



## Editor's Choice

# Identifying the best fishing-suitable areas under the new European discard ban

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The spatial management of fisheries has been repeatedly proposed as a discard mitigation measure. A number of studies have assessed the fishing suitability of an area based on units of by-catch or discard per unit effort. However, correct identification of fishing-suitable areas should assess biomass loss with respect to the benefits. This study therefore, proposes the analysis of by-catch ratios, which do represent benefit vs. loss and are standardized to a wide range of effort characteristics. Furthermore, our study proposes the use of two ratios: the proportion of total unwanted biomass out of the total catch as an indicator of the overall ecological impact, and the proportion of unwanted but regulated species biomass as a proxy for the economic impact on fishers resulting from the new European discard ban that prohibits the discard of regulated species. These discard ratios are modelled by means of a Bayesian hierarchical model, specifically, a spatio-temporal beta regression model, which has several advantages over the traditional arcsine transformation. Results confirm the standardizing capacity of by-catch ratios across vessels and identify at least two economically fishing-suitable areas where discards ratios are minimized by reducing unwanted catch.

**Keywords:** beta regression, by-catch, discard ban, fishing-suitable area, spatial modelling.

## Introduction

Fishery discards have been a matter of debate over the last decades. Unwanted catches and discards constitute a substantial waste of natural resources that negatively affect the sustainable exploitation of marine ecosystems and the financial viability of fisheries (Kelleher, 2005; Viana *et al.*, 2013b). As a consequence, the new EU Common Fisheries Policy plan (European Commission, 2013) proposed for 2014–2020, is controversial in its goal to enforce the landing of fishing discards as a measure to encourage their reduction (Sardà *et al.*, 2015). This measure

implies that fishers will have to land all regulated species regardless of their size and that landing quotas will be replaced by catch quotas. While many potential consequences of this policy are still unclear for different fishing grounds and fisheries (Catchpole *et al.*, 2005; Bellido *et al.*, 2014; Sigurðardóttir *et al.*, 2015), it will undoubtedly have a negative economic impact on the primary fishery sector (Poseidon, 2013; Catchpole *et al.*, 2014). Indeed, fishers will be obliged to land products of little value, which will devalue the economic potential of their catch quotas. Similarly, in those areas where the fishery is not managed by quotas (e.g.

Mediterranean Sea), fishers will have to keep the fish on-board which may imply additional costs associated with handling the fish and reduced storage capacity.

Under these circumstances, a possible consequence of the upcoming EU fishing scenario is that it will motivate fishers to maximize revenues by fishing in areas that minimize the catch of unwanted regulated fish species (Vilela and Bellido, 2015). In this context, advanced spatial analysis techniques could help to identify areas where by-catch and/or discards are minimized. By providing spatial or spatio-temporal by-catch/discard predictive maps, both management bodies and fishers could better assess the fishing suitability of a given area.

Several studies have assessed discard concentration areas based on the expected amount of total discards per unit effort (DPUE) (Feekings *et al.*, 2012, 2013; Viana *et al.*, 2013a; Cosandey-Godin *et al.*, 2014; Pennino *et al.*, 2014). However, the use of DPUE units as a criterion to identify these areas can lead to ecologically and economically misleading results for two main reasons. Firstly, such an approach does not include the landed portion of the fishing haul in the analysis, and so it does not identify whether the amount of discard is disproportionate to the catch or not. This is crucial to quantify the economic and ecological balance between the marketed food biomass and the lost biomass. Secondly, from a technical point of view, modelling discards involves dealing with a wide range of commercial vessels with different characteristics (e.g. length of the vessel and engine-power), haul duration, and other effort characteristics. Consequently, calculating a standardized DPUE criterion may be difficult or even infeasible in most cases.

A better approach may be to use discard and by-catch ratios, defined as the discarded or by-caught biomass divided by the total haul biomass. In contrast to the DPUE criterion, discard ratios implicitly include benefit vs. loss, which allows us quantify both, the ecological impact in terms of “food biomass vs. wasted biomass” and the economic impact by quantifying the percentage of quota loss (if applicable) and percentage of storage room occupied in the vessel by non-marketable fish. Therefore, discard ratios allow a better identification of both, economically and ecologically, fishing-suitable areas. In addition, technically speaking, discard/by-catch ratios are inherently standardized to a wide range of effort variables (vessel size and fishing time) apart from the most gear specific ones (hook size and mesh size).

Interestingly, proportions have been widely used in many descriptive studies on fishery discards (Tsagarakis *et al.*, 2013); however, we found no fishery study that applies statistical regression to them. Vilela and Bellido (2015) proposed a random forest based algorithm to assess the fishing suitability of an area. Their algorithm is based on a fishing suitable–unsuitable (binomial) response variable that is created by manually setting a cut-off discard ratio that classifies hauls as suitable or unsuitable. It is therefore somewhat intuitive that results using this method may be very sensitive to the cut-off percentage set at the beginning of the analysis.

An easier and more straightforward approach is to directly apply regression on discard or by-catch ratios using the appropriate beta distribution. The beta distribution has historically had a very wide range of applications (Gupta and Nadarajah, 2004), although not until recently has it been used in regression modelling (Ferrari and Cribari-Neto, 2004).

