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Research Paper

A model combining landings and VMS data to estimate landings by fishing ground and harbor

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ABSTRACT

At present, the assessment and management of Adriatic Sea fishery resources are based on data that do not fully account for the complex spatial patterns arising from fleet behavior and/or species' behavior and biology, mainly because logbooks do not guarantee adequate coverage of the fishing activity exerted by the fleet. For data collection, the Adriatic Sea is divided into two management areas (namely FAO Geographical Sub-Areas–GSAs). To account for these spatial patterns while using the data available, we propose a method for estimating the monthly landings of Italian trawlers operating in the Adriatic Sea at a higher spatial resolution than the GSA. We use a stepwise approach based on the combined analysis of questionnaire-derived vessel-specific landings and the spatial activity of the vessels with respect to a set of fishing grounds. Thus, we sequentially 1) analyze the available vessel monitoring system data, 2) partition the study area into fishing grounds (the origin of the landings), 3) cross analyze vessel-specific fishing efforts with the available vessel-specific monthly landings to estimate the LPUE of each fishing ground, and 4) estimate the monthly landings (by vessel, fishing ground, and harbor) for the whole fleet and the monthly fluxes between fishing grounds (origin) and landing harbors (the destination of the landings). We apply the method to two species: the Norway lobster and the European hake. For both species, we find a few fishing grounds to be consistently more productive than others and the landings per harbor to vary greatly but with few harbors regularly receiving a significant share. In particular, the results suggest that the Pomo/Jabuka pit area represents a critical area for both species. Additional outcomes include a detailed characterization of the activity of the Adriatic bottom trawling fleet, highlighting the strengths and shortcomings of the official data available. We discuss the results in the context of the current management paradigm.

1. Introduction

In the Mediterranean Sea, resources are managed at the Geographical Sub-Area (GSA) scale (Cataudella and Spagnolo, 2011). The definition of GSAs is based on jurisdictional and management convenience, rather than biological inference (Smedbol and Stephenson, 2001; Stephenson, 1999). Official fishery-dependent data (i.e., catches and landings) are delivered at the same scale. To appropriately account for complex patterns of fleet behavior and/or different aspects of species behavior and biology, the assessment of the status of several species of commercial interest may need to be based on data collected at a higher spatial resolution than the GSA. The FAO General Fisheries Commission for the Mediterranean (GFCM) and the EU Scientific, Technical and Economic Committee for Fisheries (STECF) have repeatedly recognized the limits of a GSA-based approach, but an alternative has yet to be found (STECF, 2014). However, the modification of National Programs for the Data Collection Framework (DCF) may not be possible or immediately feasible and would not solve the problem for past data. In this paper, we propose a method to split the official GSA-based landings into sub-zones of interest both in terms of the landings origin (i.e., the fishing ground) and destination (i.e., the harbor) by estimating the monthly landings according to a higher spatial

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resolution. The proposed method would also allow the application of modern modeling approaches based on a spatial management of fishing effort (Bastardie et al., 2014; Campbell et al., 2014; Dunn et al., 2011; Holland, 2003; Mchich et al., 2006; Pelletier et al., 2009; Russo et al., 2014a; Russo et al., 2017; Sampson et al., 2011; Zeller and Reinert, 2004). In fact, these methods entail the reconstruction of the origin and the fate of catches and landings in terms of well-defined areas and times in which resources are harvested and harbors to which they are delivered for sale, respectively. Although fishing logbooks could represent the master source for estimating the landings by species and harbor (Gerritsen and Lordan, 2011), there is evidence that fishers are reluctant to provide complete information about the location of fishing grounds (Sampson, 2011). Additionally, for several reasons such as the high number of fishing vessels (more than 13,000), the numerous landing locations scattered over 8000 km of coastline, the high number of species landed, and the consequent difficulty in ensuring appropriate monitoring and control of the landings declared in the logbooks, logbooks do not record all Italian landings. Consequently, Italian landings data are collected through a statistical sampling scheme, based on questionnaires, and official landings are estimated from a subsample of the fleet, that are then raised to the total of the fleet (EC, 2008; EUROSTAT, 2015). This, and similar methodologies, are applied in other Mediterranean countries with similar characteristics. To integrate this approach, the method we propose combines questionnaire-derived vessel-specific landings with the spatial origin of the landings as reconstructed *a posteriori* using the Vessel Monitoring System (VMS). In EU waters, the VMS comprises a tracking device on board each fishing vessel with length overall (LOA) ≥ 15 m (EC, 2011) that periodically sends data on vessel position, speed, and heading to a network of land-control stations via satellite transmission. VMS data are widely used in the scientific literature for analyzing fishing effort patterns (Campbell et al., 2014; Lambert et al., 2012; Russo et al., 2016) and for assessing fishing impacts (Eigaard et al., 2016; Gerritsen et al., 2013; Scarcella et al., 2014). We apply the method to two species fished by Italian trawlers operating in the Adriatic Sea: the Norway lobster (*Nephrops norvegicus*, L. 1758–NEP hereafter) and the European hake (*Merluccius merluccius* L. 1758–HKE hereafter). It is our hope that this method will provide a standard that could be applied to any Mediterranean GSA should the necessity of splitting official data into smaller spatial entities arise. At the time of writing, the smallest spatial unit for data collection (and assessments) in the Mediterranean is the GSA. This means that any stock whose areal distribution/definition is smaller than the GSA has to be aggregated with all other stocks in the GSA to be assessed together at a GSA level. In situations where the population dynamics of these smaller "stocks" or stocklets are different from others within the same GSA (e.g., NEP in GSA 17), assessments at a GSA level will provide distorted pictures of the situation. Among the outputs of the methodology we propose are estimates of the landings for sub-zones of a GSA, allowing stock assessments of these particular species to be based on the best ecological knowledge available rather than having to tailor them to the structure of the official data at hand.

