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Assessing the spatial distribution of five non-commercial fish species in the Aegean Sea (Greece, eastern Mediterranean Sea) based on discards data

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ABSTRACT

Spatial management of discards has attracted increasing interest as a potential mitigation measure. However, most studies are restricted to commercial species. The aim of the present work was to fill this gap by identifying and mapping the spatial distribution of five non-commercial species with high frequency of occurrence in the discarded catch of bottom trawl fishery in the Aegean Sea, i.e., Brown comber *Serranus hepatus*, Mediterranean scaldfish *Arnoglossus laterna*, Red bandfish *Cepola macrophthalma*, Argentine *Argentina sphyraena*, and Boarfish *Capros aper*. For this purpose, Generalized Additive Models were used to account for catch dependency on environmental parameters in order to explore the spatial distribution of species. Modeling results revealed that the spatial distribution of species was driven by environmental variables. Depth was the most informative variable explaining most catch variation in all species. For *A. laterna*, *C. macrophthalma*, and *S. hepatus* the highest estimated values of catch were located over the continental shelf and at shallower waters inside gulfs, whereas *C. aper* and *A. sphyraena* catch were more broadly distributed across the study area and at greater depths. Seasonal variations in species catch were also observed, probably related in most cases to species reproduction period. Mapping species distribution is essential for the identification of priority areas of protection in future marine spatial plans.

1. Introduction

Capturing non-target organisms during commercial fishing operations, is a crucial problem often hampering the sustainable use of fishery resources (Bellido et al., 2011). Non-target organisms are either species of no commercial value or unwanted fractions of commercial ones. When these organisms are returned to the sea, either dead or alive, not accounted in landed catch, they represent discards (Kelleher, 2005). A recent estimation of annual global discards is 9.1 million tonnes or 10.8% of the global catch (Gilman et al., 2020). Discards rates can vary across different regions (Uhlmann et al., 2014) and among the fishing gears reaching up to 55% for shrimp trawls (Gilman et al., 2020). Discarding has both economic and ecological implications; it is a waste of natural resources without any financial profit for the fishers and has been identified as a great threat to both the sustainability of marine biodiversity and the status of marine fish stocks (Kelleher, 2005; Bellido et al., 2011; Catchpole et al., 2017).

Bearing in mind that the capture of non-target organisms is an inevitable result of fishing activity and the reasons for discarding can act in a synergistic way (Johnsen and Eliasen, 2011), solving the problem of discarding is a difficult commission. Gear modifications to increase selectivity (Stergiou et al., 1997; Catchpole and Revill, 2008; Massutí et al., 2009), effort reductions, discard bans (Condie et al., 2014), imposition of spatio-temporal closures (Dunn et al., 2011; Little et al., 2015), real-time fishery

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closures and fleet communication (Gilman et al., 2006) are some actions usually taken in fisheries management to regulate discarding (Sigurðardóttir et al., 2015; Suuronen and Gilman, 2019). The spatial and temporal nature of discards has attracted much attention in European Union waters, given that the reform of the Common Fishery Policy with the introduction of the landing obligation (EU, 2013) has as ultimate goal to promote fishers to adopt more selective fishing practices by avoiding fishing areas or seasons associated with high quantities of unwanted catches.

Discard rates can be high when the nature of the fishery is multi-specific and the selectivity of the fishing gear is low. A typical example is the Mediterranean bottom trawl fishery (Machias et al., 2001; Tsagarakis et al., 2014). The Mediterranean Sea is a region with high biodiversity (Bianchi and Morri, 2000), where fisheries are mixed and multispecies (Stergiou et al., 2003; Caddy, 2009), and highly valuable species are harvested together with non-commercial species leading to high discards rates. In the Mediterranean Sea, the main drivers behind discarding include legal constrains (e.g., Minimum Conservation Reference Size, MCRS) and market demand (Catchpole et al., 2014; Tsagarakis et al., 2014). Mediterranean bottom trawl discards are estimated around 32.9% of total catch (Tsagarakis et al., 2014) with the non-commercial species being an important part (Machias et al., 2001; Sánchez et al., 2004). In Greek waters, the number of different species caught by bottom trawl can reach up to 300 species with almost 50% having no commercial value and being completely discarded (Machias et al., 2001).

