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Modelling the spatiotemporal distribution of fisheries discards: A case study on eastern Ionian Sea trawl fishery

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ABSTRACT

The mitigation and incorporation of fisheries discards into the spatial management perspective call for a well-planned approach considering their high spatiotemporal variability. This study describes an approach to map the spatiotemporal distribution of bottom trawl discards taking into account on-board observer data, environmental information and high-resolution estimates of fishing effort derived from Vessel Monitoring System data. Two were the main objectives: i) mapping the Discards Per Unit Effort (DPUE: kg/h) and ii) mapping the total discards quantities (in kg) in a predefined spatial unit (grid cell of 5 × 5 km). For this purpose, discards data from commercial bottom trawlers (seasonal basis, period 2003–2006, 2008) operating on the continental shelf of the eastern Ionian Sea were analyzed. The DPUE for a) all species with Minimum Landing Size (MLS), b) all species without MLS and c) all fish species, were modeled by means of Generalized Additive Models (GAMs) using satellite environmental parameters, bathymetry and season as independent covariates. Mapping discards quantities in a predefined spatial unit was based on the spatial overlapping between GAM estimates for the year 2010 and fishing effort distribution for the same year. Spatial clusters of high discard quantities (hot spots) and their spatiotemporal persistence were also investigated. Results revealed how the environmental and temporal factors influence the DPUE distribution of each discard group and indicated increased discards quantities in areas of high fishing effort. The potential implications of the resulting DPUE maps for advancing discards spatial mitigation are further discussed. Mapping discards quantities using both the DPUE and the fishing effort distribution provide valuable insights that can be useful to investigate the broader ecosystem consequences of the EU landing obligation and other potential fishery management policies.

1. Introduction

Fisheries discards are defined as the portion of the catch, which is brought onto the desk of a fishing vessel and subsequently thrown away for whatever reason (Kelleher, 2005). The discarding fraction often includes commercial and non-commercial species. Commercial species of low economic value can be discarded, depending on the market demand, to allow space for more profitable fish (high-grading) (e.g. Catchpole et al., 2005; Damalas and Vassilopoulou, 2013). Furthermore, multiple factors can be responsible for high discarding (i.e. of both commercial and non-commercial species) including technical (e.g. the use of unselective fishing techniques), economical (e.g. low market value and high-grading), legislative (e.g. Total allowable catches - TACs and Minimum Landing Sizes – MLS according to EC, 2006) as well as biological and environmental factors affecting species distribution and recruitment period (Machias et al., 2001; Rochet and Trenkel, 2005; Johnsen and Eliasen, 2011; Tsagarakis et al., 2014; Damalas et al., 2015; Christou et al., 2017). The Mediterranean bottom trawl fishery is multispecies in nature and usually characterized by high discarding compared to other fishing gears (Tsagarakis et al., 2008, 2014), while the undersized individuals, which are illegal to land (e.g. EC, 2006), often constitute about half of total discards depending on the region (Machias et al., 2001; Tsagarakis et al., 2008). Since the mortality rate of discards is extremely high, often approaching 100% (Kelleher, 2005), these removals may have a large impact on the underlying ecosystem (Viana et al., 2011).

Abbreviations: CFP, Common Fisheries Policy; DCR, Data Collection Regulation; DPUE, Discards Per Unit Effort; DF, Discarded Fish; DMLS, Discarded species with MLS; DnonMLS, Discarded species without MLS; GAMs, Generalized Additive Models; kg/h, kilograms per hour; ML, Maximum Likelihood; MLS, Minimum Landing Size; SST, Sea Surface Temperature; CHL, Sea Surface Chlorophyll; SLA, Sea Level Anomaly; POC, Particulate Organic Carbon; REML, REstricted Maximum Likelihood; RMSE, Root Mean Square Error; DE, Deviance Explained; VIF, Variance Inflation Factor; VMS, Vessel Monitoring System

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Currently, the European Commission has recognized the 'discard problem' as a substantial component of marine ecosystem functioning and as a driver of poor financial performance (EU, 2013). Therefore, issues concerning mitigation or elimination of discards are of utmost importance (Johnsen and Eliasen, 2011). Under the framework of the reformed Common Fisheries Policy (CFP) a landing obligation is introduced and fishers are forced to land all catches of regulated species, which in the Mediterranean concern those species with MLS (EU, 2013). Although the Greek trawl fisheries are in practice subject to an exemption of the regulation so far (EU, 2017) based on the *de minimis*[1] criterion (EU, 2013), this does not prevent for any changes to be a matter of fact in the coming years (Damalas, 2015). In any case, the "reduction of unwanted catches" (including discards) is a key statement in the CFP for all Member States (EU, 2013), as well as many steps have been taken and tested (e.g. through pilot projects) the last years for this purpose (Catchpole and Gray, 2010). Towards dealing with these issues in practice, management frameworks for the mitigation of discards are mainly headed towards two directions: (i) to modify the fishing gears (i.e. to improve selectivity) and/or (ii) to avoid fishing in areas with high discards rate. This work is actually dealing with the second direction, aiming to identify areas with high potential of "unwanted catches".

