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13 **Environmental implications of discarding fish in Northern**
14 **Spanish coastal bottom otter trawl fisheries**
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Abstract

Overfishing contributes to the depletion of fish stocks. Among fishing practices, discarding fish is a waste of valuable resources and results in lost income that is associated with the impact on future stock growth. This practice depends on several factors, although the highest quantity of discards is produced in trawl fisheries. In this work, the impacts of a specific fraction of the Galician (northwest Spain) bottom trawl fishery were evaluated using the ecological footprint, focusing on the contribution of the discarding rate. The fishing grounds and carbon footprints were the categories that were selected for the analysis. The results showed that 11.6 global hectares per ton of catch were required for an average fishing trip, ranging between 2.2 and 27.1. Discards represented 55% of this value, while the carbon footprint only represented 11%. Therefore, measures are needed to reduce the significant impact of discards, especially in these fisheries. The findings indicate that the discard ban promoted by the Common Fisheries Policy could reduce the ecological footprint of these fisheries by 3.4 global hectares per ton of catch landed on average.

Keywords trawl fisheries; fish discarding; environmental impact; fisheries legislation

1. Introduction

Fisheries contribute to food security and nutrition as a source of protein and nutrients and provide employment opportunities for many people worldwide (FAO, 2018). For this reason, it is essential to guarantee the long-term viability of fisheries and ensure the sustainable management of fish resources, which implies maintaining ecosystems in a healthy and productive condition and keeping the abundances of fish stocks at or above the level associated with the maximum sustainable yield (Bellido et al., 2011; European Commission, 2013). However, the current tendency contradicts this aim. The percentage of global stocks that is fished within biologically sustainable levels is declining, with 33.1% of stocks being overfished (FAO, 2018).

The practice of discarding fish contributes to the depletion of marine populations, inflicting unnecessary mortalities and affecting the balance, diversity, and functioning of ecosystems (Bellido et al., 2011; Uhlmann et al., 2014; Pérez-Roda et al., 2019). Catching resources that are not used has prevented several fish stocks from recovering despite having low quotas (European Commission, 2009). This practice also results in lost income that is associated with the impact on future stock growth and is a waste of valuable resources (Bellido et al., 2011; Pérez-Roda et al., 2019). Furthermore, the continuous discarding of fish in the same fishing area may have a number of adverse ecological impacts due to ecosystem changes in the overall structure of trophic links and habitats that could risk the sustainability of fisheries (Kelleher, 2005; Alonso et al., 2010). Likewise, fish evisceration and cleaning generate considerable amounts of waste, such as heads, bones, guts, and skins. Demersal species (e.g., monkfish, cod, hake, haddock, conger, etc.) as well as cartilaginous species, such as sharks and skates, are traditionally gutted onboard; variable amounts of fish waste (mostly composed of viscera) are generated that are generally dumped at sea. In addition to the adverse effects of this practice on trophic chains, discarding fish may contribute to the

93 accumulation of pollutants, such as polychlorinated biphenyls (PCBs), dioxins and
94 heavy metals (Mackenzie et al., 2004; Polak-Juszczak, 2009), or to the spread of
95 parasites that are present in the viscera (as is the case for anisakis) in fishing areas
96 (Blanco et al., 2006).

97 Moreover, discards are difficult to estimate, since their amounts and composition vary
98 greatly depending on a wide range of factors and conditions (Rochet and Trenkel, 2005;
99 Feekings et al., 2012; Uhlmann et al., 2014). Globally, total discards account for slightly
100 less than 10 million tons per year, which represents approximately 10% of the total
101 annual catches (Zeller et al., 2018). However, the discarding rate depends greatly on the
102 fishing gear that is employed, with bottom trawlers being the gear type that produces the
103 highest quantity of discards in most fisheries (up to 46% of the catch) (Feekings et al.,
104 2012; Zeller et al., 2018; Pérez-Roda et al., 2019). This practice is considered a
105 substantial waste of fish resources and is inconsistent with the sustainable exploitation
106 of marine resources (Kelleher, 2005; European Commission, 2009).