Discarding of non-commercial species can have negative impacts on species vulnerable to fishing pressure as well as the whole fish community including the commercial species due to species interactions and species trophic relationships (Hall et al., 2000; Monteiro et al., 2001). For instance, under uncontrollable exploitation rates, rays and sharks can be at high risk of extinction owing to their life history characteristics (Casey and Myers, 1998). One more example is boarfish *Capros aper* (Linnaeus 1758), a species forming big schools often caught in large quantities as bycatch in many fisheries (Fonseca et al., 2005; Borges et al., 2008; O'Donnell et al., 2012), which can be vulnerable to fishing pressure due to its small size in combination with its late age at maturity (White et al., 2011; Hüssy et al., 2012). Therefore, fishery management plans under the umbrella of a more holistic approach should address numerous species, including also the non-commercial ones.

Towards a spatial management perspective, numerous studies have focused on the estimation of the spatial distribution of total discards (Viana et al., 2013; Pennino et al., 2014; Maeda et al., 2017; Maina et al., 2018) or the discards of commercial species (Vilela and Bellido, 2015; Paradinas et al., 2016; Bellido et al., 2019), whereas published information on the spatial distribution of discards of non-commercial species is scarce (Pennino et al., 2017). In this context, the present study used discards data for the first time in order to identify and map the spatial distribution of five non-commercial species that presented high frequency of occurrence in the discarded catch of bottom trawl fishery in the Aegean Sea, namely, brown comber *Serranus hepatus* (Linnaeus 1758), Mediterranean scaldfish *Arnoglossus laterna* (Walbaum, 1792), red bandfish *Cepola macrophthalma* (Linnaeus 1758), argentine *Argentina sphyraena* (Linnaeus 1758), and *C. aper*.

2. Material and methods

2.1. Discards data

Discards data were collected by observers on board commercial bottom trawlers operating in the Aegean Sea (Greece, Eastern Mediterranean) under the European Union Fisheries Data Collection Regulation (DCR; EC, 2001) and Data Collection Framework (DCF; EC, 2008). Onboard commercial data despite any shortcomings, it is the best available information regarding catch and discards (Suuronen and Gilman, 2019). In total, data from 547 hauls were sampled during 2003–2006, 2008, and 2013–2014 (Fig. 1). Sampling was held in a seasonal basis (i.e., autumn, winter, spring) and for each haul, the following information was recorded: date and time of sampling, coordinates (longitude, latitude), bottom depth, haul duration, and catch composition. There were no data during summer period because there is a general prohibition on bottom trawls in Greek national waters from the 1st of June to the 30th of September (Royal Decree 917/1966). Catch was divided into landings and discards by the crew and discards were identified at species level by the observers. The biomass of each species was standardized as kilograms per hour (kg/h) in each haul. Five non-commercial species, which are fully discarded, were selected for the analyses: *A. sphyraena*; *A. laterna*; *C. aper*; *C. macrophthalma*; *S. hepatus*. The five fish species contributed to 1%–2% of the non-commercial discarded fraction and were selected due to their high frequency of occurrence in the number of fish hauls, i.e., 50.1% (274 hauls) for *S. hepatus*, 41.9% (229 hauls) for *A. laterna*, 41.1% (225 hauls) for *C. macrophthalma*, 38.8% (212 hauls) for *A. sphyraena*, and 37.5% (205 hauls) for *C. aper*. Since the five species were fully discarded, their discarded catch was equal to their total catch (hereafter referred to as species catch).

2.2. Environmental data

Satellite environmental parameters along with bathymetry (natural log-transformed bottom depth), seabed substrate, and season (i.e., autumn, winter, spring) were used to model the catch (in kg/h) of the five non-commercial species. The satellite environmental variables used in the analysis, were Sea Surface Chlorophyll (CHL in mg/m^3 (natural log-transformed); oceancolor.gsfc.nasa.gov), Particulate Organic Carbon (POC in mg/m^3 (natural log-transformed); oceancolor.gsfc.nasa.gov), Sea Level Anomaly (SLA in cm; www.aviso.altimetry.fr), Sea Surface Temperature (SST in ^{o}C, oceancolor.gsfc.nasa.gov) and Sea Surface Salinity (SAL in psu; -marine.copernicus.eu). At each haul location, the monthly estimate of the environmental variables was retrieved at the best available resolution provided by the online satellite data distribution archives. This results in an average spatial resolution of ∼4 km (Valavanis et al., 2008), adequately defining environmental spatial heterogeneity and the best available resolution of the explanatory environmental variables. These environmental variables are important either as a direct influence on the distribution of several demersal fish species (e.g., SST, CHL, SAL; (Lefkaditou et al., 2008; Pennino et al., 2013; Lauria et al., 2015; Paradinas et al., 2015; Maina et al., 2016) or as proxies for causal factors. Substrate type information has been derived from European Marine Observation Data Network (EMODnet) Seabed Habitats project (http://www.emodnet-seabedhabitats.eu/), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE). EMODnet includes seven substrate categories which for the purposes of the present study were combined into four categories (i.e., muddy, sandy, muddy sand, coarse sediment).

