Manuscript Details

Manuscript number	JMPO_2020_694
Title	Towards discard quantification of Data Limited Stocks based in on-board observers data: the case of Spanish fresh trawlers targeting black hake in NW Africa
Article type	Full Length Article

Abstract

Quantification of discard per unit effort rates (DPUE) has been proposed by the European Commission as a measure to manage the discarding of commercially fished organisms. In the Spanish fresh trawling fleet operating in North West Africa, both target species of black hakes, Merluccius polli and Merluccius senegalensis are data limited stocks (DLS). Hence, discards of these fleets are even more unknown but not unimportant part of the total catch (retained and discarded). Onboard observer data from commercial surveys from 2016 to 2018 provide a detailed source of scientific information about catches, discards, effort and technical factors in this fleet. This is the first quantitative analysis to model DPUE through generalised linear mixed models (GLMM), based on the explicit distinction between abundance and technical factors coming from information of observer surveys. We describe the relationship between discards and environment, catches of target and other species, effort of the fleet, spatial and temporal variation in discard accessibility, vessel characteristics, strategy of the skippers and market decisions. Unlike hake catches, discards were higher and more dispersed in shallower than in deeper waters. We identified two separate métiers for the Spanish fresh trawling fleet determined by depth and treated total discards as a stock unit susceptible of being monitored, managed and assessed. The strategy of the skipper appears to have a more important effect on discards than vessel characteristics. This study shows the importance of observer data for this fishery and identifies recommendations for the improvement in the scientific usefulness of logbook information.

Keywords	discard per unit of effort (DPUE); data limited stocks (DLS); generalised linear mixed models (GLMM); logbooks; observers on board; trawl

Corresponding Author	Maria Soto
Order of Authors	Maria Soto, Javier REY, Ramón García-Cancela, María Liébana, Lourdes Fernández-Peralta

Suggested reviewers	Jose Sanchez, Beyah Meissa, Maria Grazia Pennino, Laurie Kell

Submission Files Included in this PDF

File Name [File Type]

Soto et al_LETTER to MP.docx [Cover Letter]

Abstract.docx [Abstract]

Title page.docx [Title Page (with Author Details)]

Blinded manuscript.docx [Manuscript (without Author Details)]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
The data that has been used is confidential

Dear editor,

EU fisheries in NW Africa are often characterised by lack of precise data on catches and discards, affecting to economic, social and management topics. Multi-specific catch and complex dynamics of demersal trawl fleet in the area can only be deeply analysed from quality on-board scientific data, particularly those concerning discards. Our study has been supported by a strong cooperation team, integrated by researchers, scientific observer, skippers and ship-owner that allowed us to identify existing gaps of this fishery, improve the knowledge about the effect affecting discards and propose recommendations for management of discards in this fishery. Thus, the following results are completely new and promising:

1. Analysis of the most detailed scientific information of the most important demersal fleet in the North-West Africa based on board observer data from 2016 to 2018.
2. Quantitative analysis of the main effects affecting discards taking into account abundance and technical variables.
3. Description of the relationship between discards and the environment, catches of target and other species, effort of the fleet, spatial and temporal variation in discard accessibility, vessel characteristics, strategy of the skippers and market decisions.
4. Index of discards rate (DPUE).
5. Replicable methodology based on GLMM fitted to DPUE data for the Spanish fresh trawling fleet in North-West African waters.
6. The treatment of total discards as a stock unit susceptible of being monitored, managed and assessed.
7. Emphasize the importance of observer data for this fishery and provide recommendations to improve the logbook information so that data can be scientifically exploited better.

Our article, in accordance to MP, is related with management and conservation issues related with the marine environment. Above all, our results are a necessary starting point to further studies heading for improving management in living resources in NW Africa: discard biodiversity, impact on marine habitat, estimating and reducing discards, etc.

Quantification of discard per unit effort rates (DPUE) has been proposed by the European Commission as a measure to manage the discarding of commercially fished organisms. In the Spanish fresh trawling fleet operating in North West Africa, both target species of black hakes, *Merluccius polli* and *Merluccius senegalensis* are data limited stocks (DLS). Hence, discards of these fleets are even more unknown but not unimportant part of the total catch (retained and discarded). Onboard observer data from commercial surveys from 2016 to 2018 provide a detailed source of scientific information about catches, discards, effort and technical factors in this fleet. This is the first quantitative analysis to model DPUE through generalised linear mixed models (GLMM), based on the explicit distinction between abundance and technical factors coming from information of observer surveys. We describe the relationship between discards and environment, catches of target and other species, effort of the fleet, spatial and temporal variation in discard accessibility, vessel characteristics, strategy of the skippers and market decisions. Unlike hake catches, discards were higher and more dispersed in shallower than in deeper waters. We identified two separate métiers for the Spanish fresh trawling fleet determined by depth and treated total discards as a stock unit susceptible of being monitored, managed and assessed. The strategy of the skipper appears to have a more important effect on discards than vessel characteristics. This study shows the importance of observer data for this fishery and identifies recommendations for the improvement in the scientific usefulness of logbook information.

Towards discard quantification of Data Limited Stocks based in on-board observers data: the case of Spanish fresh trawlers targeting black hake in NW Africa.

Soto, M.; Rey, J.; García-Cancela, R.; Liébana, M. and Fernández-Peralta, L.

Corresponding author: María Soto Ruiz
e-mail: maria.soto@ieo.es
Institution: Spanish Oceanographic Institute
address: Spanish Oceanographic Institute. Puerto pesquero s/n. 29640 Fuengirola, Málaga, Spain.

Quantification of discard per unit effort rates (DPUE) has been proposed by the European Commission as a measure to manage the discarding of commercially fished organisms. In the Spanish fresh trawling fleet operating in North West Africa, both target species of black hakes, *Merluccius polli* and *Merluccius senegalensis* are data limited stocks (DLS). Hence, discards of these fleets are even more unknown but not unimportant part of the total catch (retained and discarded). Onboard observer data from commercial surveys from 2016 to 2018 provide a detailed source of scientific information about catches, discards, effort and technical factors in this fleet. This is the first quantitative analysis to model DPUE through generalised linear mixed models (GLMM), based on the explicit distinction between abundance and technical factors coming from information of observer surveys. We describe the relationship between discards and environment, catches of target and other species, effort of the fleet, spatial and temporal variation in discard accessibility, vessel characteristics, strategy of the skippers and market decisions. Unlike hake catches, discards were higher and more dispersed in shallower than in deeper waters. We identified two separate métiers for the Spanish fresh trawling fleet determined by depth and treated total discards as a stock unit susceptible of being monitored, managed and assessed. The strategy of the skipper appears to have a more important effect on discards than vessel characteristics. This study shows the importance of observer data for this fishery and identifies recommendations for the improvement in the scientific usefulness of logbook information.

Keywords: discard per unit of effort (DPUE), data limited stocks (DLS), generalised linear mixed models (GLMM), logbooks, observers on board, trawl.

1. Introduction

Studies of discards in EU waters have aimed to develop robust methods of estimating discards [1](Sigridur Sigurdardottir et al, 2015), allowance for discards in fishery management plans [2](Nekane Alzorriz et al, 2018), development of by-catch management plans, and promotion of best practices for by-catch reduction and mitigation of incidental catches. Additional studies at national and regional levels are required to improve the precision of the global estimation of discards [3](Kelleher, 2005). Also, recent updates [4](Pérez Roda *et al*.., 2019) establish that an understanding of the relative importance of factors affecting indirect fishing mortality is necessary to estimate the total fishing-induced mortality [5](Bellido *et al*., 2007), to design and implement mitigation measures, and to provide a baseline for a time series of global marine fisheries discards in the last 20 years. Also, scientists discuss whether the current sampling regime should be either expanded or complemented by other data sources, such as comparable discard per unit of effort (DPUE) between fisheries and regions. In Europe, the Data Collection Framework (DCF) [6](EEC, 2017) legislates on how to estimate the amount of discards. As part of nationally adopted onboard observer programmes, trained personnel collect discard data from their most important commercial fisheries [7](Uhlmann *et al*., 2013). The latest reform of the EU Common Fisheries Policy [8](EU No 1380, Article15, 2013) considers the landing obligation as a basic regulation of the policy, which required a gradual phasing-in of the obligation to land all catches. This landing obligation contains numerous exemptions between fleets affected by total allowable catches (TACs) or quotas [4](Pérez Roda *et al*., 2019). In addition, the 2009 revision of the Data Collection Regulation [9](EU, 2008a) has changed the focus of fisheries sampling programmes, recognising that the new context required new methodological developments to analyse the collected data since the implementation of the DCF [10](Jardim *et al*.., 2015).

Stocks in European waters have been categorized as either data-rich or data-limited/data-poor and methodologies to provide the best scientific advice have been addressed in the last years [11]y [12](ICES. 2012a, b). Nevertheless, more categories were needed [12](ICES, 2012b) and even more so in the case of stocks out of the EU waters, where the sampling, monitoring and controlling of the fisheries are subject to political, economical and social trade-offs between EU and other countries. This is the general situation for target and by-catch stocks exploited by EU fleets under sustainable partnership fisheries agreements (SPFAs) in North West Africa and managed by the Fishery Committee for the Eastern Central Atlantic (CECAF). Discards also automatically inherit the condition of data poor from the fishery and are even more difficult to analyze since they are sampled only by observers onboard [19](STECF, 2016).

Generally, this study aimed to reveal the condition of data poor in stocks outside EU waters which are in need of: *i)* gathering further information through logbooks (haul geo-referenced and retained and discarded catches); *ii)* methodologies adapted to their particular data poor conditions; and, in particular for discards, *iii)* this study responds to issues mentioned in the beginning of this introduction: to develop a robust method to estimate discards, improve the precision of the estimates, understand the relative importance of factors affecting discards and develop a comparable DPUE between fisheries and regions.

In particular, our case of study is the Spanish fresh trawling fleet targeting black hake, where discard information has been collected by scientific observers throughout an on board programme [6](ECC, 2017. This is a reference fleet in CECAF, as it has been monitored by Spanish Administration and Spanish Oceanographic Institute since 1989 and is the principal fleet targeting black hakes in North-West Africa. The annual catches of this fishery ranged widely from 2007 to 2016, and comprised between 4800 t in 2013 and 17,000 t in 2016 [13](FAO, 2018). Global discards of this fleet are very fluctuating (both in species composition as in volume of catches), depending on diverse issues (depth, fishing strategy, season, among others).

