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A Bayesian model of fisheries discards with flexible structure and priors defined by experts

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ABSTRACT

Minimizing the probability of discards is an important step in mitigating environmental impacts of fishing activities and maximizing economic gains from fish stocks. Although several discard models have been recently developed, current approaches are still unable to robustly adjust to different circumstances (e.g. fishery target species, geographical location), and lack a closer interaction with stakeholders. Here, we present a novel approach consisting of a modular Bayesian model, which can incorporate any relevant explanatory variable, independently of data availability. The relationships between the variables and discard rates are initially delineated by stakeholders through surveys, and included to the model as priors. The priors are then used together with observed data for estimating posterior distributions of discard probability. We test this approach in two study areas at the Mediterranean Sea: the Ligurian and Tyrrhenian Seas in Italy, and the Greek part of the Aegean Sea. For each site, we evaluated the model for estimating discards from bottom trawl fishery associated with European minimum conservation reference size regulations, as well as discards caused by the low economic value of catches.

1. Introduction

Unwanted catches and discards represent major economic and environmental problems in the maritime fishery sector (Komoroske and Lewison, 2015; Sigurdardóttir et al., 2015). Unwanted catch is hereby defined as incidental catch of organisms that cannot be commercialized due to low or no economic value, or due to legal requirements (e.g. Minimum Conservation Reference Size, MCRS, provisions). Discards refer to the portion of the catches that is returned to the sea, either dead or alive (Feekings et al., 2012; Viana et al., 2013b). Discard patterns are affected initially by catch compositions, which are determined by environmental factors, relationships between species and their habitat, the fishing gear, fishing tactics, and ultimately by fishermen behaviour. The decision of which parts of the catch has to be retained is influenced by both market and regulatory conditions, and constrained by storage space onboard the vessel and sorting time (Catchpole et al., 2014). Hence, discards are a result of deliberate choices made by fishers during the fishing process (Eliasen et al., 2014).

Discarding leads to a waste of natural resources that negatively affect the sustainable exploitation of marine ecosystems and the economic gains of fisheries (Paradinas et al., 2016; Viana et al., 2013b). Unwanted catches related to MCRS can be particularly harmful to the productivity of stocks, by killing young individuals before their optimum production potential is achieved. Likewise, fishing gears with low selectivity can be detrimental to threatened species, which are unintentionally caught and released with low chances of survival (Snape et al., 2013; Tudela et al., 2005). Furthermore, food subsidies between marine and terrestrial ecosystems can alter trophic webs (Oro et al., 2013). From an economic perspective, unwanted catches reduce fishery efficiency, by making activities more laborious and time consuming, because of the substantial time spent to sort out catches (Macher et al., 2008).

Discards vary from 20 to 60% of total catch in weight in the Atlantic (STECF/SGMOS, 2008) and between 10 and 35% in the Mediterranean (Sánchez et al., 2007; Tsagarakis et al., 2014). Dis-

