixing of planktonic larval stages from nursery areas in adjacent basins (Magoulas et al., 1996). Therefore, the hydro-geographical features of this semi-enclosed basin may support the overall pattern of differentiation observed for the Adriatic common sole. The Northern Adriatic Sea (GSA 17) has a high degree of geographical homogeneity, with a wide continental shelf and eutrophic shallow waters. In contrast, the Southern Adriatic (GSA 18) is characterised by narrow continental shelves and a marked, steep continental slope (1200 m deep). This deep canyon may represent a significant geographical barrier for *S. solea*. Genetic studies (Guarniero et al., 2002) of sole specimens from 5 different central Mediterranean areas suggested that 2 near-panmictic populations of common sole exist in the Adriatic Sea. One of these populations inhabits the entire GSA 17, while the other seems to be spread along the Albanian coast (southern Adriatic, GSA 18). Further analysis of the Adriatic populations showed a low, but significant, differentiation between GSA 17 and GSA 18 populations, with possible gene flow from the eastern coastal side of GSA 18 into GSA 17 (AdriaMed, 2012).

The isolation of the common sole stock in GSA 17 from that in GSA 18 results in ideal conditions for study of the stock's population dynamics and to develop local management strategies.

Nearly all of the management strategies currently adopted by Mediterranean countries are limited to the control of fishing capacity, fishing effort, and the application of technical measures, such as mesh size regulations, establishment of minimum landing sizes, and closures of areas (e.g. 3 nautical miles from the coast permanently banned to towed gears) and seasons (e.g. fishing stop of towed gears during summer months). However, such technical measures have been rarely supported by scientific evidence (Lleonart and Maynou, 2003). For instance, the adopted EC legal minimum landing size for sole in the Mediterranean (20 cm; EC reg. n. 1967/2006) is not consistent with biologically meaningful target sizes, such as the size at first maturity ($L_m = 25.8$; Fabi et al., 2009) or the size at which a cohort attains its maximum biomass ($L_{opt} = 31$ cm; Colloca et al., 2013). Moreover, in the areas and periods with relatively high concentrations of juveniles, fishing pressure is intense due to the high relative density of fishing capacity and collateral impacts of fishing (e.g. habitat degradation, bycatch; Grati et al., 2013). Before a possible reduction in fleet capacity that would lead to sustainable and optimal exploitation of the common sole, but also to a heavy negative socio-economic impact on local fishing industries, more appropriate management measures should be evaluated. Specific spatial–temporal management of *rapido* trawl effort can be used to reduce the fishing mortality of the juvenile portion of common sole stock. In such view, the early concerns of the GFCM regarding fleet overcapacity and fishing pressure in the inshore nursery areas which might necessitate closures have been priorities for discussion since the 1950s (Caddy, 1993a).

Quantitative analysis of spatial management options is complicated, as information on the spatial dynamics of fleets and stocks is often unavailable and effective spatial models are difficult to construct (Holland, 2003).

In the present paper, we synthesise available information on the spatial patterns of *rapido* trawl fishing efforts, from Vessel Monitoring System (VMS), and common sole stock distributions, from trawl surveys, during the recruitment process and the early phase of the spawning period occurring in fall–winter. The combination of fishery dependent and independent data is utilised in an analytical framework for quantitatively simulating spatio-temporal *rapido* trawling management options aiming at reducing the catch of juveniles and increasing the spawning capacity of the stock in the medium term. The outcomes of different management approaches will be discussed, including how shifting the selection-at-age curve toward the right (older ages), can result in sustainable exploitation of the stock.

2. Materials and methods

2.1. Study area and trawl survey data

Stock distribution data were obtained from *rapido* trawl surveys (SoleMon) carried out in a 36,742-km^2 area of the northern and