Neither black hake stock nor the discards of the EU and African local fleets are fully in line with ICES DLS categories. First, there is a lack of stock unit definition; under *Merluccius* spp. (black hake), two different species are mixed up, *Merluccius polli* and *M. senegalensis* [14], [15], [16], [17], [18](Fernández-Peralta *et al.*, 2011; 2017; Rey *et al.*, 2012, 2015, 2016). Second, the stock distribution of black hakes is not considered in the assessments, as they are been assessed either independently by country (Morocco, Mauritania and Senegal) or for the total region. Third, catches and effort data are collected by local countries from their own fleets and, even from EU fleets, but data are insufficient or not available/published for scientist. Fourth, there are no fishing surveys information to provide direct knowledge of the stocks and biological parameters are unknown. Regarding discards, , the information is poorer, only known by the observer programs (EU fleets), although it is known that discards are an important part of the catches in most fleets.

One strict limitation in the Spanish fleet under study, concerning the researchers, is that logbooks are not much valuable from a scientific perspective. Trip information is aggregated by fishing day, where each daily set is not differentiated or geo-referenced separately. Also, as in many other fisheries there is no information of discards in logbooks. Fortunately, an on-board sampling programme is currently ongoing in this fresh fleet to obtain direct geo-referenced information on commercial and discarded [20](García-Isarch *et al.*, 2019). Also, other relevant information regarding fishing techniques, environmental data, skipper skills and vessel characteristics is recorded as well. Setting up this observer programme faced several technical and economic problems that have affected its continuity. However, a very consistent set of data on discards has been analysed from 2016. Until now, information on discards of Spanish fisheries in the area has been presented within the DCF framework but has yet to be fully exploited. However, it is of paramount importance for the assessment of marketed species, for the analysis of the impact on biodiversity of different fisheries, and in order to comply with EU requirements for quantification of discards to improve management measures for regulating catches by TACs [8](EU, 2013).

Several studies have analysed the components affecting discarding practices in trawling fisheries [21], [22], [23], [24], [25], [26](Mahévas *et al.*. 2004; Carbonell *et al.*., 2017; Vilela, 2015; Rochet *et al.*, 2005; Da-Rocha *et al.*., 2018; Feekings *et al.*, 2012), and some studies also distinguish and quantify catchability components in these types of fisheries, which affect both targeted and bycatch species [27], [28], [29], [30], [31], [32](Mahévas *et al.*., 2011; Mamouridis *et al.*., 2013; Pennino *et al.*., 2014; Gascuel *et al.*, 1993; Gavaris,1980; Marchal *et al.*., 2003).

This study describes the main effects on discards variability in relation to abundance covariates and technical characteristics of the fleet, identifies two different métiers within the fresh trawl Spanish fleet [33](Castro, 2012), and examines the strategy of the skipper. We also define a global DPUE and propose a method of DPUE standardisation for the Spanish fresh trawling fleet in north-west African waters, based on the explicit distinction between abundance and technical factors that affect variations in discarding rates. The proposed method is applied to the detailed data gathered by observers on-board commercial trawlers targeting black hakes, in surveys from 2016 to 2018. Obtaining standardized global DPUE trends in this study is a first step previous to elaborate detailed and comparable DPUE by species, once we have established the main factors affecting global discards. Finally, through this study we would like to emphasize that, at least from the scientific point of view, is essential and feasible to register the daily information by set in logbooks instead of information aggregated by day. So total discards could be estimated with extrapolation techniques from observers surveys.

2. Materials and methods

2.1. Observer data

Data from 606 hauls along 31 surveys of one-week each were analyzed in Mauritanian and in Moroccan waters (Western Sahara) (Figure 1), at latitudes between 17°-24° N from January 2016 to December 2018 (Table 1). Hauls were performed at depths comprised between 93 and 815 m. The surveys encompassed the spatial-temporal distribution of the Spanish fresh trawling fleet in north-west African waters. Observers surveys covered the 16% of the activity of the whole fleet during the period 2016-2018.

Vessel characteristics were similar and no detailed information on their characteristics (i.e. mesh, shape and material of the net) was used. Data was explored graphically using ggplot2 package in R (Wickham, 2016), and we tried to analyse the personal skipper preferences and skills, considered as part of the causes affecting discards (Kelleher *et al*.., 2005). Since our knowledge about fishing techniques is limited and not quantified at this stage, the skipper factor masks a variety of variables relating to the fishing power of the vessel and, in particular, selectivity of the gear. We analysed the relationships between space and time factors and the skipper through interaction plots, in order to visualise the possible fishing strategies of each skipper and their effects on discards.

Table 2 describes the general information recorded for each haul and classified in groups of information related to abundance, environment, efficiency and strategy of the skipper. We considered the route as a covariate related to the dominant currents in the area (Ramos *et al*.., 2017). Hauls carried out between 6:00 and 15:59 were considered daylight hauls; between 16:00 and 18:59 evening hauls; and between 19:00 and 4:59 night-time hauls.

2.2. DPUE model

In the absence of oceanographic fishing surveys, commercial catch and effort data are the alternatives for estimating abundance indices. In multispecies fleets, different approaches have been applied to deal with the impossibility of splitting the effort by species (Soto *et al*.., 2009). Discarding rates are an example of this issue and have been discussed in several studies (Pérez Roda *et al*.., 2019; Uhlmann *et al*.., 2013; Carbonell *et al*., 2017). At this initial stage, we are interested in the estimation of the trend of the total discard. Hence, this study deals with populations of total discards as a stock unit (Restrepo,2000), interpreted as a term susceptible of being monitored, managed and assessed, and it is considered as a group of populations with similar spatial geographical limits affected by the Spanish fresh trawl fishery. Discarded catches are defined by aggregating the total catches of all species discarded by haul. A suitable model for DPUE is:

$$D/E = qN \quad (1)$$

where q denotes the catchability coefficient, and N the total abundance of the discarded population (Mahévas *et al*., 2004). Therefore, two vessels fishing at the same time in the same area and with the same nominal fishing effort can have different discarding rates due to variations in catchability and/or abundance (Beverton and Holt, 1957) of the global discard. One of the definitions of catchability is the probability of a fish being caught by one unit of effort (Marchal *et al..*, 2003). (2)

In the Spanish trawl fishery, fishing effort is traditionally measured in number of fishing days. Nevertheless, set duration has been calculated from observer data to define a nominal measure of effort for the trawl fishery. This measure is a more accurate representation of fishing mortality, as the set durations positively related to the area swept by the net. When a trawl vessel increases its total time available for fishing, it will take more fish per set (Hilborn and Walter, 1992). Nominal observed total DPUE (kg/h) was calculated for each haul as follows:

$$DPUE_i = \frac{totaldiscard_i}{setduration_i}$$

where *i* refers to haul *i*.
Space-temporal heterogeneity in distribution of discards, and changes in efficiency of the fleet result in DPUE data that are not proportional to the total discarded population, and hence equation (1) is not met. To approximate the equality, we fitted a model to the DPUE data that will be used as the discard abundance index, taking into account the changes in factors related to abundance and efficiency.

2.3. Model selection

To identify the main effects on DPUE trends, we fitted separate models to each of the four groups of covariates in Table 2 to make a preliminary selection of the significant factors and interactions. Then, by gradually nesting the covariate groups, we observed the sequential contribution of each of them to the explained deviance of DPUE variability. Month factor captures the seasonality in the discards. Total allowable catch (TAC) on hake fisheries usually reach the limit at the end of the year. The TAC is therefore related to the fishing strategy, which involves both the choices made by the skipper between Moroccan and Mauritanian waters (ground), and the target species(hake or other species). A numerical variable was defined to consider this fact. The TAC for the Spanish trawl fishery was established at 6000 tons of annual total catch in Mauritanian waters during the study period. For sequential hauls, cumulative catch throughout the year was therefore introduced as a continuous variable to explain decisions taken by the skipper and mainly related to target species. Vessel power was considered in two ways: first, through the technical characteristics of vessels, such as HP and GRT; and second, through the vessel factor instead of vessel characteristics. In this case, vessel encompasses all the encrypted technical information not available at this stage. Haul order is important during the survey, since the decisions about targeting hake or mixed species could affect the discarding rate and therefore, it was included as a numerical covariate in the DPUE model. Regarding the environment, previous studies (Meiners, 2010) had shown cross-correlation between catch per unit of effort (CPUE) of black hake and North Atlantic Oscillation (NAO) index three years before, over a 40-year study period. In our case, the relationship between discards and the NAO index was explored to determine the possible influences on the time interval between 2016 and 2018. Finally, we assessed the contribution of DPUE variability due to the skipper as a random effect, in order to take into account the changes in inter-skipper efficiency that varied randomly. We intended to ascertain the extent of the skipper effect on discards, though we were not interested in knowing the exact nature of this effect. We assume that the variation around the intercept, for each skipper, is normally distributed with a certain variance (Feekings *et al..*, 2012).

Hence, variation in discarding rates was investigated through the most common models, Generalised Linear Models (GLMs) (McCullagh and Nelder, 1989) in R (R Core Team, 2014), Generalised Linear Mixed Models (GLMMs) (Pineiro and Bates, 2000) and through Generalised Additive Models (GAM) (Hastie and Tibshirani, 1990).
Visualisation of histogram, previous QQ-plots and goodness-of-fit tests, Kolmogorov–Smirnov and Chi-squared (Draper and Smith, 1981) were performed to select the best fit for DPUE distribution.
First, the GLM method (McCullagh and Nelder, 1989) was applied with log-normal error distribution of DPUE , to determine the set of systematic factors and interactions that significantly explained the observed variability in each model, based on the Akaike Information Criterion (AIC) (Akaike, 1974). A Chi-squared test was used to evaluate the statistical significance of an additional factor between the set of systematic factors and the interactions (McCullagh and Nelder 1989). Furthermore, the

corresponding percentage of deviance explained by each factor relative to the maximum model was estimated to obtain a profile of the most important explanatory factors in the model (Mamouridis *et al.*, 2013). A statistically significant variable may, in some instances, be omitted from the model if the amount of variation explained by the variable is small in relation to the complexity that it adds (Stefánsson, 1996). After fixed factors were assessed, skipper was tested as a random effect in the form:

$$\log DPUE_i = \alpha + \sum_{j=1}^{n} \beta_j \cdot x_{ij} + random\ factor(1|skipper_i) + \varepsilon_{ij}\ ,\ \varepsilon_{ij} \sim N\left(0, \sigma_{ij}^2\right)$$

where $\beta_j$are the linear effects of the fixed factors for all hauls, $i = 1, \ldots, 608$.