107 The negative implications of this practice have promoted the development of the
108 Common Fisheries Policy (CFP), approved in December 2013 (European Commission,
109 2013), which aims at the sustainable exploitation of fishery stocks based on the
110 maximum sustainable yield (MSY). MSY is the maximum annual catch that can be
111 taken from a fishery stock without affecting its long-term productivity. Due to the
112 negative implications of the practice of discarding fish, the CFP also aims to gradually
113 eliminate discarding by taking measures to avoid and reduce this practice and by forcing
114 the capture of all regulated species to land. This so-called landing obligation (LO),
115 which is reflected in Article 15 of the CFP of the European Union, indicates that all
116 specimens of regulated species should be retained, landed and counted against quotas.

117 The fishing sector in Galicia accounts for approximately 50% of the total volume of
118 captures in Spain, which is one of the major producer countries on a worldwide scale

(FAO, 2018; IGE, 2019). Several different fishing gears are used in Galician fisheries, with coastal bottom trawlers representing approximately 17% of the total landings (Vázquez-Rowe et al., 2011; IGE, 2019). In this context, different biological indicators have been used to quantify the environmental performance of the fishing sector. Hornborg et al. (2012), Vázquez-Rowe et al. (2012) and Langlois et al. (2014) developed different indexes based on the appropriation of primary production to characterize the impact of discards. Moreover, Emanuelsson et al. (2014) applied an impact category based on the MSY to quantify the level of overfishing across different fish stocks. These indicators only account for the impact of discarding; however, the ecological footprint (EF) metric allows for the incorporation of all material and energy fluxes that are necessary to maintain an activity or production process in the same index.

In this sense, the EF provides information about the area of bioproductive land that is necessary to produce resources that are consumed and to absorb the waste that is generated (Borucke et al., 2013; Lin et al., 2016). This metric is widely used to analyze the sustainability of populations, sectors or activities (Nicolucci et al., 2008; Parker and Tyedmers, 2012; Lin et al., 2018). In the fisheries sector, the EF has been previously used to analyze reef fish marine aquaculture (Warren-Rhodes et al., 2003), marine ecosystem pressures (Swartz et al., 2010), Italian fisheries (de Leo et al., 2014) and port activities (Lopes et al., 2013).

The goal of this study was to evaluate the sustainability of Galician trawl fisheries using two representative categories from the EF: fishing grounds and carbon demand on the land. The total EFs of the discarding rate and the impact and contribution of the practice of discarding were also calculated; the species that were subjected to total allowable catches (TACs) were differentiated since they were subjected to LO. This separation

between TAC and non-TAC species allowed us to clearly quantify the reduction in environmental impacts in a scenario with full compliance with this discard ban.

2. Methodology

2.1. Data

The cornerstone of the understanding of the fleet's dynamic is to undertake the fleet segmentation by identifying homogeneous groups of fishing activity developed by vessel groups with similar technical features. The definition of these homogeneous groups, termed *métier* (Laurec et al. 1991; Marchal, 2008) among other names in literature, contributes to design more efficient sampling schemes.

In this work, the analyzed or considered *métier* due to its representative high level of discards (Azevedo et al., 2010, Fernandes et al., 2015) is the Northern Spanish coastal bottom otter trawl fleet (OTB10), composed by: i) Northern Spanish coastal bottom otter trawl fleet vessels targeting a variety of demersal species in ICES Divisions 8c and 9a-North (OTB11); ii) Northern Spanish coastal bottom otter trawl fleet vessels targeting horse mackerel in ICES Divisions 8c and 9a-North (OTB12) and; iii) Northern Spanish coastal bottom otter trawl fleet vessels targeting Atlantic mackerel in ICES Divisions 8c and 9a-North (OTB13). The inventory data were compiled by an onboard observer during 37 fishing trips on 9 different trawlers of OTB10 from mid-2015 to mid-2018.

Regarding the size of the sample, the performed pilot trips on board commercial vessels of OTB10 represent more than 80 days at sea generating total catch profiles of 317 hauls during the period mid 2015 – mid 2018 (3 years), figures that are in accordance with other similar works to estimate fish discards in trawl fisheries, as the ones by Fernandes et al. (2015) and Mortensen et al. (2017).

The dataset included the retained catch and discarded biomass for each haul and was quantified and classified by species; other information, such as shooting and hauling time, number of hauls and time at sea, was also collected. The raw data were then used to obtain the total capture, discarding rates, and percentage and total mass of each species in both the landings and unwanted catch. The discarding rates were calculated as the percentage of animal origin biomass in the catch that was thrown away with respect to the total capture. Additionally, the percentage of the species that were discarded that were subjected to TACs was also determined together with the total trawling and steaming time for each fishing trip (Table 1). An example of the distribution of species in the retained and discarded capture is shown in the Supporting Information.