2.3. Modeling approach

Generalized Additive Models (GAMs) were used to account for species catch dependency on explanatory variables in order to infer their spatial distribution. GAMs employ non-linear and non-parametric techniques for regression modeling (Hastie and Tibshirani, 1990). The selection of the smoothing predictors was

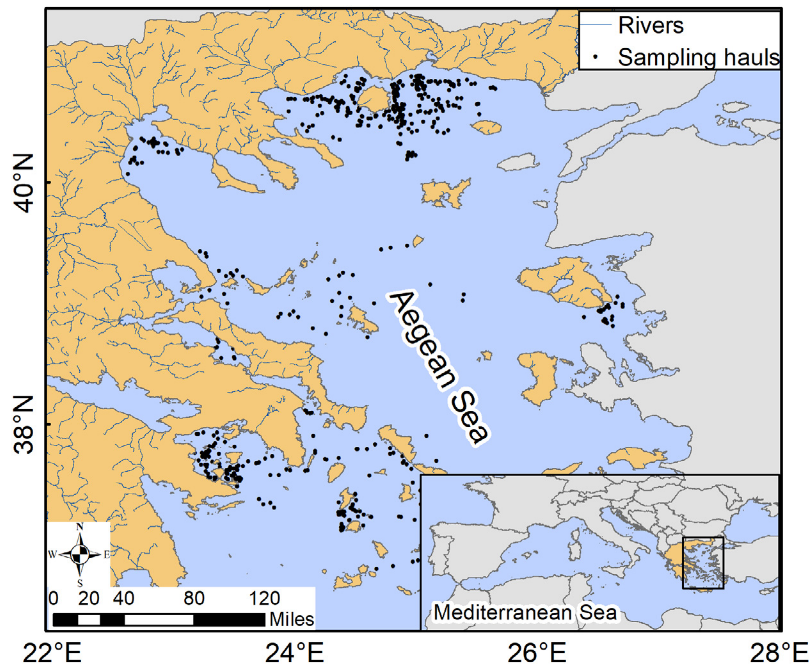

Fig. 1. Location map and sampling station (haul) positions collected by observers on board commercial bottom trawlers in Aegean Sea.

made using the "mgcv" library in R (R version 3.5.2; R Core Team, 2018). Due to the presence of a large number of zeros in the data, they were modeled using a compound Poisson-Gamma error distribution and a log link function. The compound Poisson-Gamma error distribution belongs to the Tweedie family distributions and is suitable for modeling zero-inflated positive continuous data (Tweedie, 1984; Jørgensen, 1987; Candy, 2004; Dunn, 2004; Shono, 2008; Hasan and Dunn, 2011; Foster and Bravington, 2013). The advantage of using a Tweedie distribution is the avoidance of a multi-stage zero-inflation modeling (Peel et al., 2012; Lecomte et al., 2013). The degree of smoothing was chosen based on the observed data and the restricted maximum likelihood (REML), as suggested by Marra and Wood (2011). For each species, the final model selection was made on a stepwise forward approach by testing all variables, starting from a simple initial model with one explanatory variable and adding the explanatory variables one by one. Only statistically significant explanatory variables were kept in the final model. The minimization of the Akaike's information criterion (AIC) and the level of Deviance Explained (DE) led to the selection of the model that best fitted the response variables (Wood, 2006). To avoid over-fitting and to simplify the interpretation of the results, the maximum degrees of freedom allowed to the smoothing functions were limited to k = 5 for the main effects. Validation graphs (e.g., residuals versus fitted values, QQ-plots, and residuals vs the original explanatory variables) were used to detect the existence of any pattern or trend in the residuals vs predictors and any model deficiency.