In this study, we propose the use of by-catch or discard ratios to identify fishing-suitable areas. The approach is applied to a bottom trawling fishery of the western Spanish Mediterranean Sea by means of a Bayesian hierarchical model, specifically, a spatio-temporal beta regression model using R-INLA software (Martins *et al.*, 2013). We modelled two different by-catch/discard ratios: a total by-catch or discard ratio variable as a proxy of the global ecological impact and the by-catch or discard ratio of regulated species (non-discardable fraction under the new EU regulation). By doing so, we hope to identify fishing-suitable areas for the upcoming EU fishing scenario and provide a useful tool for fishery management.

## Material and methods

### Discard data

Trawl discard data were collected according to the European Commission (2009/93/EU) decision, which establishes a métier-based sampling programme of discards. Specifically, this study was based on bottom trawl data for the south-eastern part of the Spanish Mediterranean Sea (Figure 1). Bottom trawlers in this area are segregated into two different métiers due to the difference in catch composition at different depths: the bottom otter trawl for demersal species métier (OTB-DES) and the bottom otter trawl for deep-water species métier (OTB-DWS) (see Pennino *et al.*, 2014, for a more detailed description of the métiers).

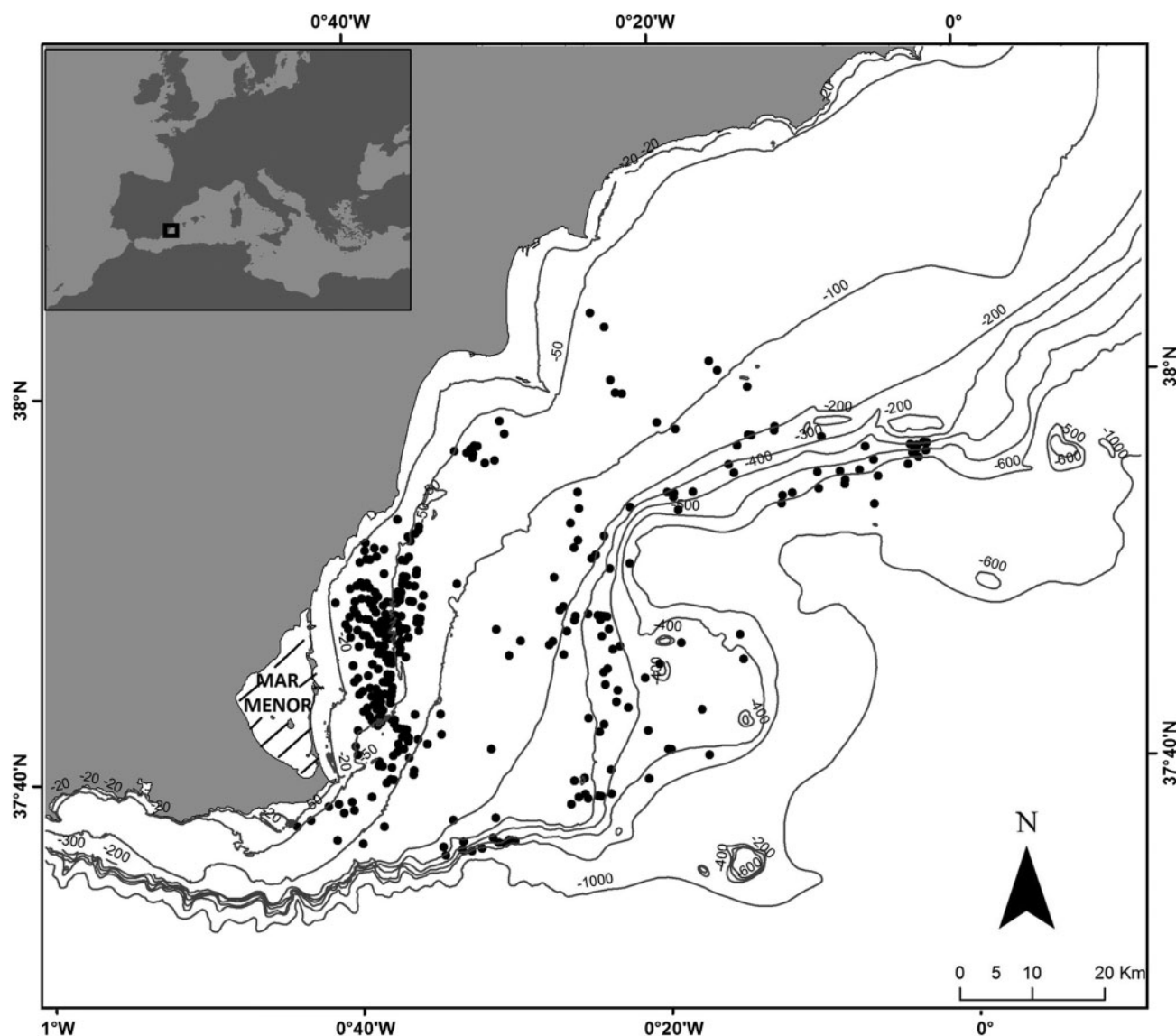
The database, provided by the Instituto Español de Oceanografía (IEO, Spanish Oceanographic Institute), contains a total of 391 hauls collected by 17 vessels between 2009 and 2012, including catch and discard data disaggregated by species. Two by-catch/discard ratio (henceforward simply discard) response variables were created. A total discard ratio variable was created to assess the global ecological impact of the fishery by dividing the discarded biomass by the total catch biomass. In addition, a discard ratio of regulated species variable was created to account for the non-profitable but also non-discardable fraction of the haul by dividing the regulated biomass that had been discarded by the total catch.

$$\begin{aligned} \text{Total discard ratio :} & \quad \frac{\text{Discard biomass}}{\text{Total biomass}} \\ \text{Regulated discard ratio :} & \quad \frac{\text{Regulated species discard biomass}}{\text{Total biomass}} \end{aligned}$$

The six most discarded fish species were: bogue (*Boops boops*) representing ~12% of the total discards, followed by the axillary seabream (*Pagellus acarne*) with 6%, the small-spotted catshark (*Scyliorhinus canicula*) with 4.5%, horse-mackerel (*Trachurus* sp.) with a 3.8% and the common pandora (*Pagellus erythrinus*) with 2.3%. Of these, the axillary seabream, the horse mackerel and the common pandora must be landed under the new EU discard ban.