2.4. DPUE abundance index

Year effect is interpreted as a relative index of abundance of DPUE. The relative abundance DPUE index was obtained as the least squares means(LSM) of the year effect in the GLM (Littell *et al.*, 2006), using the lsmeans package in R (Lenth, 2016). In unbalanced, multi-way designs, the LSM estimation is often assumed to be closer to reality, as if the data were balanced, because LSM somehow correct the design's imbalance. LSM are computed based on the linear model, and the variance of the index is estimated from the LSM standard deviations. Model evaluation and diagnosis were carried out through residual analysis (McCullagh and Nelder, 1989).

3. Results

3.1. Observer data

Global discards

Global averaged discard in the sampled hauls during 2016 to 2018 accounted for the 39% of total catches in surveys. By year, this percentage varied from 43% en 2016, 39%in 2017 and 32% in 2018.

Métier definition

Exploratory analysis confirms the presence of two separated métiers of the Spanish fresh trawling fleet. Along the period 2016-2018, 87% of the hauls targeted hake, while the remainder targeted a mix of several other species. Average haul duration was 4.8 hours and varied between 1 and 9 hours. The haul bathymetric distribution showed two main fishing groups (Figure 2). The first group corresponded to the shallowest hauls (<300 m), that were done in Mauritanian waters only during daytime. The second group corresponded to the deepest hauls (>300 m) done in Morocco and Mauritania throughout the whole day. The coral reef between 400 and 500 m appeared as a boundary. In shallower waters, the predominant catches consisted of mixed species.
Distributions of total catches of discards, hake and other species by depth are shown in (Figure 3). Discards were higher and more dispersed in shallow than in deeper waters, exactly the opposite to hake. A small fraction of hake catches was captured up to 300 m, where a mix of species other than hake predominated. These results showed that depth determines the type of fishing strategy and, indeed, generates two different métiers for the Spanish trawling fleet. Hence, we established two alternative strategies (metiers) for the trawling fleet, based on target species and depth:

$$\text{target} = \begin{cases} \text{hake} & \text{hauls} < 300\text{ m depth} \\ \text{other species} & \text{hauls} \geq 300\text{ m depth} \end{cases}$$

The distribution of the log-transformed discard rates showed different patterns by target species (Figure 4, left panel). Hauls targeting hake, and hauls targeting other species appeared to come from two different probability distributions according to the histogram patterns. Hence, the evidence of two métiers indicates that discard analysis must be made separately accordingly to this classification. Clear differences were also observed in all the covariates by target, validating the evidence of two métiers. Once this classification of total observer data was assumed, we focused our analysis to model a robust relative abundance discard index of the Spanish trawl fishery in the hake métier.

Total discards for the hake métier were always greater than zero, so DPUE had a positive distribution. The histograms, QQ-plots and Kolmogorov test showed that the best distribution followed by the DPUE is lognormal (Figure 4, right).

Abundance and environmental covariates revealed systematic inter- and intra-métier differences in DPUE (Figure 5). Significant differences in the year, month, ground and depth affected changes in DPUE, as did latitude. Despite the apparent nonlinear relationship between the average monthly NAO index and the DPUE, this covariate was not considered in the standardisation model, due to the short study period of discard rates, which limited the interpretation of results. Further analysis are needed for a extended period to investigate effects of the environment on discards.

The fishing strategy factors also reveal differences by métier. Mixed species are only caught during daytime and, in general, show higher associated discard rates than hake.

To explore the vessel effect we consider by one side, the vessel technical characteristics of the fleet, HP and GRT and, alternatively, only the vessel instead its own characteristics. DPUE is always lower when the target species is hake, independently of the vessel, the HP levels or the GRT values. Also, differences by HP, GRT or vessel are not significant in the hake métier. On the contrary, these differences are more evident when target species is not hake (mixed). One particular vessel showed less and similar discards rates in both métiers than the other vessels. In fact, this particular vessel had the highest values of HP and GRT. This could mean that the effect of the vessel or the technical characteristics are not as important as the skipper effect, i.e. the skipper who worked in the best vessel had the lower discard rates. Another conclusion could be that the best vessel also has the best skipper combining the best technology with the best fishing practices.

Skipper effect

Figure 6 confirm that the most efficient skipper (s3) minimised discard rate in both métiers. As skipper interactions with abundance, efficiency and fishing strategy were unbalanced due to lack of data in several of all the possible combination of covariates, they were investigated through interaction plots (Figure 7) or contingency tables (not presented). The most efficient skipper fished in deeper waters than the others, clearly reaching the minimum discard rates in Mauritanian waters, followed the south-east route and operated between evening and night hours.

3.2. Model selection for DPUE

Robust GLM models were fitted to selected data excluding outliers. A abundance covariates effects on the logarithm of DPUE of the GLM abundance model are shown in Figure 8. Discards were less abundant in the deepest waters, and DPUE increased with latitude, which was consistent with the observed increase in nominal DPUE in Moroccan waters. Annual discarding rates fell sharply from 2016 to 2018. Month effect captures both the seasonality and a global decreasing trend throughout the year, confirming the decline of discards at the end of the year, when the hake spawning season begins and the fishery moves in search of adults in deeper waters. After a exploratory model of abundance effects was fitted, the remaining separated groups of effects were examined. After selection of covariates in each group, nested effects and interactions were fitted (Table 3). Values of the percentage of explained deviance, AIC and BIC (Bayesian Information Criterion) (Schwarz, 1978) were calculated by group of effects and the absolute difference between AIC and BIC. Not all models were nested because of the interactions. Therefore, predictive power and significance of covariates were tested according to more than one criterion, apart from the principle of parsimony. There is always a chance that the AIC will choose a model that is too big, regardless of the number of observations. The BIC has very little chance of choosing too big a model if the sample is sufficient, but it has a greater chance than AIC of choosing too small a model.

There were no differences between the two alternative models of efficiency, since vessel factors alone explained as much as vessel characteristics. Variability in efficiency was better explained by GRT than by HP.

The NAO index modelled by the GAM with a Gaussian response is too short to assess fluctuations or seasonality in DPUE, or to explore time series correlation across different lags. However, it does explain 7.36% of the deviance in DPUE. The significance of the smooth term evidenced that a smooth curve was needed compared with a linear, but at this stage, we do not consider environment for standardisation through this variable due to the short period considered in this study.

The selected covariates of each effect were summarised in Table 6. Once the selection of covariates in the separated groups of abundance, efficiency and strategy were investigated, stepwise models were fitted starting with the abundance covariates, followed by terms of efficiency, strategy and interactions.

Table 4 shows the full model with all possible selected covariates and interactions. The statistically significant covariates at 95% confidence level included in the log-normal model fitted to hauls of the hake métier were year, month, ground, latitude at the end of the haul, depth, route and the interaction month:ground and ground:log(cumulative catches). This model explained 58.60% of total deviance in DPUE data. Besides the statistical significance of covariates, we considered a covariate candidate to be included in the final standardisation model if it captured more than 5% of the deviance explained by the model. This is the case only for abundance covariates **year, month, ground** and **depth**. These four covariates account for 82% of the total deviance explained by the model. Hence, for standardisation purposes and future improvements in the collection of data and statistics, we considered that with information about these four covariates is possible to provide admissible DPUE standarised index.
After selection of fixed effects, we nested the skipper covariate as a random effect. Inter-skipper variability explained 41% of the total variance. This variability represents the existing differences in the efficiency between a combination of gear characteristics and skipper skills, which is hard to quantify. Both AIC and BIC chose the simplest model of fixed effects to predict DPUE rates as the best candidate.
Diagnostic plots (Figure 9) show that the hypothesis of error distributions in the final selected model is acceptable, as there were no trends in residuals and no significant deviations from normality.

3.4. The index

The final DPUE standardised index (Figure 13) presented a clearly decreasing trend in DPUE abundance in the short period considered. Nominal DPUE was underestimated during this period compared with the standardised, but was very similar in 2018. Nominal DPUE laid under the lower confidence interval of the standardised DPUE.

4. Discussion

This study remarks the condition of DLS of a particular fishery in North West Africa, as it has been addressed in a recent study (García-Isarch, E. 2016). While current landing discards obligation (Regulation EU 1380/2013), does not affect directly to EU fleets under non-EU jurisdiction the European Commission is making efforts on their monitoring at the most global extension in EU and non-EU waters (STECF, 2016). Furthermore, in North West African waters discards are not managed in this area by local countries.

The assessment of global marine fisheries discards in nowadays progressing, taking advantage of available data and promoting studies focused in quantifying discards and standardizing sampling protocols (Pérez Da Roda, 2019). In this frame, it has been undertaken the task of quantify discards in the Spanish fresh trawler fleet operating in NW Africa, a fishery dealing with serious limitations of data but with a challenging potential to lead improvements in the assessment framework for African stocks. In particular, this fleet target mainly black hakes, *Merluccius polli* and *M. senegalensis*, composing the vast majority of the retained catch and a portion of discards.

From a total of 260 stocks assessed by ICES, 60% are considered DLS (ICES, 2012a). It would be desirable to extend this classification to stocks exploited by EU fleets under SPFAs, considering the particularities of these fisheries. Under DLS, target stocks from SPFAs have a particular identity, mainly because EU fleets operates under the sovereignty and jurisdiction of third countries, which assess the stocks attending to political boundaries (Fernández Peralta et al. 2019; CECAF, 2018) instead of real stock identification.