2.4. Mapping species distribution

Taking advantage of the availability of satellite environmental data over a wider area, the final selected GAMs were applied over a wider grid of mean monthly satellite environmental values at an average spatial resolution of ∼4 km, covering the Aegean Sea from 30 to 600 m to predict species catch. Monthly maps presenting the spatial distribution of species catch (in kg/h) were constructed over the 2004–2014 period. Subsequently, the average seasonal maps (i.e., autumn, winter, spring) were estimated at each grid point. Mapping was performed using the ArcGIS (ESRI, 2012). For each species, predicted values smaller than the mean weight of a single individual were considered equal to zero. The mean weight of the individual (i.e., *A. sphyraena* ∼0.009 kg, *A. laterna* ∼0.007 kg, *C. aper* ∼0.007 kg, *C. macrophthalma* ∼0.022 kg, *S. hepatus* ∼0.011 kg) was estimated from the collected data.

2.5. Model validation

Model validation was performed through a repeated 10-fold cross validation with 10 repeats using the "*caret*" package in R (Kuhn, 2008). Model's predictive performance was assessed using the Root Mean Square Error (RMSE) and the Mean Absolute Error (MAE). Lower values of RMSE and MAE indicate better model fit.

3. Results

3.1. Modeling the non-commercial species catch

Results revealed that bathymetry, season, substrate type, and environmental variables related to the ecosystem productivity (i.e., POC, CHL) were the most common variables among the final selected models for all species (Fig. 2). Bottom depth was the variable explaining most catch variation in all species. In detail, the final model for *A. sphyraena* included depth, SST, and season explaining ∼37% of the deviance. Higher catch values were estimated at depths greater than 90 m and at temperature ranging from 14.5 to 21.5 °C. Also, higher catch values were estimated during winter. For *A. laterna*, the final model included POC, depth, substrate type, and season, explaining ∼46% of the deviance, with higher catch values estimated at swallower (depth <90 m) and more productive waters (POC >90 mg/m^3). Also, a positive effect for autumn and substrate type of muddy sand was identified. For *C. aper*, the final model included CHL, depth and season, explaining ∼48% of the deviance. A positive effect was identified for CHL values smaller than 0.37 mg/m^3, at depths greater than 75 m, and for spring. The final model for *C. macrophthalma* included CHL, depth, SLA, season, and substrate type explaining ∼50% of the deviance. Higher values of catch were estimated during

Table 1
Results of the repeated 10-fold cross-validation. RMSE: Root Mean Square Error, MAE: Mean Absolute Error.

Scientific name	Common name	RMSE	R^2	MAE
Argentina sphyraena	Argentine	0.42	0.16	0.20
Arnoglossus laterna	Mediterranean scaldfish	0.16	0.26	0.07
Capros aper	Boarfish	0.30	0.14	0.11
Cepola macrophthalma	Red bandfish	0.22	0.17	0.11
Serranus hepatus	Brown comber	0.43	0.15	0.24

spring, at depths swallower than 145 m, in muddy substrate and more productive waters with positive values of SLA. For *S. hepatus*, the final model included CHL, depth, and substrate type explaining ∼31% of the deviance, with higher catch at depths <150 m and medium productive waters and lower catch in sandy substrate. Detailed GAMs results and diagnostics are presented in the Appendix (Table A1, A2; Fig. A1, A2, A3, A4, A5).

3.2. Mapping the spatial distribution of non-commercial species

Mean seasonal maps for each species (Fig. 3) indicated that *C. aper* and *A. sphyraena* catch were more broadly distributed across the study area and at greater depths. In contrast, for *A. laterna*, C. *macrophthalma*, and *S. hepatus* the highest estimated values of catch were located over the continental shelf and at shallower waters inside gulfs (Fig. 3). For *A. laterna*, a decrease of the catch from autumn to spring was observed, whereas the opposite was true for *C. aper*, *C. macrophthalma* and *S. hepatus*, for which catch increased from autumn to spring. Finally, for *A. sphyraena* the catch decreased from winter to autumn.

3.3. Model validation

The detailed results of the repeated 10-fold cross-validation are presented in Table 1. RMSE values ranged from 0.16–0.42 and MAE values ranged from 0.07 to 0.22, reflecting a moderate predictive performance for the models.

4. Discussion

Globally, bottom trawls are known to produce the highest quantities of discards compared to other fishing gears (Cashion et al., 2018). In the Mediterranean, the species synthesis and the quantity of bottom trawl discards show great variability among regions and countries (Tsagarakis et al., 2017). Also, the bulk of discards consists of species with low or no commercial value that attracts little attention in research (Machias et al., 2001; Damalas et al., 2018). In this context, the present study aimed to fill knowledge gaps regarding five non-commercial species (*A. laterna*, *C. macrophthalma*, *S. hepatus*, *A. sphyraena*, and *C. aper*), identify and map their spatial distribution using the catch information of bottom trawl discards in the Aegean Sea.