The main species that were discarded on these fishing trips were Atlantic horse mackerel (*Trachurus trachurus*), blue whiting (*Micromesistius poutassou*), Atlantic mackerel (*Scomber scombrus*) and small-spotted catshark (*Scyliorhinus canicula*) due to their low commercial value; European hake (*Merluccius merluccius*) and megrims (*Lepidorhombus* spp.) were discarded because of the existence of a minimum legal size for these species; Henslow's swimming crab (*Polybius henslowii*) was discarded due to the fact that it has no commercial value; and blackmouth catshark (*Galeus melastomus*) was discarded because its capture is not permitted. The target species that were landed were mostly European hake, megrims, anglers (*Lophius* spp.), Atlantic horse mackerel and squid (*Ommastrephidae* spp.). Table 2 shows a summary of some representative fishing trips.

2.2. Ecological Footprint

The impacts on the environment of the several fishing trips were evaluated via their EFs. The EF is an ecosystem-based indicator that measures the bioproductive area that a population, process or activity requires to produce the resources that are consumed and to absorb the waste that is generated (Lin et al., 2016). This metric tracks the use and

overuse of natural resources and the derived impacts on ecosystems and biodiversity in six categories: cropland, grazing land, fishing grounds, built-up land, forest area and carbon demand on the land (Galli et al., 2014; Lin et al., 2016; Mancini et al., 2016).

The total EF is calculated by Equation 1:

$$EF = \sum_i \frac{P_i}{Y_{w,i}} \cdot EQF_i \quad (1)$$

where P_i is the amount of each primary product or waste product i that is consumed or released; $Y_{w,i}$ is the annual world average yield for the production or sequestration of each product i ; and EQF is the equivalence factor of the land that produces each commodity i (Borucke et al., 2013). In this work, the EF was calculated as the sum of the fishing grounds footprint (FGF) and carbon footprint (CF) since, among the 6 land types defined by this methodology (Borucke et al., 2013), those types were the most representative for this case study. The FGF represents the demand of fisheries on aquatic ecosystems in terms of equivalent surface area, while the CF represents the area of forest land that is necessary to sequester carbon dioxide emissions (Lin et al., 2016). The FGF was calculated based on the primary productivity required (PPR) to sustain the capture. The mass of each species in the retained and discarded catch was converted to PPR with Equation 2 (Pauly and Christensen, 1995; Borucke et al., 2013) and then summed to obtain the total PPR. This value was then compared with the world average available primary productivity ($4.25 \text{ t C} \cdot \text{wha}^{-1} \cdot \text{y}^{-1}$) to obtain the FGF (Lin et al., 2016).

$$PPR = B \cdot CC \cdot \left(\frac{1}{TE} \right)^{(TL-1)} \quad (2)$$

where B is the biomass of each species in tons; CC is the carbon content of the wet weight biomass; TL is the species-specific trophic level; and TE is the transfer efficiency of carbon between trophic levels. TE is an ecosystem-specific property with high natural variability between ecosystem types, and the estimated value for temperate shelves is 14% (Libralato et al., 2008). The value that was considered for CC was 1/9,

while the TLs for each species of fish and invertebrates were gathered from Pauly and Christensen (1995), Froese and Pauly (2018) and Palomares and Pauly (2018). Finally, the total FGF was evaluated per ton of catch landed while considering the contribution of the discarded species and the percentages of those species that were subjected to TACs (European Commission, 2018).

The calculation of the CF was based on the carbon dioxide emissions that were related to each fishing trip and was determined according to Equation 3 (Borucke et al., 2013; Mancini et al., 2016):

$$CC = \frac{CO \cdot (1 - S_{ocean})}{Y_c} \quad (3)$$

where CO represents the emissions of carbon dioxide (t CO₂); S_{ocean} is the fraction of emissions sequestered by oceans (0.281); and Y_c is the annual rate of carbon dioxide sequestration per hectare of average global forest land, which has a value of 2.7 t CO₂·wha⁻¹·y⁻¹ (Mancini et al., 2016). Carbon dioxide emissions depend directly on the fuel consumption of a vessel, which was estimated with the approximation of Prado and Dremiere (1990). However, this equation was specifically adapted for this fleet after speaking with the ship owners; the power of the engine and the time that the vessel was cruising or trawling were accounted for:

$$C = \frac{A \cdot P_{max} \cdot S \cdot t}{d} \quad (4)$$

where C represents fuel consumption (L); A is the activity factor, which was set to 0.9 for steaming and 0.6 for trawling; P_{max} is the maximum engine power (hp); S is the specific fuel consumption (0.15 kg·hp⁻¹·h⁻¹); d is the fuel density (L·kg⁻¹); and t is the time of engine use (h).