Stock assessments of DLS in African countries are limited by SPFAs discontinuities and methodological issues. Nevertheless, significant improvements in the sampling programs of the Spanish fleets can be achieved. Although Spanish fisheries administration collect logbook catch information from national fleets, discard data are only recorded from observer programs on-board, managed by scientific national organisms (Spanish Oceanographic Institute and AZTI). Logbooks catch data are aggregated and recorded daily, without specifying the correspondent to each fishing operation. Furthermore, no information on discard volume is recorded in logbooks. From a scientific point of view it is desirable to expand the data gathered in logbooks to each fishing operation as well as include an estimation of total discard volume per haul. This study shows the usefulness of on-board observer data in identifying factors and their relative effect on discards, as well as its composition. Such data provide quantitative discard information, essential to establish priorities in the global management of discard practices, and are a first step in the ecosystem approach (Bellido *et al*., 2011), aimed at maintaining sustainable levels of catches on target species, while keeping discards under control. Unfortunately, the discontinuity and vulnerability of observer programs threaten the continuity of annual updates of discards statistics, including estimation of DPUE.

This study describes the main effects on discards variability in relation to abundance covariates and technical characteristics of the fleet, identifies two different métiers within the fresh trawl Spanish fleet, and examines the strategy of the skipper. Also a global DPUE is defined and standarized for the Spanish fresh trawling fleet in north-west African waters, based on the explicit distinction between abundance and technical factors that affect variations in discarding rates. Standardized global DPUE trend is a first step previous to elaborate detailed and comparable DPUE by species, once the main factors affecting global discards have been established.

Métier

Two métiers were identified and defined in the Spanish fresh trawl fishery: one targeting 'hake' (>300 m) and other targeting 'mixed species' (<300 m). As in other studies for metier identification (Castro, 2012), multivariate techniques (PCA) have been used to validate this result in species composition of discards. Haul data (geo-referenced and by bathymetric levels) were essential to conclude that depth is the most important spatial variable determining the amount of discards and clearly defining two métiers with different fishing strategies in this fishery. This point should be considered in the compilation of fisheries statistics, assessment and management, not only for black hake fishery landings, but also for total catches (Vilela and Bellido, 2013; European Parliament Plenary, 2013).

Effects on discards

This study shows that time-area related factors affecting catchability are the most important to explain variations in discard rates. A marked seasonality characterizes this fishery, associated with the spawning season of the black hakes (Fernández-Peralta et al., 2011). In this season, the fleet mainly targets the biggest female spawners at deeper waters, where discards usually are lower. Accordingly, a decreasing DPUE trend throughout the beginning of the spawning season has been observed (October-December). Other factors affecting discards are not considered here, such as the distribution of the consumption of the legal quota per vessel; other market decisions or regulations; and whether or not the fish is damaged (Feekings *et al*.., 2012).

Using the vessel itself as a covariate in model instead of vessel characteristics is preferred here for assessing the efficiency components of catchability because its simplicity. Despite scant data on detailed vessel and gear characteristics of the Spanish trawl fleet, this result is consistent with similar studies on hake trawler fleets (Mahévas *et al*.., 2004, 2011). Hence, differences in the catch rates could be more related to gear selectivity and to the specific fishing skills of the skipper, responding to his strategy in the long term or to the tactic in the short term (Marchal *et al*.., 2006).

The most efficient skipper developed throughout 2018 an efficient strategy which visibly reduced discards in both metiers in Mauritania. Future research should be carried out on 'how' skippers operate in order to thoroughly identify the features of a sustainable fishing strategy (gear setting, selection of materials, fishing operations, boat dynamics and vulnerability of the species to the gear).

Several studies have attempted to model DPUE using a multitude of covariates related to abundance and efficiency (Carbonell *et al*.., 2017; Mahévas, *et* al. 2004; 2011). In this study, the causes of discarding have been investigated, but also tried to simplify the task of predicting discards in a pragmatic way, taking into account the data poor conditions of the fishery. Some simple but extended information from commercial trips would allow estimating a reliable discard statistics but also relative abundance index of discards for the whole fleet. Adding data on *depth* and *total discard estimation* at fishing operation level in logbooks can offer significant estimations of relative discard rates. Hence, from the management point of view, regulations of fishing seasons, grounds and depths could reduce discards in the short term in a very effective way.

The index

Results showed an apparent decrease of discards between 2016 and 2018. However, a reduction in the discard rates of this fleet in such a short period of years can be interpreted in different ways: *i)* the abundance of the whole stock is declining, and therefore overfishing consequences are emerging; *ii)* on the contrary, good fishing practices are being implemented, resulting in an effective reduction of discards and *iii)* a combination of these two facts. This conclusion is based on results obtained from on-board observer data and not on the complete data set of Spanish fresh trawling fleet hauls. In one hand, observed decreasing trend in discards in this period matches with black hake nominal CPUE trend in these years (Fernández-Peralta, 2019), supporting the first option. Nevertheless, discard reduction in 2018 due to a particular skipper skill and ability, evidenced the second choice. Thus, a combination of both does occur, although further analysis would be necessary to draw a definite picture of which are the main effects driving discard trends.

The surveys

The synergy between ship-owners, skippers, observers and scientists has indeed facilitated this study. Unfortunately, designing an optimal survey for scientists is not always possible. Currently, several issues (mainly ship-owner cooperation and vessels habitability) determine the availability of commercial vessels for sampling. In 2018, surveys were performed only on-board one single vessel (and same skipper) and therefore sampling was necessary biased. That said, the information gathered from this year, skipper and vessel has been extremely valuable for improving our knowledge about the nature and causes of discards, the distribution of effort in the fleet, and how the trawling fleet could succeed in reducing them in the future.

Future research

This initial analysis of discard should be complemented by further studies, extending to other related perspectives. Once a global index of discards has been calculated as proposed here, multi-specific indices of abundance can be derived from multinomial or delta GLM approaches, based on information of specific proportions of catches for each species (Soto, 2009). Another important forward step is to extrapolate rates of discards to the whole fresh trawling fleet. Also, other fleets discards would be characterized through simulation techniques, as suggested (García-Isarch, 2016) in the estimation of surplus for SPFAs fleets in North West Africa or be included as percentage of misreporting catches in assessment production models as SPICT (Pedersen and Casper, 2017).

Summarizing, a more precise and conclusive discard estimation would be achieved when different sources of information concurred. Two basic lines for improvement have been highlighted here: first, observer information should ideally cover a broader range of trips, sampling all the vessels in the fleet with the commitment of all skippers and owners; and second, a more efficient template should be designed to collect geo-referenced logbook information by set, recording the time of day, duration and the corresponding depth of the each fishing operation. At this stage, skippers should be disturbed as little as possible when registering information haul by haul. These improvements have minimum economic costs, but would lead to a better quantification of discards, a global index of discards for the whole fleet, and a better assessment for the management of the target and discarded populations.

6. References

Akaike, H. (1974). A new look at the statistical model identification. IEEE Transactions on Automatic Control, 19(6), pp. 716-723.

Aldorriz, N., Jardim, E., Poos, J. J. Likely status and changes in the main economic and fishery indicators under the landing obligation: A case study of the Basque trawl fishery. Fisheries Research 2018, 205: 86-95.

Arreguín-Sánchez, F. (1996). Catchability: a key parameter for fish stock assessment. Reviews in Fish Biology and Fisheries, 6(2), pp. 221-242.

Bellido, J.M.ª and Pérez, N. (2007). A new optimal allocation sampling design to improve estimates and precision levels of discards from two different Fishery Units of Spanish trawlers in northeast Atlantic waters (ICES subareas VIIc, j, k). Bol. Inst. Esp. Oceanogr. 23 (1-4). 2007. pp. 73-83.

Bellido, J., Santos, M., Pennino, M.G., Valeiras, J. and Pierce, G. (2011). Fishery discards and bycatch: Solutions for an ecosystem approach to fisheries management? Hydrobiologia. 670. pp. 317-333. DOI: 10.1007/s10750-011-0721-5.

Beverton, R.J.H. and Holt, S.J. (1957). On the dynamics of exploited fish populations. Fisheries Investigations, 19, pp. 1-533.

Bouzouma M., Cervantes, A. and Roux, O. (eds.) 2018. Rapport de la Réunion annuelle du Comité Scientifique Conjoint relatif à l'Accord de pêche signé entre la République islamique de Mauritanie et l'Union européenne. Nouakchott, Mauritanie, 18 au 21 septembre 2018. Rapports des Comités Scientifiques Conjoints. Bruxelles, 94 pp. https://ec.europa.eu/fisheries/documentation/studies/report-2018-meeting-joint-scientific-committee-eu-mauritania-fisheries_fr

Campbell, R. A. (2004). CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fisheries Research, 70(2-3), pp. 209-227. DOI:10.1016/j.fishres.2004.08.026.

Carbonell, A., García, T., González, M., Alvarez-Berastegui, D., Mallol Martínez, S., Serna-Quintero, J., Bultó, C., Bellido, J., Barcala, E. and Baro, J. (2017). Modeling trawling discards of the Alboran fisheries in the Mediterranean Sea. Regional Studies in Marine Science. DOI: 10.1016/j.rsma.2017.11.010.

Castro, J., Marín, M., Pérez, N., Pierce, G. and Punzón, A. (2012). Identification of métiers based on economic and biological data: The Spanish bottom otter trawl fleet operating in non-Iberian European waters. Fisheries Research, 125-126, pp. 77-86.

Catchpole, T. L., & Gray, T. S. (2010). Reducing discards of fish at sea: a review of European pilot projects. Journal of Environmental Management, 91(3), 717–723. https://doi.org/10.1016/j.jenvman.2009.09.035

Catchpole, T., Feekings, J., Madsen, N., Palialexis, A., Vassilopoulou, V., Valeiras, J., Garcia, T., Nikolic, N. and Rochet, M. (2013). Using inferred drivers of discarding behavior to evaluate discard mitigation measures. ICES Journal of Marine Science, 71(5), pp.1277-1285.

CECAF, 2018. Summary of the status of demmersal stocks in the northern area of the Eastern Central atlantic. Fishery Committe for the Eastern Central Atlantic. Scientific Sub-Committee Eighth Session.

Da-Rocha, J., García-Cutrín, J. and Gutiérrez, M. (2018). Mitigating unwanted catches in the southern Iberian hake stock fisheries: Improving fishing technology vs market control policies. Scientia Marina, 82(S1), pp. 63-74.

Draper, N. R., and Smith, H. (1981). Applied Regression Analysis, John Wiley and Sons. New York, 407.