4.1. Environmental factors related to species distribution

Identifying species potential habitats and mapping species spatial distribution are essential in spatial management planning intending to minimize the negative impact of fishing on marine ecosystem (Colloca et al., 2015). In the Mediterranean Sea, the nurseries of a number of commercial demersal species have been identified, e.g., red mullet *Mullus barbatus* (Linnaeus 1758), European hake *Merluccius merluccius* (Linnaeus 1758), deep-water rose shrimp *Parapenaeus longirostris* (Lucas, 1846), horned octapus *Eledone cirrhosa* (Lamarck, 1798), thornback ray *Raja clavata* (Linnaeus 1758), etc. (Politou et al., 2008; Fortibuoni et al., 2010; Garofalo et al., 2011; Colloca et al., 2015). Moreover, spatial distribution models based on environmental parameters have been used to estimate the potential grounds of pelagic fish species such as European pilchard *Sardina pilchardus* (Walbaum, 1792) (Giannoulaki et al., 2011), European anchovy *Engraulis encrasicolus* (Linnaeus 1758) (Giannoulaki et al., 2013), Atlantic mackerel *Scomber scombrus* (Linnaeus 1758) (Giannoulaki et al., 2017a) and vulnerable demersal species such as sharks, rays and chimaera, e.g., Lesser spotted dogfish *Scyliorhinus canicula* (Linnaeus 1758), blackmouth catshark *Galeus melastomus* (Rafinesque, 1810) velvet belly *Etmopterus spinax* (Linnaeus 1758) (Pennino et al., 2013, 2016), rabbit fish *Chimaera monstrosa* (Linnaeus 1758), smooth-hound *Mustelus mustelus* (Linnaeus 1758), marbled electric ray *Torpedo marmorata* (Risso, 1810), etc. (Lauria et al., 2015), as well as for discards (Pennino et al., 2014, 2017; Maeda et al., 2017; Maina et al., 2018).

Species distribution modeling was applied for the five non-commercial species based on commercial discards data recorded by on board observers. Onboard commercial data, even if they are subjected to numerous sources of sampling bias, are considered the most reliable source of information for the estimation of discards (Suuronen and Gilman, 2019). Moreover, onboard commercial data along with survey data are considered the main sources of information for the distribution of marine species (Pennino et al., 2016). Given that both sources have been shown to provide similar results in the spatial patterns obtained (Pennino et al., 2016), and that on board data provide a substantial amount of information spanning in different times of the year, the maps produced here, based on species distribution modeling, can provide a fair picture of species distribution (Pennino et al., 2016).

The results indicated that the spatial distribution of the five non-commercial species was shaped by environmental parameters which reflect the characteristics of the ecosystem (e.g., productivity, bathymetry). In particular, depth was the most informative variable, explaining most of the total variation of all species. The effect of depth on species distribution has also been shown by other studies and is ascribed to the alterations in species composition of the fish communities as depth changes (Demestre et al., 2000; Katsanevakis et al., 2009). Indeed, for *A. laterna*, *C. macrophthalma*, and *S. hepatus*, the highest catch was estimated at shallower waters as these species prefer to live within a depth range of 20–200 m (Smith, 1981; Stergiou, 1993; Damalas et al., 2010; Munroe, 2016). In contrast, for *A. sphyraena* and *C. aper* the highest catch was estimated in deeper waters as these species are mainly found in the continental shelf and along the shelf edge within a depth range of 100–300 m (Halliday, 1969; Blanchard and Vandermeirsch, 2005; Damalas et al., 2010).

CHL and POC as proxies of the ecosystem productivity (Maina et al., 2016) and subsequently food availability (Druon et al., 2015) explained, also, part of the species catch variability with higher species catch observed at waters with moderate and higher values of CHL and POC. For *C. macrophthalma*, SLA was also found to be related to the species distribution, possibly operating as another proxy for water circulation regimes of favoring food concentrations (*sensu* Giannoulaki et al., 2013, 2017a). Variations among seasons have been also detected. For C. *aper* and *C. macrophthalma*, the catch gradually increased from autumn to spring, whereas for *S. hepatus*, the pattern was reverse. Temporal variations of the discarded catch have been stressed by other studies and are attributed to a plethora of reasons including, the market demand varying depending on season (Tsagarakis et al., 2008), the weather condition (Machias et al., 2004; Maina et al., 2018), and the seasonal behavior of species related to its life cycle (Feekings et al., 2012; Pennino et al., 2014, 2017), e.g., migration/aggregation at specific locations during reproduction/recruitment period (Tzanatos et al., 2007; Maina et al., 2018).