### Independent variables

Fishing haul characteristics, such as date, time, geolocation and depth were extracted directly from the onboard observer database. Fishing geolocation and depth were computed using an average point between the start and end point of each fishery operation. The total catch of each fishing haul, in kilograms, was also included as a potential predictor.



**Figure 1.** Map of the study area, located in the south-eastern part of the Spanish Mediterranean Sea. Dots represent the centroids of the 391 sampled hauls.

Two temporal cyclic variables, namely “Moon phase” and “Ordinal day”, were created to explore possible mean temporal trends in both discard ratios. The moon is an environmental factor that affects the behaviour of fish (Mackinson, 2001; Pennino *et al.*, 2014) as well as seasons. Specifically, the “Moon phase” variable was created using the phenology package (Marc, 2015) implemented in R software (R Core Team, 2014). This variable can take any continuous value between 0 and 100, where 0 and 100 represent full moon and 50 new moon. The “Ordinal day” variable was created using the date package (Therneau *et al.*, 2014), which assign an integer value to each fishing haul based on the date of the haul, starting from 1 (1st January) to 365 (31st December). By fitting cyclic temporal effects (i.e. January 1 goes after December 31) to these two variables, we expect to identify any general temporal patterns in discard ratios related to seasons and/or the moon phase.

### Modelling discard ratios

Discard ratios can take any continuous value ranging between 0 and 1. This kind of data has frequently been modelled by transforming the dependent variable using the arcsine square root transformation (Sokal and Rohlf, 1995; Zar, 1999). This approach, however, has several drawbacks. First, model parameters cannot be easily interpreted in terms of the original response (Ferrari and Cribari-Neto, 2004). In addition, the measures of proportions typically display asymmetry, hence inference based on normality can be misleading (Ferrari and Cribari-Neto, 2004). In relation to this, the symmetry of the normal distribution can result in non-sensical predictions, e.g. confidence intervals out of the [0,1] range.

In contrast, the beta distribution fulfils the required characteristics and it is very flexible in terms of shapes (Gupta and Nadarajah, 2004). The only drawback of the beta distribution is

that it does not provide a satisfactory description of the data at the two extremes, i.e. 0 and 1, in which case, 0 and 1 inflated models are required (Ospina and Ferrari, 2012). A simple ad hoc solution to this problem is to add a small value to the observed proportion, which introduces minimal bias while still satisfying the (0,1) criteria (Warton and Hui, 2011). However, as a general rule, the catch of every fishing operation is made up of the discarded and landed fractions, neither of which is equal to 0 or 1, except for the most selective gears (pots and traps) and purse seiners. Therefore, 0/1 proportion data are scarce in the scope of this study.

### Identifying trawl fishing-suitable areas

A hierarchical Bayesian spatial beta regression model was used to identify the trawl fishing suitability of an area based on two types of discard ratios. On the one hand, we used total discard ratios to assess the global ecological impact. On the other hand, we used the discarded ratio of regulated species as a proxy to both, the economic impact on fishers under the new EU landing obligation due to occupying part of the vessel's hold and the ecological impact due to the biomass loss caused in the system by landing unwanted but regulated species.

Trawl discard ratios  $Y_{ijdt}$  of vessel  $j$ , haul  $i$ , depth  $d$  and time  $t$  were assumed to follow a beta distribution  $Y_{ijdt} \sim \text{Be}(\mu_{ijdt}, \phi_{ijdt})$ . The exploratory analysis revealed non-linear relationships between depth and discard ratios. These relationships were modelled using second order random walk (RW2) latent models based on 18-m-depth increments, i.e.  $x_d = 2x_{d-2} - x_{d-1} + \epsilon_d$  where  $\epsilon_d \sim N(0, \rho_d)$ . This model performs as a Bayesian smoothing spline (Fahrmeir and Lang, 2001). Similar RW2 structures were applied on the "Moon phase" and "Ordinal day" temporal variables, but with cyclic indexations so that the models account for the temporal cyclical nature of these variables, i.e. January 1 goes after December 31.

In addition, a geostatistical term with location-specific random effects  $S = (s_1, \dots, s_n)$  was included in the linear predictor of both discard ratios. It is important to note that due to the relatively low spatio-temporal resolution of the data ( $\sim 10$  spatial observations per month), the spatial effect and the temporal effect were fitted independently. Distances were standardized in between 0 and 1, where 1 is equal to the maximum distance in the study area. Such a spatial effect allows the identification of fine-scale spatial variation based on the principle that close observations are

more related than distant observations (Tobler, 1970). It is customary to assume, under R-INLA, that  $S \sim N(0, Q(\kappa, \tau))$  is a Gaussian field with zero mean and a covariance matrix  $Q$  that depend on two hyperparameters,  $\kappa$  and  $\tau$ , defining the variance and range of the spatial effect (Lindgren et al., 2011).