Dunn, D., Boustany, A. and Halpin, P. (2011). Spatial-temporal management of fisheries to reduce by-catch and increase fishing selectivity. Fish and Fisheries. 12(1), pp. 110-119. DOI: 10.1111/j.1467-2979.2010.00388.x.

European Parliament Plenary. 2013. European Parliament legislative resolution of 6 February 2013 on the proposal for a regulation of the European Parliament and of the Council on the Common Fisheries Policy (COM(2011)0425 – C7-0198/2011 – 2011/0195(COD)) [online]. Available at: http://www.europarl.europa.eu/sides/ getDoc.do?pubRef=−//EP//TEXT+TA+P7-TA-2013-0040+0+DOC+XML+V0//EN.

FAO. (2018).Report of the FAO/CECAF Working Group on the Assessment of Demersal Resources – Subgroup North. Tenerife, Spain. CECAF/ECAF Series No. 18/78. Rome, FAO. Available at: http://www.fao.org/3/ca1003b/CA1003B.pdf

Feekings, J., Bartolino, V., Madsen, N., Catchpole, T. (2012) Fishery Discards: Factors Affecting Their Variability within a Demersal Trawl Fishery. PLoS ONE 7(4): e36409. doi:10.1371/journal.pone.0036409.

Fernandez-Peralta, L., Salmeron, F,. Rey, J, Puerto, M., García, R. (2011). Reproductive biology of black hakes (Merluccius polli and M. senegalensis) off Mauritania. Ciencias Marinas. 37. 527-546.DOI: 10.7773/cm.v37i4B.1841.

Fernández-Peralta, L., Quintanilla, L. F. and Rey, J. (2017). Overlapping distribution of two sympatric species: the case of black hakes, *Merluccius polli* Cadenat 1950 and *Merluccius senegalensis* Cadenat 1950, off Mauritania. In Deep-sea ecosystems off Mauritania: Researching marine biodiversity and habitats in West African deep. Ana Ramos, José Luis Sanz y Fran Ramil (Eds.). Chapter 6. Springer. 241-275 pp.

Fernández-Peralta, L., Bouzouma, M., Balguerías, E., Braham, C., Brahim, K., Corten A., Dia, M., García-Irsach, E., Habib, B., Licandro, P., des Clers, S., Röckmann, C. (2019). Rapport de la Réunion annuelle du Comité Scientifique Conjoint relatif à l'Accord de pêche signé entre la République islamique de Mauritanie et l'Union européenne Santa Cruz de Tenerife - 11 au 14 juin 2019.

Gascuel, D., Fonteneau, A., & Foucher, E. (1993). Analyse de l'évolution des puissances de pêche par l'analyse des cohortes : application aux senneurs exploitant l'albacore (Thunnus albacares) dans l'Atlantique Est. Aquatic Living Resources, 6(1), 15-30. DOI: 10.1051/alr:1993002.

García-Isarch, E., Gascuel, D., Guijarro, E., Gaertner, D., Merino, G., Coelho, R., Rosa, D., Murua, H., Wakeford, R., Jouffre, D., Figueiredo, I., and Abaunza, P. (2016). Scientific advice on the estimation of surplus for Sustainable Fisheries Partnership Agreements. Specific Contract No. 10 under Framework Contract No. MARE/2012/21. Final Report. April 2016. 133 pp.

García-Isarch, E., Clark, J., Fernández-Peralta, L., González-Lorenzo, G., Corten, A., Duque, V., Rey, J., Perales, C. and Sieto, S.(2019). Study on improvement for the analysis and exploitation of observers' reports in EU fisheries from NW African waters. Interim Report. Specific Contract No 12 of the Framework Contract EASME/EMFF/2016/008. July 2019, 106 p. + Annexes.

Gavaris, S. (1980). Use of a Multiplicative Model to Estimate Catch Rate and Effort from Commercial Data. Canadian Journal of Fisheries and Aquatic Sciences, 37(12), pp. 2272-2275.

Goodyear, C. and Ortiz, M. (2007). GLM CPUE standardizations: interpretation risks for model fits from alternative software packages. Col. Vol. Sci. Pap. ICCAT. 60, pp.1622-1629.

Hastie, T. and Tibshirani, R. (1999). Generalized additive models. Boca Raton, Fla.: Chapman & Hall/CRC.

Hilborn, R. (1990). Determination of Fish Movement Patterns from Tag Recoveries using Maximum Likelihood Estimators. Canadian Journal of Fisheries and Aquatic Sciences, 47(3), 635-643. DOI: 10.1139/f90-071

Hilborn, R. and Walters, C. (1992). Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty.

ICES Implementation of Advice for Data-limited Stocks in 2012 in its 2012 Advice. ICES CM 2012/ACOM 68. 42 pp.

ICES. 2012. Report of the Workshop on the Development of Assessments based on LIFE history traits and Exploitation Characteristics (WKLIFE), 13–17 February 2012, Lisbon, Portugal . ICES CM 2012/ACOM:36. 140 pp

Jardim, E., Giannoulaki, M., Pirounaki, M., Tsagarakis, K., Osio, G., Scott, F., Damalas, D. (2015). A4a short research project: Stock assessment to Hellenic Small Pelagic Stocks. EU27484 Luxembourg. Publications Office of the European Union. DOI: 10.2788/102281

Kelleher, K. (2005). Discards in the world's marine fisheries. An update. FAO Fisheries Technical Paper. No. 470. Roma: FAO.131 pp.

Lenth, R. (2016). Least-Squares Means: The R Package lsmeans. Journal of Statistical Software, 69(1), pp. 1-33.

Littell, R., Milliken, G., Stroup, W., Wolfinger, R. and Schabenberber, O. (2006). SAS for Mixed Models; Second Edition. SAS Institute.

Mahévas, S., Sandon, Y. and Biseau, A. (2004). Quantification of annual variations in fishing power due to vessel characteristics: an application to the bottom-trawlers of South-Brittany targeting anglerfish (Lophius budegassa and Lophius piscatorius). ICES Journal of Marine Science, 61(1), pp. 71-83.

Mahevas, S., Vermard, Y., Hutton, T., Iriondo, A., Jadaud, A., Maravelias, C., Punzon, A., Sacchi, J., Tidd, A., Tsitsika, E., Marchal, P., Goascoz, N., Mortreux, S. and Roos, D. (2011). An investigation of human vs. technology-induced variation in catchability for a selection of European fishing fleets. *ICES Journal of Marine Science*, 68(10), pp.2252-2263.

Mamouridis, V., Klein, N., Kneib, T., Cadarso, C. and Maynou, F. (2013). Extended Additive Regression for Analysing LPUE Indices in Fishery Research. Extended Additive Regression for Analysing LPUE Indices in Fishery Research. Vol. 29/10/2013 (2013-01).

Marchal, P., Ulrich, C., Korsbrekke, K., Pastoors, M. and Rackham, B. (2003). Annual trends in catchability and fish stock assessments. Scientia Marina, 67(S1), pp. 63-73. DOI:10.3989/scimar.2003.67s163.

Marchal P., Andersen B., Bromley D., Iriondo A., Mahévas S., Quirijns F., Rackham B., Santurtún M., Tien N., and Ulrich, C.(2006). Improving the definition of fishing effort for important European fleets by accounting for the skipper effect. Canadian Journal Fisheries and Aquatic Sciences, 63: 510–533.

McCullagh, P. and Nelder, J.A. (1989). Generalized linear models. Chapman & Hall, London, 512 pp.

Meiners, C., Fernández, L., Salmerón, F. and Ramos, A. (2010). Climate variability and fisheries of black hakes (Merluccius polli and Merluccius senegalensis) in NW Africa: A first approach. Journal of Marine Systems, 80(3-4), pp. 243-247.

Official Journal of the European Union. (2013).Protocol between the European Union and the Kingdom of Morocco setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Union and the Kingdom of Morocco.L328, 7.12.2013, p. 2–21. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22013A1207(01)&qid=1562932179877&from=EN.

Official Journal of the European Union. (2014). Agreement on a Sustainable fisheries Partnership between the European Union and The Republic of Senegal.L304, 23.10.2014, p. 3–40. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22014A1023(01)&qid=1562932054704&from=EN.

Official Journal of the European Union. (2015). Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Community and the Islamic Republic of Mauritania for a period of four years. L315, 1.12.2015, p. 3–71. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:22015A1201(01)&qid=1562932104286&from=EN.

Pedersen, M. and & Berg, C. (2017). A stochastic surplus production model in continuous time. Fish and Fisheries, 2017, 18, 226–243.

Pennino, M.G, Muñoz, F., Conesa, D., López-Quílez, A. and Bellido, J. (2014). Bayesian spatial-temporal discard model in a demersal trawl fishery. Journal of Sea Research, 90, pp. 44-53.
Pérez Roda, M.A. (ed.), Gilman, E., Huntington, T., Kennelly, S.J., Suuronen, P., Chaloupka, M. and Medley, P. 2019. A third assessment of global marine fisheries discards. FAO Fisheries and Aquaculture Technical Paper No. 633. Rome, FAO. 78 pp. Licence: CC BY-NC-SA 3.0 IGO.

Pérez Roda, M.A. (ed.), Gilman, E., Huntington, T., Kennelly, S.J., Suuronen, P., Chaloupka, M. and Medley, P. 2019. A third assessment of global marine fisheries discards. FAO Fisheries and Aquaculture Technical Paper No. 633. Rome, FAO. 78 pp.

Pinheiro, J. C. and Bates, D. M. (2000). Mixed-effects models in S and S-PLUS. New York, NY: Springer.

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Ramos, A., Ramil, F. and Sanz, J. (2017). Deep-Sea Ecosystems Off Mauritania: Research of Marine Biodiversity and Habitats in the Northwest African Margin. DOI: 10.1007/978-94-024-1023-5.

REGLAMENTO (UE) No 1380/2013 DEL PARLAMENTO EUROPEO Y DEL CONSEJO de 11 de diciembre de 2013 sobre la Política Pesquera Común, por el que se modifican los Reglamentos (CE) no 1954/2003 y (CE) no 1224/2009 del Consejo, y se derogan los Reglamentos (CE) no 2371/2002 y (CE) no 639/2004 del Consejo y la Decisión 2004/585/CE del Consejo.