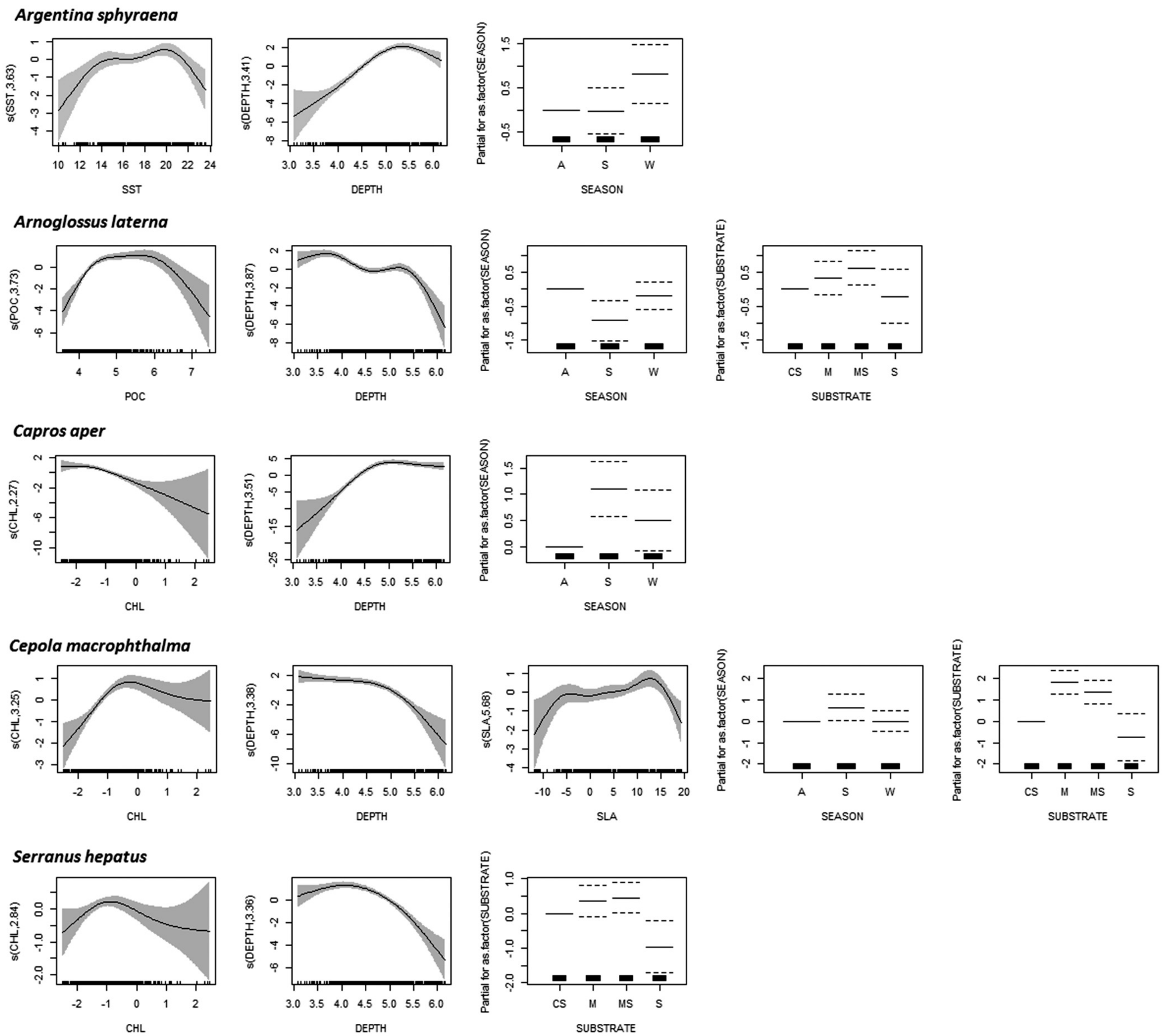

Fig. 2. Effect of the significant smoothing functions (black solid line) on catch of the five studied species. CHL: natural log-transformed surface chlorophyll concentration (in mg/m^3); POC: natural log-transformed particulate organic carbon (in mg/m^3); SLA: sea level anomaly (in cm); SST: sea surface temperature (in °C); DEPTH: natural log-transformed bottom depth (in m); SEASON: autumn (A), winter (W), spring (S); SUBSTRATE: muddy (M), sandy (S), muddy sand (MS), coarse sediment (CS). Shadowed areas represent the 95% confidence intervals. The rug under the single variable effects plots indicates the density of points for different variable values.