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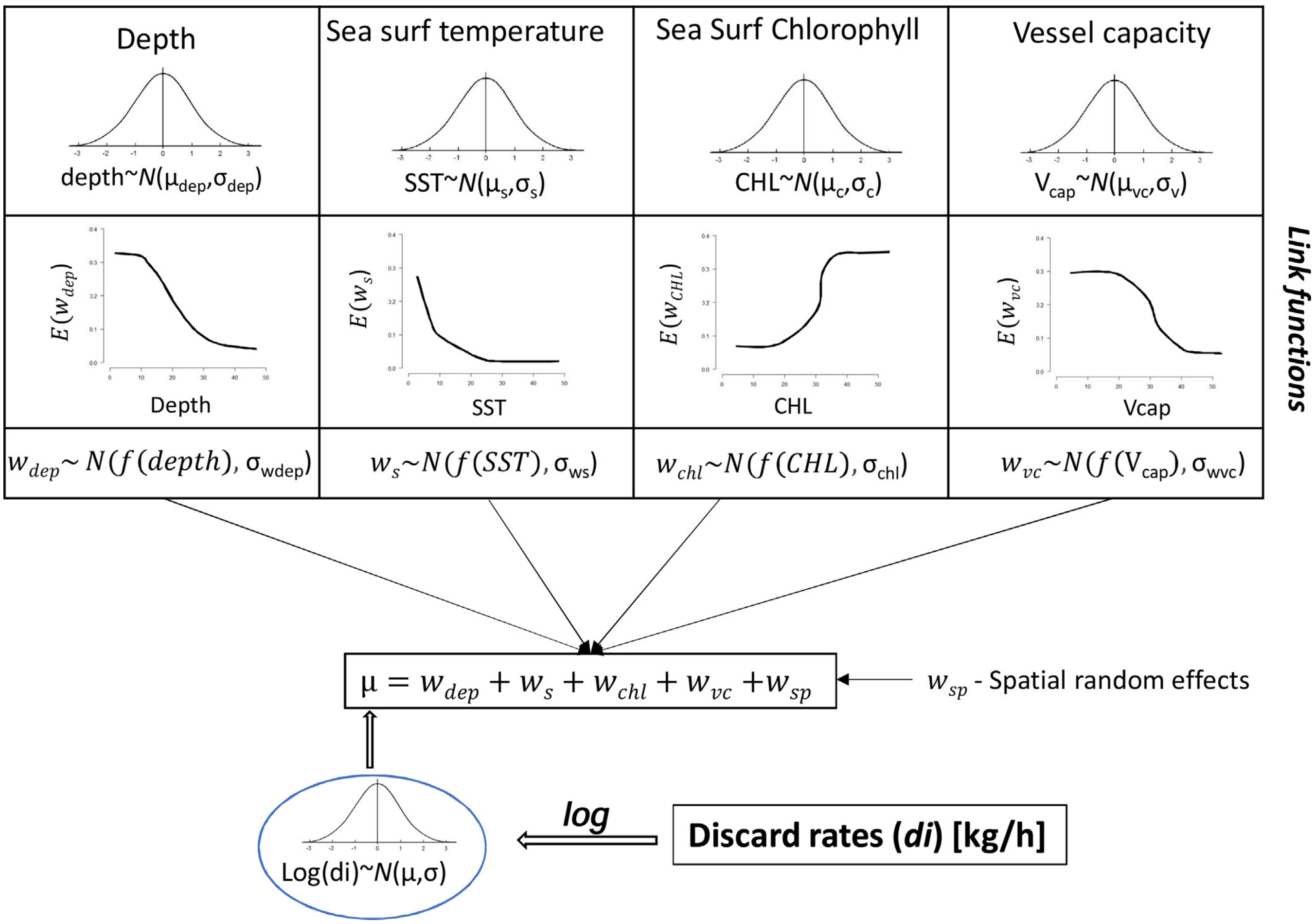

Fig. 1. Graphical illustration of the Bayesian model of fishery discards.

cards in the Mediterranean present a high diversity of species and a wide size range, which makes discards mitigation by using only fishing gear selectivity difficult. Out of the 300 species caught in the Mediterranean bottom trawl fisheries, only around 10% are consistently marketed and 30% are occasionally retained (depending on the sizes and market demands), whereas up to 60% are always discarded.

European fisheries are transitioning to new rules aiming at reducing discards and mandatorily bringing all catches to land ("discard ban" or "landings obligation": Art. 15 of the new Common Fisheries Policy, CFP, EU Regulation 1380/2013). These new rules are likely to significantly affect fishery activities in Europe. Given the impossibility to completely avoid unwanted catches and the fact that CFP will progressively phase out discards of regulated species (i.e., those subject to quota, and species with MCRS in the Mediterranean; see Reg. EC 1967/2006), it is essential to develop new technological solutions, along with economic and social incentives, to gradually reduce unwanted catches. In this context, combining technical solutions and economic incentives of discards-free fishing has the potential to considerably reduce unwanted catches and facilitate a more ecologically sound harvesting regime.

Mathematical models can have a key role in the transition for these new rules, as they may assist managers and fishermen in identifying areas with lower probability of unwanted catches. Moreover, models can be used to estimate the impacts of discarding on population productivity. Although modeling tools to address these problems are not abundant in the literature, several models have been developed in recent years for assessing bycatches/discards, using a variety of methods and parameterization strategies. For instance, Sims et al. (2008) developed a Bayesian hierarchical model framework for mapping bycatch of marine mammal and seabird, using data collected from the United States gill net fishery for groundfish in the northwest Atlantic. They concluded that models represent an important tool for understanding spatial variations in bycatch, being able to generate alternative summaries of bycatch, and having considerable promise for bycatch management and mitigation (Sims et al., 2008).

Madsen et al. (2013) applied generalized additive models (GAM) to analyze factors driving discards of plaice (*Pleuronectes platessa*) under MCRS in the Danish part of North Sea. They identified mesh size and geographical location as significant factors defining discard volumes. Pennino et al. (2014) developed Bayesian hierarchical models to analyze trawl fishing operations in the Spanish Mediterranean Sea. They argued that the Bayesian spatial approaches have the advantage of allowing the incorporation of spatial random-effects and uncertainty about the parameters in the modeling process, resulting in clearer uncertainty estimates and improved predictions (Pennino et al., 2014). Nonetheless, they point out that the model developed in their study was based on linear mixed models, and therefore could only account for linear relations between the dependent and explanatory variables.

Although these previous approaches have significantly improved our knowledge on the factors driving discards, many bottlenecks still restrict the use of models for effectively managing this issue. For instance, in most cases, models are designed to conform to data availability. This means that the variables driving the model do not always have a direct causal relationship with