REGULATION (EU) No 1380/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2013 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

Reports of the Scientific, Technical and Economic Committee for Fisheries (STECF) – 52 nd Plenary Meeting Report (PLEN-16-02). 2016. Publications Office of the European Union, Luxembourg, EUR XXXXXX EN, JRC XXXXXXX, 162 pp.

Restrepo, V. (2000). Glossary of Fishery Terms. International Commission for the Conservation of the Atlantic Tunas. [Online] Iccat.int. Available at: http://www.iccat.int/Documents/SCRS/Other/glossary.pdf.

Rey, J., Soto, M., García-Cancela, R., Salmerón, F. and Fernández, L. (2018, Jun).Analysis of discards in the Spanish black hake fishery in Mauritanian waters: impact in the biodiversity. Poster presented at International Symposium on Marine Sciences 2018. Vigo.

Rochet and, M.J., Trenkel, V.(2005). Factors for the variability of discards: assumptions and field evidence. Canadian Journal of Fisheries and Aquatic Sciences,62(1): 224-235. DOI: 10.1139/f04-185

Schwarz, G. (1978). Estimating the dimension of a model. The annals of statistics, 6(2), 461-464.

Sigurðardóttira, S., Stefánsdóttira, E., Condie, H., Margeirsson, S., Catchpole, T. L., Bellido, J. M., Goñif, S., Madsen, N., Palialexis, A., Uhlmann, S. S., Vassilopoulou, V., Feekings, J., Rochet, M-J. (2015). How can discards in European fisheries be mitigated? Strengths, weaknesses, opportunities and threats of potential mitigation methods. Marine Policy, (51), 366-374.
Soto, M. 2002. Estandarización de series de CPUE con S-Plus, http://www.ieo.es/

Soto, M., Delgado de Molina, A. and Chassot E. (2013). Standarised CPUE for juveniles yellowfin, skipjack and bigeye tuna from the EU PS fleet in the Indian Ocean from 1982 to 2011. IOTC-2013-WPTT15-23.

Soto, M., Pallarés, P., Delgado de Molina, A. and Gaertner, D. (2009). Standardized CPUE for juvenile yellowfin, skipjack and bigeye tuna from the EU PS fleet in the Atlantic Ocean from 1991 to 2006. Collect. Vol. Sci. Pap. ICCAT, 64(4), pp. 1044-1053.

Stefánsson, G. (1996). Analysis of groundfish survey abundance data: combining the GLM and delta approaches. ICES journal of Marine Science, 53(3), 577-588.

Stephens, A. and MacCall, A. (2004). A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fisheries Research, 70(2-3), pp. 299–310.

Team, R. C. (2014). R: A Language and Environment for Statistical Computing http://www. R-project. org.

Uhlmann, S., van Helmond, A., Kemp Stefánsdóttir, E., Sigurðardóttir, S., Haralabous, J., Bellido, J., Carbonell, A., Catchpole, T., Damalas, D., Fauconnet, L., Feekings, J., Garcia, T., Madsen, N., Mallold, S., Margeirsson, S., Palialexis, A., Readdy, L., Valeiras, J., Vassilopoulou, V. and Rochet, M. (2013). Discarded fish in European waters: general patterns and contrasts. ICES Journal of Marine Science, 71(5), pp.1235-1245.

Vilela, R. and Bellido, J. M. (2015). Fishing suitability maps: helping fishermen reduce discards. Can. J. Fish. Aquat. Sci. 72(8), pp. 1191-1201.

Wickham, H. (2016). *ggplot2:* Elegant Graphics for Data Analysis. Springer-Verlag, New York. ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

Table 1. Survey information

SURVEY	GROUND	YEAR	MONTH	% discard in survey	Depth (m)		number of hauls by depth		hauls sampled
					min	max	MIXED (<300 m)	HAKE (>300m)	
1	MOROCCO	2016	11	52%	595	725		8	3

2		2016	11	40%	506	756		18	8
3		2016	11	45%	502	763		21	10
4		2017	12	44%	446	740		17	7
5		2017	12	47%	558	789		13	6
6		2018	6	43%	476	779		18	10
7		2016	1	32%	104	725	2	17	8
8		2016	2	35%	334	815		15	6
9		2016	3	51%	102	712	12	14	10
10		2016	4	50%	112	688	11	13	10
11		2016	6	38%	112	766	6	14	8
12		2016	6	45%	121	697	7	16	9
13		2016	10	40%	112	735	3	17	7
14		2017	2	48%	98	697	8	18	12
15		2017	2	49%	106	727	9	18	14
16		2017	4	37%	502	787		20	9
17		2017	4	35%	493	725		23	12
18		2017	6	43%	106	707	3	19	10
19	MAURITANIA	2017	6	38%	478	740		23	11
20		2017	9	33%	115	744	2	20	8
21		2017	9	31%	132	725	2	14	6
22		2017	11	25%	521	725		18	8
23		2018	1	41%	225	768		18	6
24		2018	2	34%	93	697	5	16	9
25		2018	3	29%	100	787	8	12	9
26		2018	4	38%	231	763		23	11
27		2018	5	45%	651	800		15	7
28		2018	7	25%	362	732		21	4
29		2018	8	38%	304	690		16	3
30		2018	9	19%	407	770		18	7
31		2018	10	13%	409	781		15	6
					TOTAL HAULS		78	528	254

Table 2. Description of covariates for the Spanish trawl hake fishery in African waters

Variable	Unit	Number of levels/continuous	Related to
Year	From 2016 to 2018	3	Abundance
Month	From 1 to 12	12	Abundance

Ground	Morocco/Mauritania	2	Abundance
Latitude	17.04–23.74 m	1	Abundance
Depth*	110.5–824.5 m	1	Abundance
NAO	0.01, 0.10, 0.54	Continuous	Environment
Vessel	Vessel code	3	Efficiency
GRT	209, 405 tons	2	Efficiency
HP	480, 486, 490 CV	3	Efficiency
Skipper	Skipper code	5	Efficiency
Haul number	(integer from 1 to 27)	Continuous	Strategy
Target	Mixed or hake	2	Strategy
Day_Night	Day/evening/night	3	Strategy
Route	NE, NW, SE, SW	4	Strategy
Cumulative_catching survey	660–479861 kg	Continuous	Strategy
route	NE, NW, SE, SW	4	Strategy

* average value between depths at the initial and final latitudes of the trawl.

Table 3. AIC, BIC and percentage of deviance explained for log-normal models fitted to selected variables in each group. Best option is emboldened for each criteria.

Effect	%Deviance explained	AIC	BIC	|AIC-BIC|
Abundance	50.19%	593.39	669.25	**75.86**
Abundance+interactions	53.73%	582.51	713.16	130.65
Abundance+efficiency	50.59%	591.31	671.39	80.08
Abundance+efficiency+interactions	52.59%	568.63	**652.93**	84.29
Abundance+efficiency+Strategy	52.68%	577.84	678.99	101.15
Abundance+efficiency+Strategy +interactions	56.28%	**553.95**	684.61	130.65

Table 4. Deviance table for the log-normal model. Explanatory final covariates selected for standardisation are in bold.

DPUE

Model formulation	DF	Change in deviance	Residual deviance	*p*-value	Percentage of total deviance
1			179.19		
Covariates					
+**year**	2	42.71	136.48	<0.001	40.67%
+**month**	11	15.06	121.43	<0.001	14.34%
+**ground**	1	18.39	103.03	<0.001	17.51%
+lat.stop	1	4.23	98.81	<0.001	4.03%
+**depth.mean**	1	9.55	89.26	<0.001	9.09%
+vessel	1	0.72	88.53	0.034	0.69%
+haul	1	0.23	88.30	0.234	0.22%
+logcumcatch	1	0.62	87.68	0.050	0.59%
+route	3	3.21	84.47	<0.001	3.05%
Interactions					
+month:ground	1	3.95	80.53	<0.001	3.76%
+ground:lat.stop	1	0.71	79.82	0.036	0.68%
+month:depth.mean	11	1.44	78.37	0.631	1.37%
+ground:haul	1	0.35	78.03	0.143	0.33%
+ground:logcumcatch	1	2.63	75.40	<0.001	2.50%
+depth.mean:haul	1	0.08	75.32	0.476	0.08%
+depth.mean:logcumcatch	1	1.12	74.20	0.009	1.06%
+vessel:logcumcatch	2	0.02	74.18	0.929	0.02%

Figure 1. Hauls distribution map.