Once the fuel consumption was calculated, an emission factor (EEA, 2016) was applied to obtain the total carbon dioxide emissions. Equivalence factors (Lin et al., 2016) for

fishing grounds ($0.37 \text{ gha} \cdot \text{ha}^{-1}$) and forest ($1.29 \text{ gha} \cdot \text{ha}^{-1}$) were used to convert both the FGF and CF into their equivalent areas of global average bioproductivity (Equation 1), and the results were then added to obtain the total EF.

3. Results and discussion

The results obtained by applying the previously described methodology to quantify the EF of the considered trawling fleet indicated that 11.6 global hectares per ton of catch were required on an average fishing trip, ranging between 2.2 and 27.1 gha per ton of catch (Fig. 1). The FGF represented 89% of this value; the value of the discarded fraction was 6.4 gha per ton of catch, while the CF only accounted for 11%.

3.1. Fishing Grounds Footprint

The FGF of each fishing trip is shown in Fig. 2. The dataset was divided into two groups since the discard rate is closely related to the species that is targeted. The first group included fishing trips with a high discard rate, while the second group included fishing trips where the percentage of mackerels and horse mackerels in the capture was over 80% (low discard rate). The FGF varied between 4.0 and 25.1 gha per ton of catch for the first group, with an average value of 11.3 gha per ton of catch. However, the mean value corresponding to the retained capture was 4.1 gha per ton of catch, ranging between 2.5 and 7.0 gha per ton of catch. Thus, the retained fish only represented 36% of the total FGF value, with the remainder derived from the discarded fraction. The variation in the FGF of the landed fraction was due to its composition, since a species with a relatively higher TL requires more space to grow on a continental shelf to grow than a species with a lower TL (i.e., a ton of Atlantic horse mackerel with a TL of 3.7 requires 5.8 gha less than a ton of European hake, with a TL of 4.4). However, the FGF variation that is related to the discarded fraction also depends on the value of the discarding rate, which ranged between 27 and 94% of the total capture.

270 The FGF was 77% lower for the fishing trips that targeted Atlantic horse mackerel and
271 Atlantic mackerel, with an average value of 2.8 gha per ton of catch. This finding was
272 due not only to the lower discarding rate, which ranged from 2 to 17%, but also to the
273 lower mean TL of the catch, which ranged from 3.8 – 4.1. If only the species that were
274 subjected to TACs (57% of the discarded fraction) were accounted for, the FGF of the
275 first group decreased to an average value of 8.5 gha per ton of catch. The results for the
276 second group remained almost constant, since approximately 90% of the discarded
277 species in this group were subjected to quota regulations. The environmental impacts of
278 discards in trawl fisheries were also assessed using indicators based on PPR by
279 Hornborg et al. (2012) and Vázquez-Rowe et al. (2012). Hornborg et al. (2012) found a
280 mean value for the discarded fraction of 104.5 tons of carbon (t C) per ton of *Nephrops*
281 landed when evaluating the Swedish *Nephrops* conventional trawl fishery. This value
282 would equate to an FGF of 9.1 gha per ton landed, which was 42% higher than the value
283 obtained in this study. Moreover, Vázquez-Rowe et al. (2012) evaluated the
284 environmental impacts of the Galician coastal trawling fleet, obtaining a value of 127.74
285 t C per ton of catch, which corresponds to 11.1 gha per ton landed. Both values are
286 higher than those found in this study, despite having lower discarding rates (59 and
287 42%, respectively). Thus, this difference may be related to the TE value, since this
288 property has a substantial impact on the outcome of the PPR (Parker and Tyedmers,
289 2012; Cashion et al., 2016). While a mean system-specific TE value of 14% was applied
290 in this study, an average TE value of 10% for aquatic ecosystems was used in Hornborg
291 et al. (2012) and Vázquez-Rowe et al. (2012). Moreover, Lopes et al. (2013) calculated
292 the EF of trawlers operating in the Port of Vigo and included other related services,
293 such as fishing nets and ice. The value of the EF reached 8.8 gha per ton of catch.
294 Again, the results were similar to the previously mentioned studies (Hornborg et al.,
295 2012; Vázquez-Rowe et al., 2012), despite not accounting for the fraction of discarded

fish, and probably due to the low value that was used in Lopes et al. (2013) for natural productivity.