A remaining potential source of variation on discards could be due to differences among vessels (Eliassen et al., 2014). These differences can be caused by a skipper effect or unobserved gear characteristics. Consequently, and because we are not interested in knowing the specific nature of the observed vessels, we included this vessel effect as a random effect  $v_j$ . Finally, the total catch of the haul was included as a linear effect based on Rochet and Trenkel (2005), who concluded that discard ratios may not be proportional to the total catch.

The Bayesian approach requires the assignment of prior distributions to every parameter of the model. In this case, no prior information on the parameters of the model was available, so we used vague default prior distributions implemented by default in R-INLA. It was only in the case of the RW2 functions that a visual pre-selection of priors was made, to avoid overfit, by changing the prior of the precision parameter while the models were scaled to have a generalized variance equal to 1 (Sørbye and Rue, 2014). A sensitivity analysis of the choice of priors was performed by verifying that the posterior distributions concentrated well within the support of the priors.

Models were selected based on the Conditional Predictive Ordinate (Geisser, 1993) via its logarithmic score (LCPO) (Gneiting and Raftery, 2007), the Watanabe Akaike Information Criterion (WAIC) (Watanabe, 2010) and the effective number of parameters (ENP) of the model. WAIC uses the posterior densities more effectively than the traditional Deviance Information Criterion (DIC) (Gelman et al., 2014). All the available variables were included in the analysis. First, the proposed temporal variables were individually compared against the null model to identify general trend patterns. After this preliminary selection of variables, all the subsequent combinations of variables were fitted and compared.

### Results

Final models for both response variables included a non-linear bathymetric effect and the total catch of the haul as explanatory variables (Table 1). Specifically, the total catch of the haul had a positive effect on the expected ratios of both the total discard

**Table 1.** Model comparison for the total discard and regulated discard ratios.

		Total discard			Regulated discard		
		WAIC	LCPO	ENP	WAIC	LCPO	ENP
Temporal trend	I+M	−66.86	−0.085	3.15	−1109.2	−1.418	2.32
	I+OD	−67.25	−0.086	3.64	−1109.3	−1.419	2.37
	I	−67.32	−0.086	1.98	−1110.4	−1.420	1.98
Final model selection	I+D+V+C+S	–	–	–	−1201.0	−1.534	20.67
	I+D+C+S	–	–	–	<b>−1201.6</b>	<b>−1.535</b>	15.91
	I+D+V+C	−273.9	−0.354	9.82	−1170.9	−1.504	9.83
	I+D+C	<b>−274.1</b>	<b>−0.355</b>	7.25	−1165.3	−1.493	7.26
	I+D	−201.3	−0.268	6.97	−1117.3	−1.422	4.26
	I+C	−189.2	−0.243	2.98	−1145.7	−1.470	2.98
	I+S	−183.1	−0.23	13.2	−1164.9	−1.479	36.45

Missing values represent a bad fit of the spatial latent models, whose variance converged to nearly 0. Lower WAIC and LCPO scores represent a better compromise between fit, parsimony and predictive quality of the models. I, intercept; D, depth; V, vessel; M, moon phase; OD, ordinal day; C, total catch; S, spatial effect.



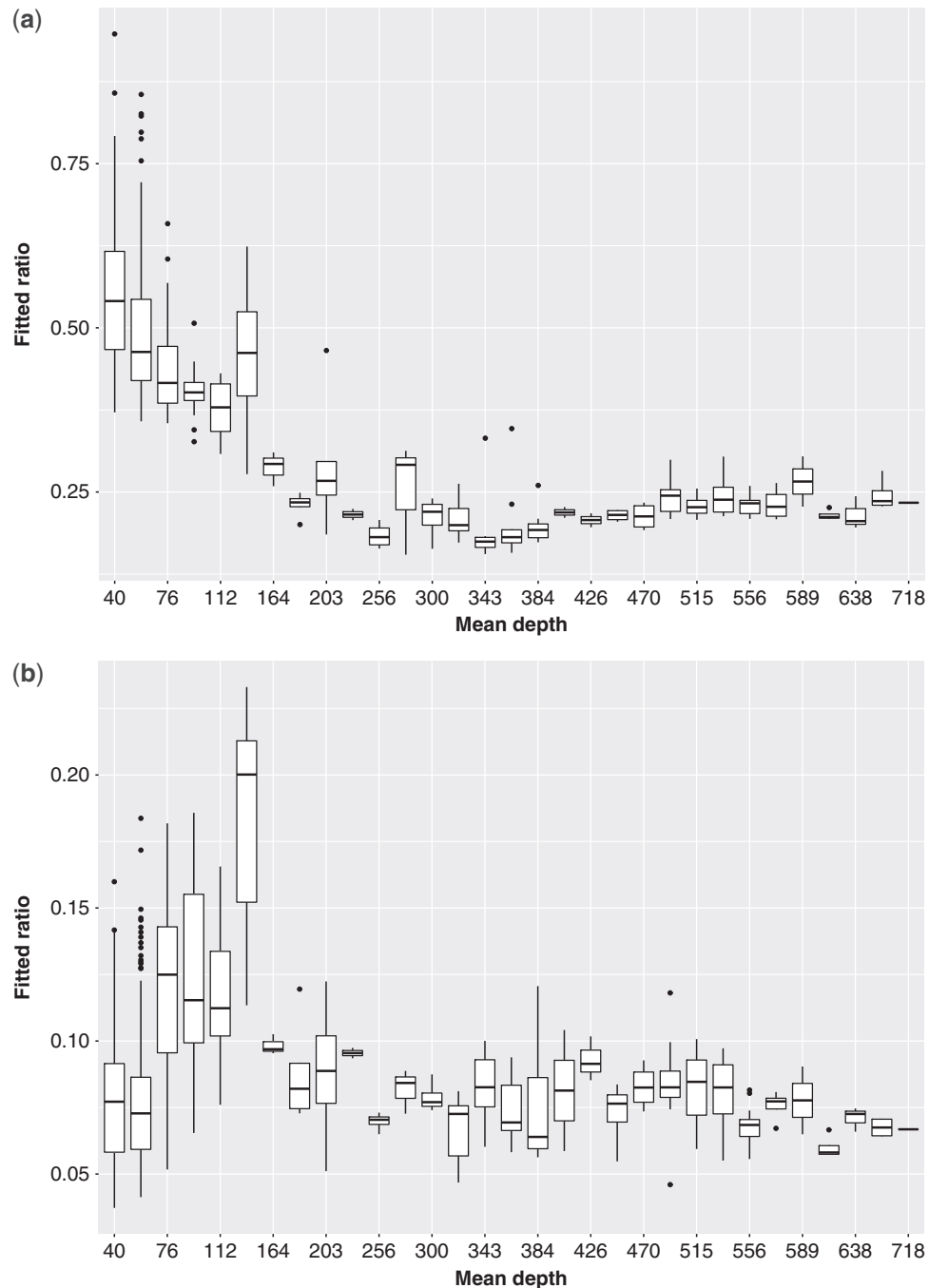
(posterior mean = 0.0023; 95% CI = [0.0018, 0.0029]) and the regulated discard ratio (posterior mean = 0.038; 95% CI = [0.0027, 0.0049]).