The knowledge of the spatiotemporal structure of discards can be essential in designing sustainable spatial management measures and mitigation plans (Dunn et al., 2011; Viana et al., 2013; Uhlmann et al., 2013) as well as to further investigate the broader impact of discarding on the ecosystem which is of critical importance under the framework of ecosystem-based approaches to fisheries management (Bellido et al., 2011). Recent studies have addressed discard rates as dynamic in space and time, which are, likely to fluctuate within regions, seasons or/and fishing periods (Catchpole et al., 2011; Pennino et al., 2014). In this context, a comprehensive approach can involve spatial distribution modelling techniques based on environmental information such as temperature, chlorophyll-a and bathymetry as well as other parameters (e.g. economic or vessel characteristics; Pennino et al., 2017). This is already applicable for species (e.g. Giannoulaki et al., 2011, 2013), discards assemblages (e.g. Borges et al., 2006; Feekings et al., 2012; Viana et al., 2013) as well as discard ratios (Paradinas et al., 2016; Pennino et al., 2017). This approach can be combined with the spatial distribution of fishing effort. The analysis of Vessel Monitoring System (VMS) data (EU, 2003) provide high resolution information on fishing effort (e.g. Lee et al., 2010; Hintzen et al., 2012; Russo et al., 2014), has gained attention as a management tool in recent years (e.g. Russo et al., 2013; Bastardie et al., 2014; Maina et al., 2016; Rijnsdorp et al., 2016) and can offer important insights in the area of discards research (Uhlmann et al., 2013). Methodological approaches using fisheries-dependent data (such as VMS and observers' on board data) along with environmental information are likely to provide a more comprehensive mapping of discards and thus to shed more light on the spatial management of discarding.

The current work aims to map the spatiotemporal distribution of bottom otter trawl discards in the eastern Ionian Sea (central Mediterranean) taking into account observers' on board data, environmental information and high-resolution estimates of fishing effort, derived from VMS data. The hourly quantities of three main discards groups were investigated, modeled and mapped: (a) the discarded fish (the predominant discard group), (b) the discarded species with MLS (mainly composed of juveniles of species with high commercial value) and (c) the discarded species without MLS (mainly composed of non-marketable or low market value species). Particularly, this work addresses two different objectives: i) use modelling techniques along with environmental variables to map DPUE over a wider area ii) raising the discard data to the total fishing fleet level to map discards quantities per spatial unit. This allows the investigation of broader ecosystem consequences as well as the identification of sites where fishery management should focus.

2. Materials and methods

2.1. Study area and bottom trawl fisheries

In the eastern Ionian Sea, the continental shelf (< 200 m) corresponds to 78% of the total area exploited by bottom trawlers, which do not usually operate deeper than the 500 m isobath (Maina et al., 2016). River outflows, mainly influencing the productivity and subsequently the fishing grounds' dynamics, are located close to the mainland Greece in the central-northern part of the area under study (Fig. 1).

A total of 33 bottom trawlers operate in the study area targeting mainly European hake (*Merluccius merluccius*), common squids (*Loligo* spp.), red mullets (*Mullus barbatus*, *Mullus surmuletus*), the pandoras (*Pagellus* spp.) and the caramote prawn (*Penaeus kerathurus*) (IMAS-Fish: Kavadas et al., 2013; STECF, 2015). Based on the EU legislation, trawling is prohibited within 3 nautical miles of the coast or within the 50 m isobath where that depth is reached at a shorter distance from the coast and within 1.5 nm of the coast for any depth (EC, 2006). According to the national legislation, the period from the end of May up to the end of September is prohibited for bottom trawling in all Greek territorial waters. Additional temporal restrictions for bottom trawlers exist in the gulf of Kerkyra (i.e. eastern part of Kerkyra) where fishing is banned from the beginning of April until the end of October. Bottom trawling is totally banned in Amvrakikos gulf and Messolonghi lagoon (Fig. 1).

2.2. Data analysis

The analysis included three basic steps. Initially, we modeled the DPUE expressed in kilograms per hour using data collected by observers on board commercial trawlers in the study area. Generalized Additive Models (GAMs) were used to identify environmental parameters related to DPUE. Mapping the potential spatial distribution of DPUE in the broader area was performed using satellite environmental data. Subsequently these maps (representing the potential DPUE) were multiplied by the spatial distribution of fishing effort by bottom trawlers to map discard quantities in a predefined spatial unit (fixed-square grid cell of 5 × 5 km). Finally, the areas indicating high discard quantities (hot spots) were identified and their spatiotemporal persistence was investigated. The methodological steps of the approach are summarized in Fig. 2 and described in detail within the subsections 2.2.1 to 2.2.9.

2.2.1. Discards data

Discards data were collected by observers on board commercial bottom trawlers within the framework of the Greek Data Collection Regulation (DCR: EC, 2001). Sampling was held in the eastern part of Ionian Sea (Fig. 1) in seasonal basis (i.e. autumn, winter, spring) for the period 2003–2006 and 2008. Hauls used for analysis were those carried out within the continental shelf (i.e. < 200 m depth). A total of 261 hauls were included in the analysis, of which 128 corresponded to autumn, 57 to winter and 76 to spring. Haul characteristics such as sampling date and time, longitude, latitude, duration and depth were recorded. The catch was separated in marketable and discarded parts (landings and discards) by the crew of the vessel. All species were identified and the commercial as well as discards biomass of each species was standardized and estimated as total kilograms per hour (kg/h) in each haul. The working datasets were retrieved through the integrated fisheries information system IMAS-Fish (Kavadas et al., 2013).

[1] *De minimis* - a flexibility mechanism that under certain conditions allows fishers to discard species that would otherwise be subject to the landing obligation (see details in EU, 2013, 2017).