3.2. Discarding rate

The average value obtained for the weighted discarding rate was 78% of the total catch. This value decreased to 56% if only species that were subjected to quotas were accounted for. A complete catch profile for the analyzed fleet can be found in the Supporting Information to this work. These results reveal the significant impact of discards in trawl fisheries, since the global estimated discard rate is slightly less than 10% (Zeller et al., 2018). The discard rate of these trawlers was also evaluated by Vázquez-Rowe et al. (2011) and Pérez-Roda et al. (2019), with values of 42 and 31%, respectively. The differences may be due to the species that were targeted, since trawling for multiple species, prevalent in this study, has been demonstrated to have relatively higher discarding rates (Pérez-Roda et al., 2019). Other reasons influencing the results may be the fishing area, season and species that were included in the calculation of the discarding rate. The abovementioned divergences in the discard rates could also be due to the different methodologies that were carried out to obtain the analyzed fishing data. While the work by Vázquez-Rowe et al. (2011) was based on surveys that were given to crews and skippers, the data used in this work were obtained by an observer that was onboard the commercial trawl vessels during real daily fishing activity by completely sampling the total catch.

To complete the analysis of discard rates in the selected Galician trawling fisheries, some recent trials to determine the survival rates of some species that are subject to TAC regulation, such as skates, sharks and Norwegian lobster, are currently being carried out to evaluate discard exemptions (i.e., reducing the discard rates) to the LO of the EU.

Regarding studies on the survival of finfish discarded from trawler decks like the fleets considered in this work, they have generally documented high discard mortality rates, although types and severity of injuries which generally impact mortality are highly specific to the fishing gear used, operational modes, environmental conditions, species and size, and handling and release practices (Broadhurst et al., 2006; Benoît et al., 2010). In the other hand, invertebrates with protective shells or exoskeletons are less likely fatally damaged from gear contact and handling.

We have performed a literature review about discards mortality in similar fisheries and species mainly caught by the analyzed Galician trawling fleet, defining an interval for mortality rates to each specific species (if possible, since information on the species rate is highly dependent in the target species, fishing gear, etc.). From the data acquired in this review, together with available discard data, it can be stated that the range of death discards produced by the analyzed fleet ranges from an optimistic scenario (if lowest mortalities considered) of 5,293.67 t/year (25.71 % of total discards) to the worst case (with highest mortalities) of 19,833.68 t/year (96.31 %). Therefore, the real scenario for the fleet will be between these values. By following the main guidelines described by FAO in Pérez-Roda et al. (2019) that predicts high survival rates for species like sharks, skates, crustaceans and invertebrates and high mortalities for finfish discarded from trawler decks, we can estimate a total amount of death discards of 17,586.02 t/year (85.4 % of total quantified discards). From this result, a rough estimation of affection/reduction due to this survivability parameter over the EF associated to discards of around 14.5 % can be made. However, this value must have considered with caution since it derives from a hypothetical scenario of fishing activity where considered discard mortalities can be considerable different when compared with real fishing activity since we have not performed during our pilot tests on board trawling vessels any survivability measurements or monitoring to allow to verify this estimated value.

3.3. Carbon Footprint

The CF had an average value of 1.3 gha per ton of catch, ranging between 0.2 and 5.3 gha per ton of catch, and no significant difference between the 2 groups (Fig. 3) was observed. These values were derived from fuel use intensity (FUI) of 1,254 L per ton of catch, varying between 169 and 2,463 L per ton of catch. However, there was a fishing trip with an extremely high consumption of fuel, 5,688 L per ton of catch, mainly due to the low mass that was landed. If this fishing trip was not included in the calculation, the mean value decreased to 1.2 gha per ton of catch.