The highest values of catch were observed for *A. sphyraena* during the winter, and for *C. aper* and *C. macrophthalma* during spring. This coincided with their reproductive period (Stergiou, 1999; Tsikliras et al., 2010; Serrat et al., 2018) and is assigned to possible differences in the aggregative or migratory behavior of these species due to reproduction. Probably, individuals of these species migrate to certain locations for spawning that coincide with the fishing grounds (*sensu* Tzanatos et al., 2007) of bottom trawl.

Species presence is also related to the type of substrate (Demestre et al., 2000; Katsanevakis et al., 2009; Damalas et al., 2010; Pennino et al., 2016). Some species inhabit different bottom types, whereas others exhibit preferences for a specific habitat (Demestre et al., 2000). Indeed, a portion of catch variability has been explained by the substrate type. The highest estimated values of catch, for *A. laterna*, on muddy sand can be attributed to the species preference for mixed and muddy bottoms (Ilkyaz et al., 2017). Similarly, the highest catch for *C. macrophthalma* at muddy bottom is explained, by the fact that this species lives in vertical borrows formed at muddy bottom (Stergiou, 1993). Finally, *S. hepatus* was found to occur over a wider range of substrate types (Smith, 1981) with less preference for sandy bottom.

4.2. Management considerations

Understanding the spatio-temporal nature of discards is an essential step to sustainably manage fisheries resources (Dunn et al., 2011; Viana et al., 2013; Pennino et al., 2014). The knowledge of areas with high probability of discards for non-commercial species and how these areas overlap with the fishing grounds of the main commercial species provides valuable information. Non-commercial species are not targeted by the fishery, however, if they are strongly related to the fishery's target species, either due to trophic interactions or by sharing the