2. Materials and methods

2.1. Study area

The Adriatic Sea (Fig. 1) is the portion of the Mediterranean basin located between the Italian Peninsula and the Balkan Peninsula. It is more than 150–200 km wide, covering an area of approximately 138,000 km^2, and can be divided into three basins (northern, central and southern) characterized by different widths and topographic gradients. A combination of geopolitical and geomorphological characteristics led to the subdivision of the Adriatic into two GSAs for the purpose of fishery management (Fig. 1a). GSA 17 (north and central Adriatic) includes Croatia, Bosnia-Herzegovina, Italy and Slovenia, while Italy, Albania and Montenegro comprise the southernmost GSA 18. The Pomo/Jabuka pit area comprises three depressions (> 200 m depth) in the middle of the Adriatic Sea (Fig. 1a), covering an area of approximately 2000 km^2. Owing to a peculiar combination of bottom morphology and position, it hosts important spawning and nursery areas for several species of commercial interest, including the species targeted in this study (Colloca et al., 2013). The resources in the Pomo/Jabuka pit area are shared among the fleets of different countries (mainly Italy and Croatia) and are subjected to high fishing pressure. With the aim of protecting the main HKE nursery area in the Adriatic Sea, an area corresponding to approximately 2750 km^2 and including the Pomo/Jabuka depressions in international waters was closed to bottom trawling for over one year (~15 months from 25/07/2015 to 16/10/2016) within an Italian-Croatian management agreement (Italian Administrative Order. 03/07/2015). This agreement demonstrates a shift from the traditional Mediterranean management paradigm resting on the regulation of fishing capacity towards one based on spatial planning.

2.2. The fleet, the main target species and the fishery

Mediterranean Sea and Black Sea fisheries are classified by "métier" (https://datacollection.jrc.ec.europa.eu/wordef/fishing-activity-métier), which represents a group of vessels with the same "exploitation pattern" (i.e., gear used and target species) over time and reflects the fishing intention at the start of the fishing trip (Marchal, 2008). Demersal fishing in the Adriatic Sea consists of only one métier, namely bottom otter trawl (OTB) (Fouzai et al., 2012). According to the Common Fleet Register (CFR-EC, 2010), Adriatic trawlers do not exceed 25 m in LOA. The NEP is the most valuable crustacean species landed in the Adriatic Sea, where it is exploited predominantly by bottom trawls (Ungfors et al., 2013; Vrgoč et al., 2004). In the Adriatic Sea, the NEP occurs at depths from approximately 50 m to over 400 m (Wieczorek et al., 1999), with important concentrations occurring at approximately 70 m depth off Ancona and at approximately 220 m in the Pomo/Jabuka pit area and in the Croatian channels (Anon., 1994; Froglia and Gramitto, 1988, 1986, 1981; Karlovac, 1953). The NEP population in the Pomo/Jabuka pit area is of particular interest owing to the high density of individuals, which, for a number of possible reasons, are characterized by slower growth compared to those present in the rest of the Adriatic Sea (Anon., 1994; Froglia and Gramitto, 1988, 1981).

The HKE is the most important demersal species in the Adriatic Sea in terms of both catches and commercial value (IREPA, 2012; UNEP-MAP-RAC/SPA, 2014). With the exception of a small area north of the Po river, the HKE in the Adriatic is found from several meters depth in the coastal areas to 800 m of the south Adriatic (GSA18), but the most abundant population is located at depths between 100 m and 200 m (Jukić-Peladić et al., 1999; Kirinčić and Lepetić, 1955; Ungaro et al., 1993; Županović and Jardas, 1986). The Pomo/Jabuka pit area comprises its main HKE nursery area in the Adriatic Sea (Colloca et al., 2013).

According to the most recent STECF (STECF, 2016) and GFCM (SAC, 2015) reports, the HKE in the Adriatic Sea is overexploited, while the status of the NEP is unassessed. In Italy, landing points are scattered along the coast, 39 of which are in the Adriatic Sea: 27 in GSA 17 and 11 in GSA 18 (Fig. 1a). The landings for both the NEP and the HKE are entirely sold at market, and demand largely exceeds landings (Parliament European, 2008), without export to foreign countries. The NEP and the HKE are consumed fresh, without processing.

2.3. Rationale of the model

Given a partitioning of the Adriatic Sea into G fishing grounds (see section 2.5), a fleet composed of V vessels, targeting a set of S species, over a time frame of T time intervals (months), the model presented in this paper firstly aims at estimating the $LPUE_{s,g,t}$ for the species s in the fishing ground g during the month t for all the V vessels. The study