Predicted total discard ratios showed a marked relationship with respect to bathymetry (Figure 2). Highest total discard ratios were observed in shallow waters, between 40 and 200 m. Regulated species discards, however, showed a maximum expected discard ratio in the 75–175 depth strata, while remaining relatively low in shallower and deeper waters.

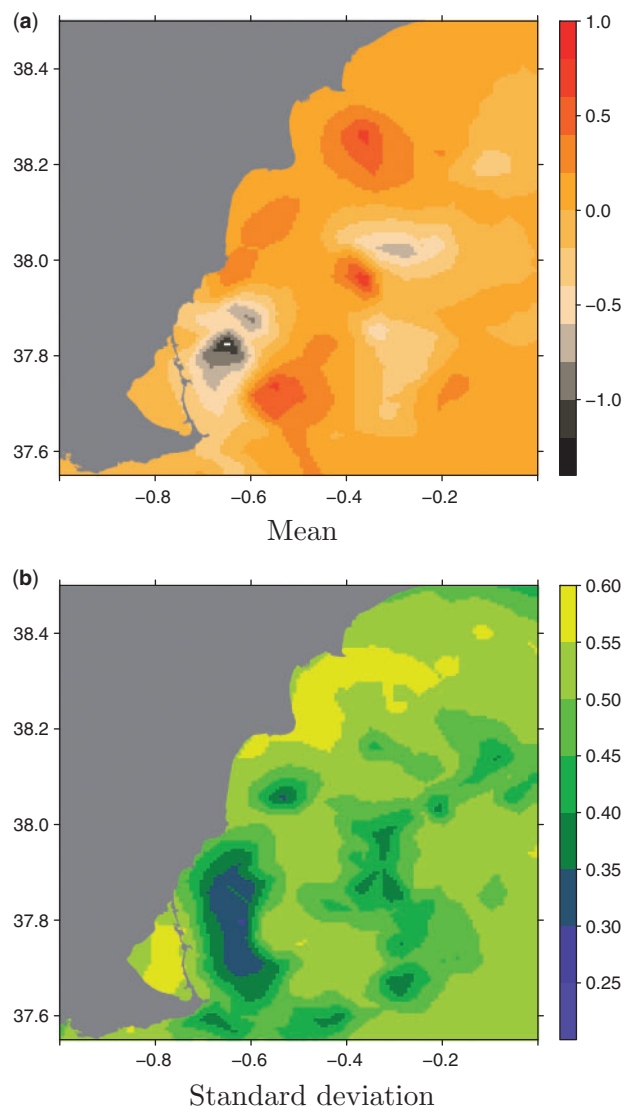
No relevant temporal patterns were found in the study area. Indeed, all models with temporal effects, showed higher WAIC

and LCPO scores than those without them for both response variables (Table 1). Similarly, the model selection process dismissed the vessel random effect from both models, suggesting that discard ratios were fairly homogeneous across the different commercial vessels (Table 1).

The spatial effect was only included in the regulated discard ratios model (Table 1). The estimated mean range was 0.53 (CI = [0.51, 0.58]) and mean variance of 1.35 (CI = [1.14, 1.77]). Figure 3 displays the posterior mean and standard deviation of the spatial component. This component showed two main low discard areas (negative values in Figure 3), which translates into



**Figure 2.** Fitted discard ratios with respect to the mean depth of the observed hauls.



**Figure 3.** Posterior mean and standard deviation of the spatial component of the regulated species discard ratio.

lower expected discard ratios than those expected by the rest of variables. Specifically, one low discard area is located in the shallow waters in front of the Mar Menor lagoon and another along the central part of the 0.3 west meridian (Figure 3). These two low discard areas could constitute two fishing-suitable areas where expected levels of unwanted regulated species are lower than in other zones of the study area with similar bathymetric conditions. Similarly, a high discard hot-spot (positive values in Figure 3) was identified around the latitude 37.7 north and longitude 0.7 west coordinate area.