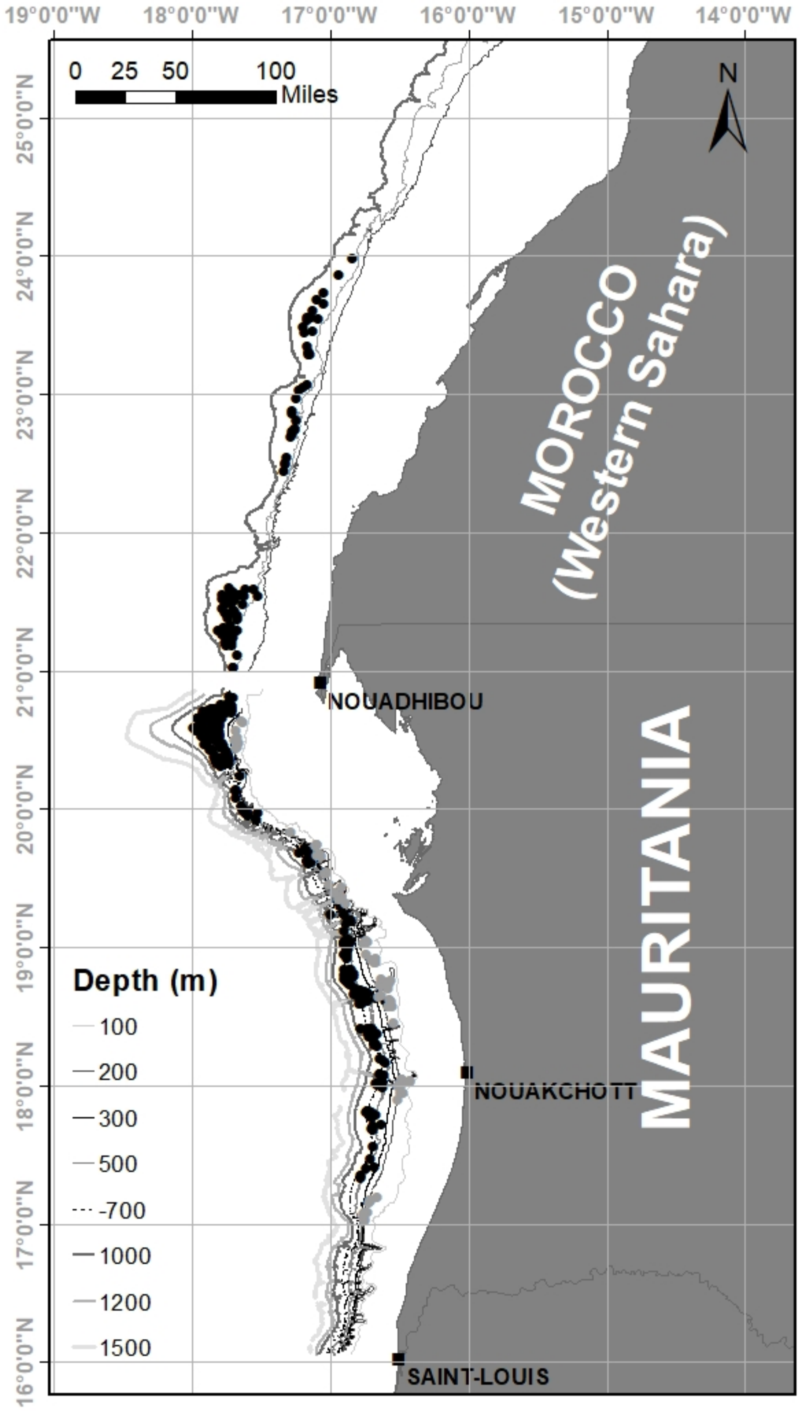

Figure 2. Proportion of hauls by depth .

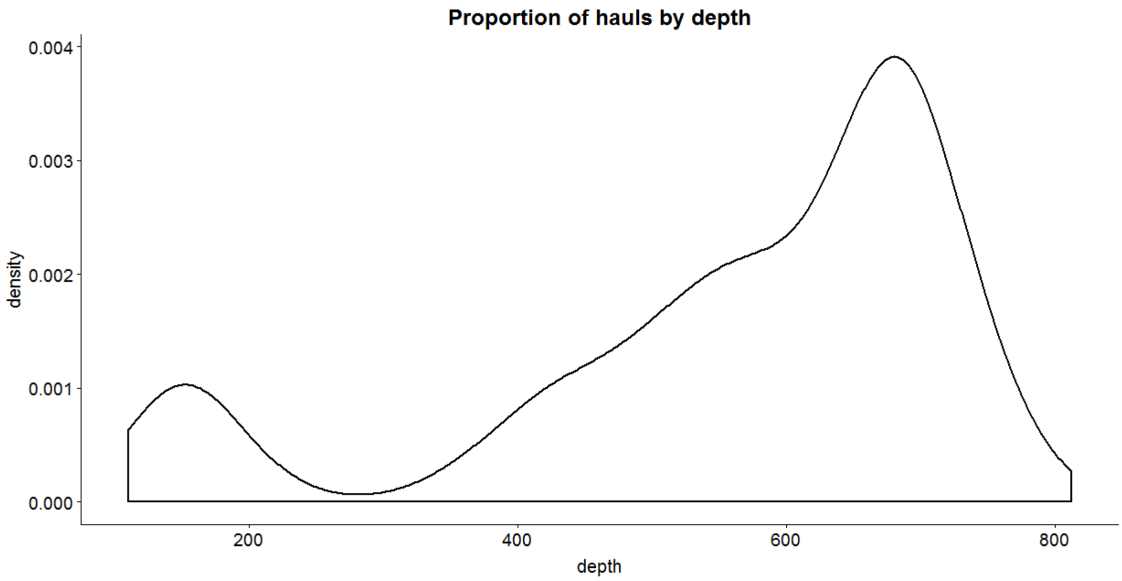

Figure 3. Discards, catches of hake and other species vs. depth.

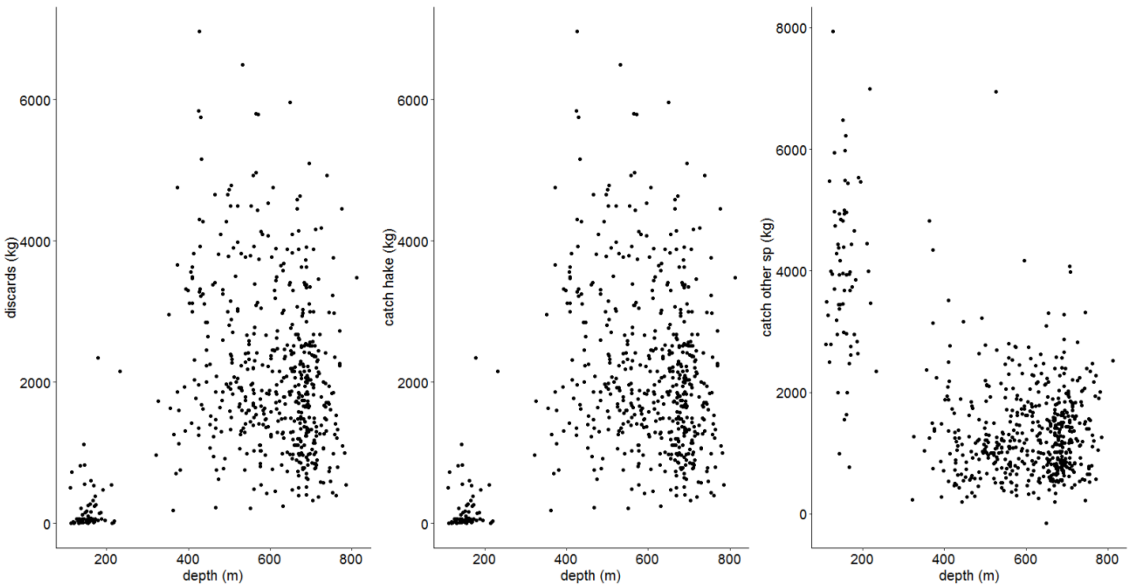

Figure 4. Histogram of log(DPUE) for hauls targeting hake compared with normal density (right panel) and histogram of log(DPUE) by target species (leftt panel).

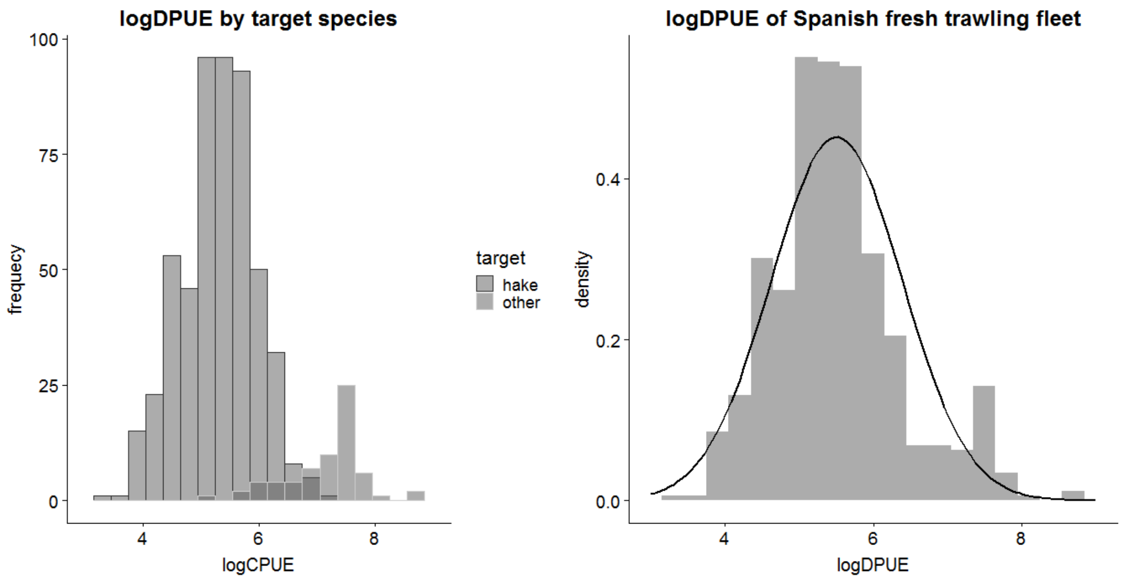

Figure 5. log(DPUE) vs. abundance covariates by target species.

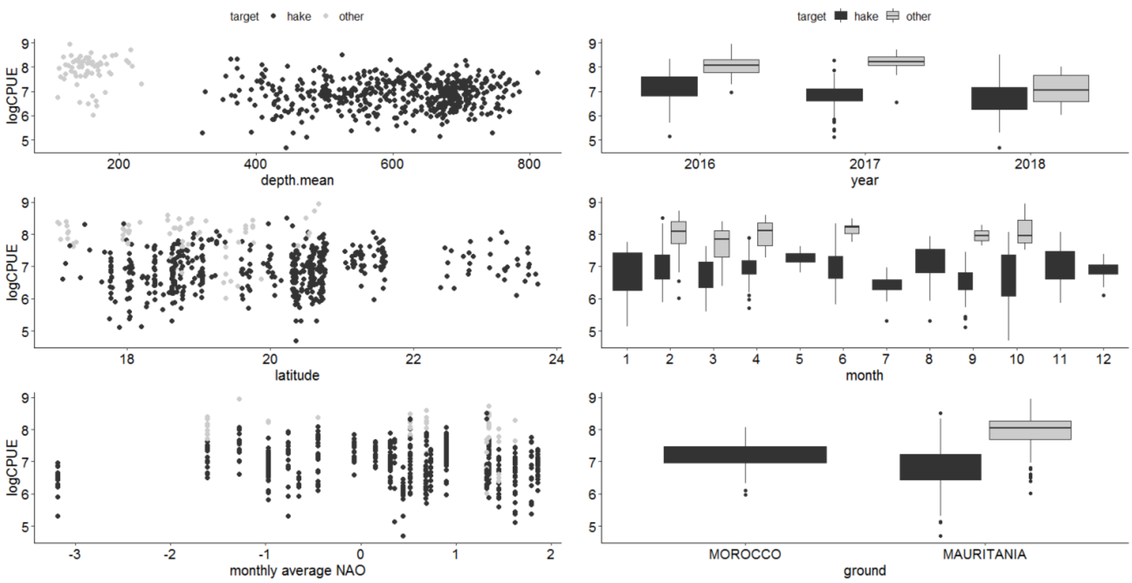

Figure 6. Discard rate by skipper and métier.