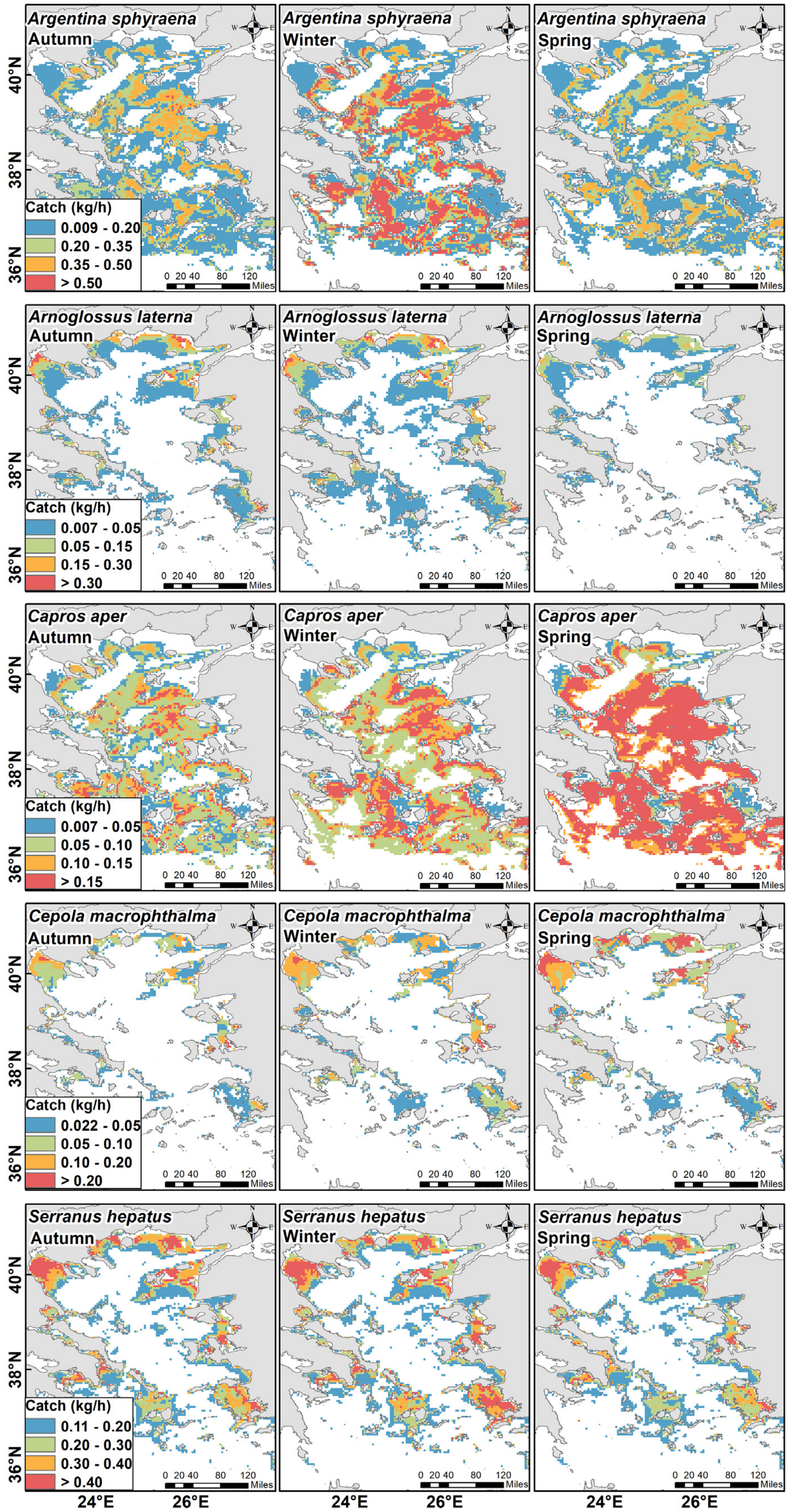

Fig. 3. Seasonal distribution maps of *Argentina sphyraena*, *Arnoglossus laterna*, *Capros aper*, *Cepola macrophthalma*, and *Serranus hepatus*.

same habitat, they will be subjected to similar degree of fishing pressure. Dimarchopoulou et al. (2018) found that changes in the mean total length of *S. hepatus* in the North Aegean, follow the changes in the mean total length of the main target species as subjected to the same degree of fishing pressure, opposed to other non-commercial species which are caught more randomly as bycatch.

Hence, mapping the non-commercial species distribution, understanding species' interactions (e.g., predator–prey relationships), and putting this knowledge on a spatial scale is valuable in marine spatial planning and ecosystem management. Spatial maps can be integrated into spatial planning tools, such as MARXAN (Dunn et al., 2016) and/or ecosystem models with a spatial dimension, such as Ecospace (Walters et al., 1999; Steenbeek et al., 2013) to identify key ecosystem areas for protection and facilitate the understanding of the trophic web structure.

A step further in marine spatial planning is to take under consideration species shifts related to environmental changes. For low trophic level species, such as the studied ones, which are more dependent on environmental changes (Fariña et al., 1997; Blanchard and Vandermeirsch, 2005; Lopes et al., 2006), modeling approaches which identify the spatial distribution based on environmental parameters can capture species catch variations and spatial distribution shifts associated to environmental variations. Higher abundance of *C. aper* is related to high offshore productivity (Lopes et al., 2006) and higher water temperature (Fariña et al., 1997; Blanchard and Vandermeirsch, 2005). In addition, higher densities of *A. sphyraena* and *A. laterna* are related to upwelling processes (Fariña et al., 1997). Thus, distribution maps that take into account environmental variation could be used for the evaluation of existing marine area closures under climate change (Hazen et al., 2018).

Furthermore, within the context of species trophic interactions, the modeled estimated catch of the studied species at spatial level combined with other spatial explanatory variables could be utilized in habitat suitability models in order to predict the spatial distribution of predator species. For instance, the probability of presence of *S. pilchardus*, was successfully used as a covariate to model the potential habitat of the short-beaked common dolphin *Delphinus delphis* (Linnaeus 1758) and the common bottlenose dolphin *Tursiops truncatus* (Gervais, 1855) based on the assumption of potential prey for the two dolphin species (Giannoulaki et al., 2017b).

The spatial management of fisheries is considered a valuable tool on the road to achieving more sustainable fisheries (Dunn et al., 2011). Thus, the resulting maps of the current work, presenting the species spatial distribution, can be a valuable first step in future marine spatial plans.

CRediT authorship contribution statement

Smaragda Despoti: Conceptualization, Methodology, Formal analysis, Writing - original draft. **Konstantinos I. Stergiou:** Conceptualization, Writing - review & editing, Supervision. **Athanassios Machias:** Investigation. **Vassiliki Vassilopoulou:** Investigation. **Konstantinos Tsagarakis:** Writing - review & editing. **Vasilis Valavanis:** Data curation. **Angeliki Adamidou:** Investigation. **Marianna Giannoulaki:** Conceptualization, Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2021.101736.

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