The total discard ratio predictive map (Figure 4) confirmed the key role of depth in the distribution of discard ratios. The posterior predictive map of regulated discard ratios (Figure 4) showed a similar pattern but with the added small-scale spatial variability provided by the spatial effect.

The predicted hot-spot of regulated discard ratios in the northern coastal zone of the study area (Figure 4) is driven by the marginal bathymetric effect due to the absence of observations in the area. Therefore, this discard hot-spot should not be considered

while new observations suggest the contrary. Such uncertainty is displayed by the standard deviation map associated to these predictions (Figure 4).

## Discussion

The present study proposes a new framework to characterize fishing-suitable areas under the upcoming EU discard ban. This study proposes using spatial beta regression models applied to discard or by-catch ratios. Specifically, we use total discard ratios and discard ratios of regulated species as a proxy to assess the global ecological impact and economic impact on fishers, respectively.

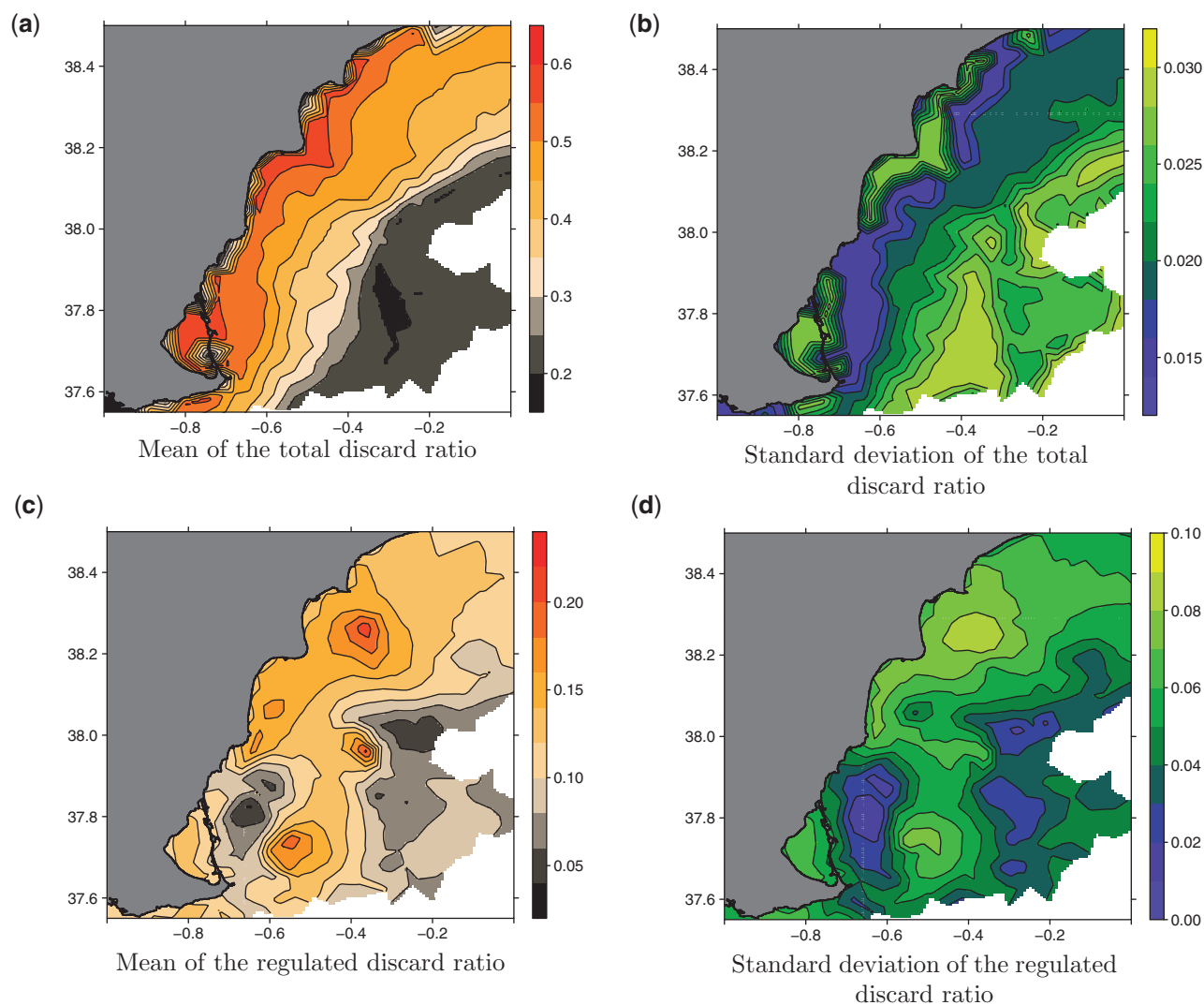
The use of discard ratios is also a good alternative to the widely used discards per unit effort (DPUE) criterion. In contrast to DPUEs, discard ratios represent benefit vs. loss, and thus allow researchers to assess whether the amount of discards is disproportionate to the catch or not. Discard ratios allow assessing the economic impact by quantifying the percentage of quota loss (if applicable) and percentage of storage room occupied in the vessel by non-marketable fish when fishing in a given sub-area. Similarly, the ecological impact is also quantified in terms of gained food biomass against wasted biomass. Furthermore, regulated species discard ratios represent the percentage of biomass removed from the system that, before the landing obligation, would have been returned to the system.