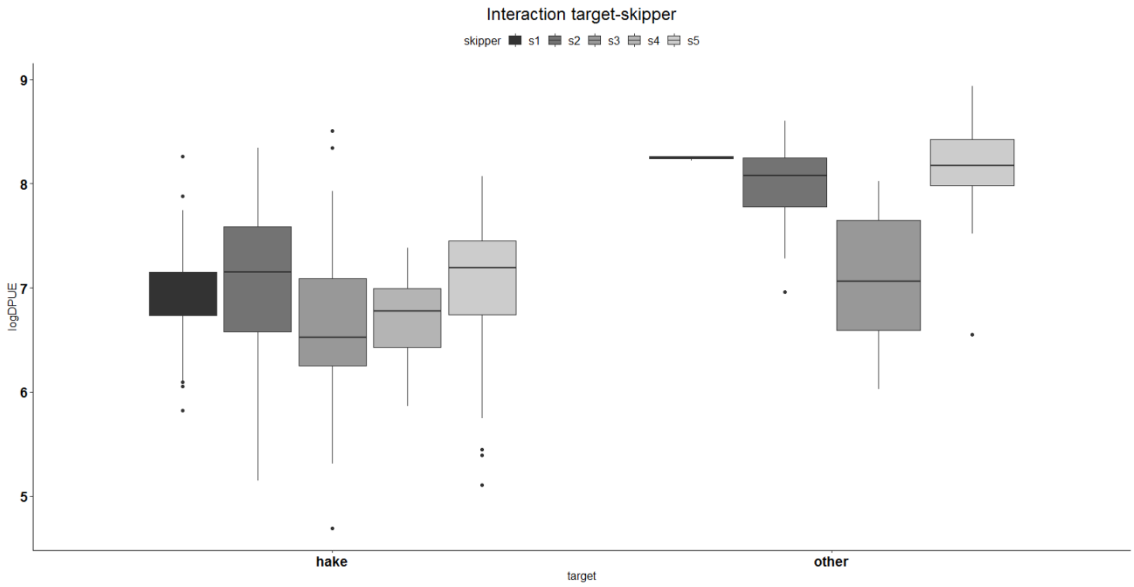

Figure 7. log(DPUE) for skipper interactions with ground, day-night, route and target species.

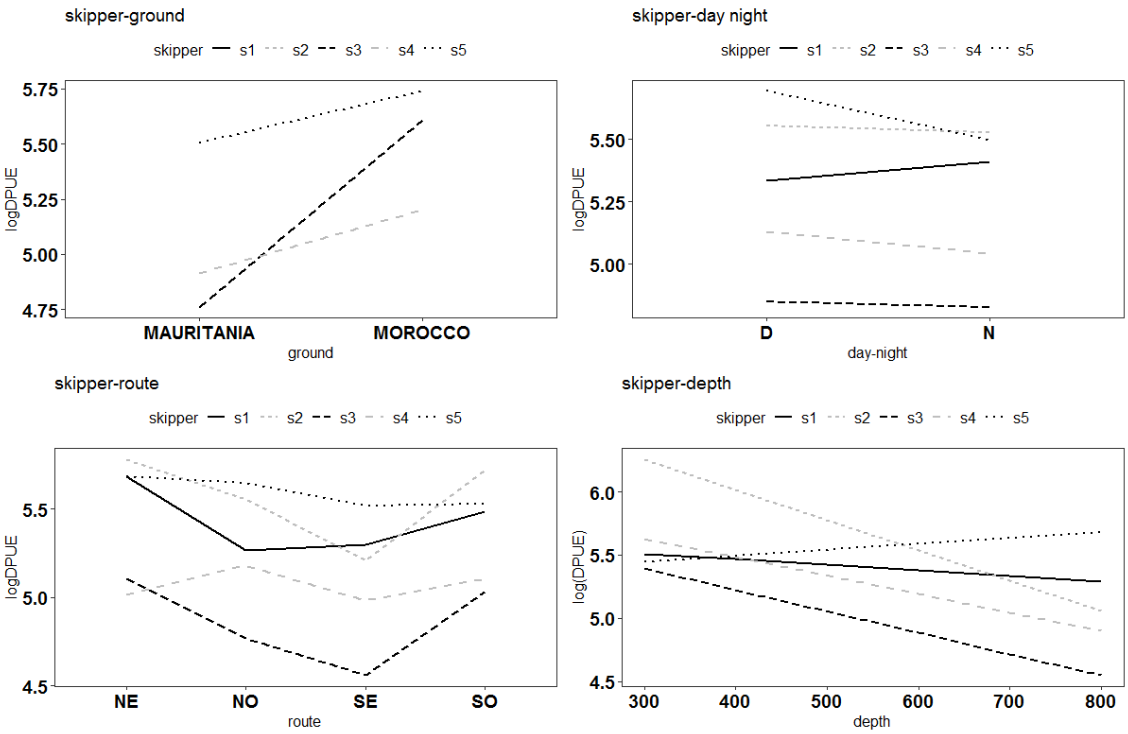

Figure 8. Effects of the GLM model fitted to abundance covariates.

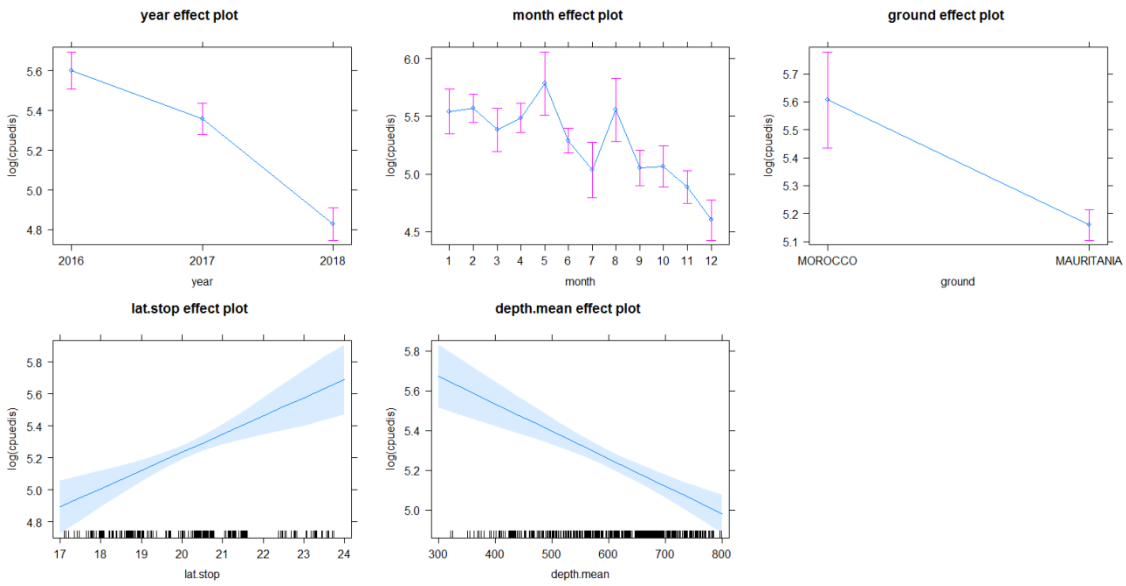

Figure 9. Diagnostic plots for the residuals of the selected log-normal GLM.

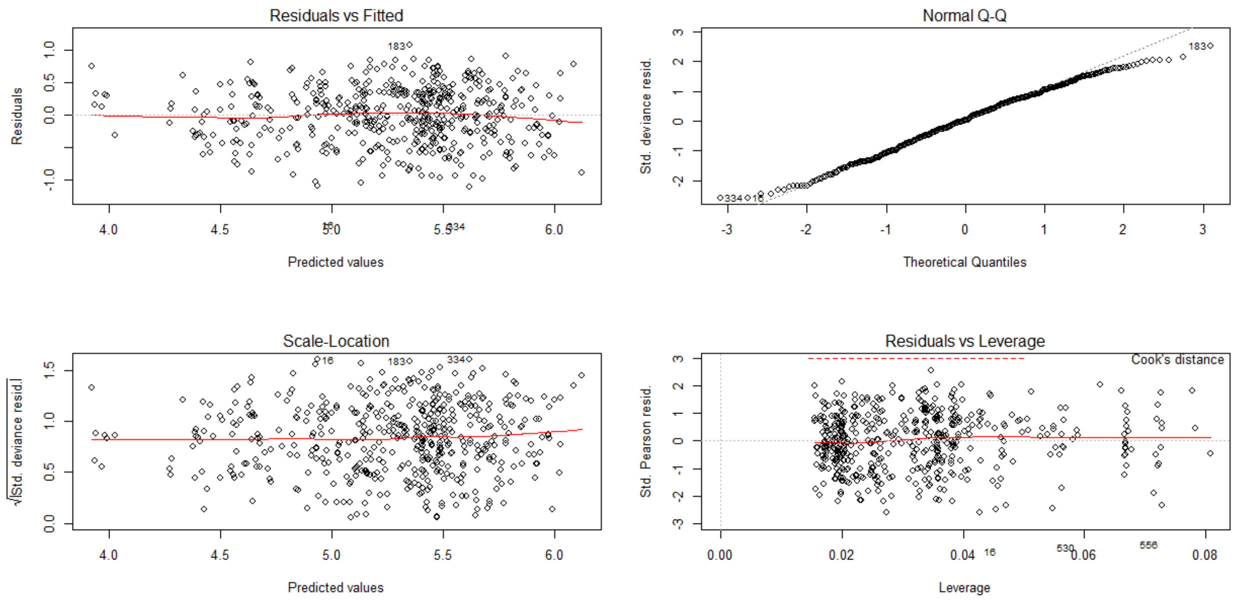

Figure 10. Scaled nominal and standardised DPUE for the Spanish trawl fishery.