From a methodological perspective, results showed that discard ratios have a good standardizing capability across different vessels. The random effect assigned to absorb extra variability among vessels was dismissed during the model selection process. Conversely, the study by Pennino *et al.* (2014), using DPUEs in the same study area, found that this component was relevant in the analysis. Our results using discard ratios compared with the results in Pennino *et al.* (2014) could provide initial evidence of the good standardizing capacity of discard ratios compared with the more usual DPUE units.

The resulting discard ratio predictive maps (Figure 4) provide intuitive tools to assess the fishing suitability of a sub-area. Fishers and policy makers could combine information on the proportion of total and regulated species discards to select economically and ecologically fishing-suitable areas. In this regard, the Bayesian approach provides an added value, which is the straightforward quantification of the uncertainty in our predictions, visualized here with the standard deviation maps.

The marginal spatial effect also provides a very informative tool for decision-making as it represents the spatial fine-scale variability of discard ratios given the effect of the covariates. In other words, the spatial effect is able to identify fishing-suitable areas by stressing the relative abundance at a given location with respect to the expected mean ratio at that location given the covariates, in this case depth. Consequently, and because trawl target species vary essentially with depth, the map of the spatial effect is particularly useful to identify fishing-suitable areas for a given target species.

This study identified two main fishing-suitable sub-areas based on the proportion of discarded regulated fish (Figure 3). Fishing in these sub-areas could reduce fishers' economic loss due to quota reduction (if applicable) or the minimization of ship hold occupied by non-marketable species. Furthermore, fishing in these sub-areas may minimize the ecological biomass loss in the system generated by the landing obligation. Under the landing obligation, it is mandatory to land some of the previously discarded biomass, which



**Figure 4.** Posterior predictive mean and standard deviation of the total discard ratios (top) and the regulated discard ratios (bottom).

results in higher energy removals from the system than before. Regarding the total proportion of unwanted fish, results showed a clear longitudinal gradient related to the bathymetry. Indeed discard ratios were higher in shallow waters (Figure 2) along the coastline (Figure 4) and may reflect the distribution of target species of these métiers. As also highlighted by Pennino *et al.* (2014), the depth-related variations of discard ratios are linked to differences in species composition of fish communities and in the length-frequency distribution of some species. Species replace each other according to their bathymetric and geographical preferences. Thus, the bogue, the most discarded species, is particularly abundant between 50 and 200 m, which may explain the increase of total discard ratios in shallow waters.

Interestingly, and although fish distribution is known to vary seasonally, none of the models found any temporal trend on the discard ratios of the study area. Discard ratios, as well as the DPUE criterion, constitute the aggregation of many different species and thus mixed species-specific distribution patterns. In this respect, a detailed species-specific study of discard could better identify masked temporal and/or spatial patterns in this study.

Lastly, results confirmed that discard ratios consistently increase with the amount of total catch, as shown previously by Pennino *et al.* (2014) and Rochet and Trenkel (2005). In this regard, Rochet and Trenkel (2005) proposed limited hold capacity of the vessels as a possible explanation for the increased discard ratios when the catch is high. This could not be the case in this area as the local fleet operates on the basis of day-trips and the total catch seldom exceeds hold capacity. An alternative reason may be related to high grading, where mid-priced fish species could be landed when the catch is low to make the trip profitable but thrown away when the catch is good enough. A more detailed study of these mid-priced fish species combined with sales notes information could confirm this hypothesis.

To conclude, we would also like to mention that the analytical approach used here to explore the distribution of discard ratios can be extended to different fishing grounds and any other spatial process measured in proportions.

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## References

- Bellido, J. M., Carbonell, A., Garcia, M., Garcia, T., and González, M. 2014. The obligation to land all catches – consequences for the Mediterranean. European Parliament, Directorate-General for Internal Policies Policy Department B: Structural and Cohesion Policies, p. 52.
- Catchpole, S., Elliot, T., Peach, D., and Mangi, S. 2014. Final report: the English discard ban trial. Tech. Rep., Cefas, Lowestoft.
- Catchpole, T. L., Frid, C. L. J., and Gray, T. S. 2005. Discards in North sea fisheries: causes, consequences and solutions. *Marine Policy*, 29: 421–430.
- Cosandey-Godin, A., Krainski, E. T., Worm, B., and Flemming, J. M. 2014. Applying Bayesian spatiotemporal models to fisheries bycatch in the Canadian Arctic. *Canadian Journal of Fisheries and Aquatic Sciences*, 72: 186–197.
- Eliassen, S. Q., Papadopoulou, K. N., Vassilopoulou, V., and Catchpole, T. L. 2014. Socio-economic and institutional incentives influencing fishers' behaviour in relation to fishing practices and discard. *ICES Journal of Marine Science*, 71: 1298–1307.
- European Commission. 2009. Commission Decision 2010/93/EU, adopting a multiannual Community programme for the collection, management and use of data in the fisheries sector for the period 2011–2013. Tech. Rep., EC (European Commission), Brussels.
- European Commission. 2013. Regulation (EU) No 1380/2013 of the European Parliament and the council, on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC. Tech. Rep., EC (European Commission), Brussels.
- Fahrmeir, L., and Lang, S. 2001. Bayesian inference for generalized additive mixed models based on Markov random field priors. *Applied Statistics*, 50: 201–220.
- Feekings, J., Bartolino, V., Madsen, N., and Catchpole, T. 2012. Fishery discards: factors affecting their variability within a demersal trawl fishery. *PloS One*, 7: e36409.
- Feekings, J., Lewy, P., Madsen, N., and Marshall, C. T. 2013. The effect of regulation changes and influential factors on Atlantic cod discards in the Baltic Sea demersal trawl fishery. *Canadian Journal of Fisheries and Aquatic Sciences*, 70: 534–542.
- Ferrari, S., and Cribari-Neto, F. 2004. Beta regression for modelling rates and proportions. *Journal of Applied Statistics*, 31: 799–815.
- Geisser, S. 1993. *Predictive Inference*, vol. 55. Chapman and Hall; CRC Press, New York.
- Gelman, A., Hwang, J., and Vehtari, A. 2014. Understanding predictive information criteria for Bayesian models. *Statistics and Computing*, 24: 997–1016.
- Gneiting, T., and Raftery, A. E. 2007. Strictly proper scoring rules, prediction, and estimation. *Journal of the American Statistical Association*, 102: 359–378.
- Gupta, A. K., and Nadarajah, S. 2004. *Handbook of Beta Distribution and Its Applications*. Chapman and Hall; CRC Press, New York.
- Kelleher, K. 2005. Discards in the World's Marine Fisheries: An Update. 470. FAO Fisheries Technical Paper No. 470 FAO, Rome, p. 131.
- Lindgren, F., Rue, H., and Lindström, J. 2011. An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 73: 423–498.
- Mackinson, S. 2001. Integrating local and scientific knowledge: an example in fisheries science. *Environmental Management*, 27: 533–545.
- Marc, G. 2015. Phenology: tools to manage a parametric function that describes phenology. <http://CRAN.R-project.org/package=phenology>. R package version 4.1.
- Martins, T. G., Simpson, D., Lindgren, F., and Rue, H. 2013. Bayesian computing with INLA: new features. *Computational Statistics & Data Analysis*, 67: 68–83.
- Ospina, R., and Ferrari, S. L. P. 2012. A general class of zero-or-one inflated beta regression models. *Computational Statistics & Data Analysis*, 56: 1609–1623.
- Pennino, M. G., Muñoz, F., Conesa, D., López-Quílez, A., and Bellido, J. M. 2014. Bayesian spatio-temporal discard model in a demersal trawl fishery. *Journal of Sea Research*, 90: 44–53.
- Poseidon. 2013. A Case Study Review of the Potential Economic Implications of the Proposed CFP Landings Obligation. Tech. Rep., Poseidon, Aquatic Resource Management, Portmore.
- R Core Team. 2014. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing. <http://www.R-project.org/>.
- Rochet, M. J., and Trenkel, V. M. 2005. Factors for the variability of discards: assumptions and field evidence. *Canadian Journal of Fisheries and Aquatic Sciences*, 62: 224–235.
- Sardà, F., Coll, M., Heymans, J. J., and Stergiou, K. I. 2015. Overlooked impacts and challenges of the new European discard ban. *Fish and Fisheries*, 16: 175–180.
- Sigurðardóttir, S., Stefánsdóttir, E. K., Condie, H., Margeirsson, S., Catchpole, T. L., Bellido, J. M., Eliassen, S. Q., et al. 2015. How can discards in European fisheries be mitigated? Strengths, weaknesses, opportunities and threats of potential mitigation methods. *Marine Policy*, 51: 366–374.
- Sokal, R. R., and Rohlf, F. J. 1995. *Biometry*. W. H. Freeman and Co., New York. <https://books.google.es/books?id=N6KCNw5NHNkC>.
- Sørbye, S. H., and Rue, H. 2014. Scaling intrinsic Gaussian Markov random field priors in spatial modelling. *Spatial Statistics*, 8: 39–51.
- Therneau, T., Lumley, T., Halvorsen, K., and Hornik, K. 2014. Date: functions for handling dates. <http://CRAN.R-project.org/package=date>. R package version 1.2-34. S original by Terry Therneau, R port by Thomas Lumley, Kjetil Halvorsen, and Kurt Hornik.
- Tobler, W. R. 1970. A computer movie simulating urban growth in the Detroit region. *Economic Geography*, 46: 234–240.
- Tsagarakis, K., Palialexis, A., and Vassilopoulou, V. 2013. Mediterranean fishery discards: review of the existing knowledge. *ICES Journal of Marine Science*, 71: 1219–1234.
- Viana, M., Jackson, A. L., Graham, N., and Parnell, A. C. 2013a. Disentangling spatio-temporal processes in a hierarchical system: a case study in fisheries discards. *Ecography*, 36: 569–578.
- Viana, M., McNally, L., Graham, N., Reid, D. G., and Jackson, A. L. 2013b. Ignoring discards biases the assessment of fisheries' ecological fingerprint. *Biology Letters*, 9: 20130812.
- Vilela, R., and Bellido, J. M. 2015. Fishing suitability maps: helping fishermen reduce discards. *Canadian Journal of Fisheries and Aquatic Sciences*, 72: 1191–1201.



- Warton, D. I., and Hui, F. K. C. 2011. The arcsine is asinine: the analysis of proportions in ecology. *Ecology*, 92: 3–10.
- Watanabe, S. 2010. Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory. *The Journal of Machine Learning Research*, 11: 3571–3594.
- Zar, J. H. 1999. *Biostatistical Analysis*. Pearson Education India Prentice Hall, Englewood Cliffs, New Jersey.

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