The fuel consumption range was similar to that for finfish fisheries employing bottom trawls in Europe, which ranged from 236 to 2,724 L per ton of catch (Parker and Tyedmers, 2015), although the mean value was 66% higher. However, the value was lower than that of trawlers targeting flatfish, which varied from 631 to 4,062 L per ton of catch, with an average value of 2,851 L per ton of catch (Parker and Tyedmers, 2015). Moreover, Iribarren et al. (2010) estimated the CF of the Galician coastal fishery; the emissions from capture to landing were included for a life cycle perspective. An average value of 2.07 t CO₂ per ton of catch landed (0.7 gha per ton of catch landed) was obtained for bottom trawlers, ranging from 0.55 to 3.99 t CO₂ per ton of catch landed (0.2-1.3 gha per ton of catch landed), depending on the species that were targeted. Although other inputs, such as antifouling and net production, were included in the calculation, fuel use is responsible for the majority of greenhouse emissions (Ziegler et al., 2018). Thus, the species that were targeted may be the reason for the differences in the fuel performance of the fleet.

3.4. Category contributions to the EF

Regarding the different contributions to the EF, the retained capture contributed 34%, discards contributed 55%, and the CF contributed 11% (Fig. 4). A similar influence was

obtained by Lopes et al. (2013) when evaluating the EF of trawlers operating in the Port of Vigo; fish represented 90%, and fuel represented approximately 6% of the total EF. Both results show the importance of including ecosystem-based indicators or biological categories when evaluating the impacts of fisheries.

4. Conclusions

The results indicated evidence of the significant environmental impact of discards in trawl fisheries and the implications of their reduction. Measures such as the inclusion of modifications to fishing gear, spatial and temporal restrictions, effort regulations or discard bans (LO) could be implemented to decrease the discard level (Pérez-Roda et al., 2019). In fact, a discard ban for species that are subjected to TACs promoted in EU waters by the CFP could reduce the EF of these fisheries by 3.4 gha per ton of catch landed on average. The application of prediction tools that would allow vessels to find optimal areas for fishing would also lessen the EF by improving the selectivity and diminishing the fuel that is consumed.

Moreover, the discarded capture was identified as the factor with the greatest variance, and therefore, this factor determined the divergence in the EF among the different fishing trips. Thus, the difference in demand for natural resources among fisheries would be more related to the discard rate than to the catch composition or fuel consumption.

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Tables:

Table 1. Main data from the 37 fishing trips.

Table 2. Species compositions of the discards and retained capture for some fishing trips (%).

Figure captions:

Fig. 1. EF for each fishing trip.

Fig. 2. FGF for each fishing trip (vertical line separating the two groups).

Fig. 3. CF for each fishing trip (vertical line separating the two groups).

Fig. 4. Different contributions to the total ecological footprint.

Supporting Information

**Environmental implications of fish discarding in
trawl fisheries on land biocapacity**

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An example of the inventory data for 4 of the 37 fishing trips is shown, including discards and retained catch classified by species. The reasons for discarding are being below the minimum landing size (MLS), being damaged (DAM), being non-commercial species (MAR), having no quota (QUO), having low commercial value (VAL), catch not permitted (NAL) or poor conservation (QAL).

Table S.1. Discards classified by species for the fishing trip 1.

Common name	Scientific name	Weight (kg)	%	Reason
Henslow's swimming crab	<i>Polybius henslowii</i>	1,7437.3	89.1%	MAR
Blue whiting	<i>Micromesistius poutassou</i>	682.5	3.5%	VAL + QAL
Four-spot megrim	<i>Lepidorhombus boscii</i>	588.3	3.0%	MLS
Megrim	<i>Lepidorhombus whiffiagonis</i>	110.7	0.6%	MLS
Black-mouth catshark	<i>Galeus melastomus</i>	106.4	0.5%	NAL
Squat lobsters	<i>Munida spp</i>	90.6	0.5%	MAR
Others		561.1	2.9%	
Total		1,9576.9		

Table S.2. Retained catch classified by species for the fishing trip 1.

Common name	Scientific name	Capture (kg)	%
Megrim	<i>Lepidorhombus spp</i>	891.0	66.5%
Horned octopus	<i>Eledone cirrhosa</i>	147.0	11.0%
Squids	<i>Loligo spp</i>	85.0	6.3%
Blue whiting	<i>Micromesistius poutassou</i>	71.0	5.3%
Monkfishes	<i>Lophius spp</i>	51.0	3.8%
Norwegian lobster	<i>Nephrops norvegicus</i>	38.0	2.8%
Greater forkbeard	<i>Phycis blennoides</i>	29.0	2.2%
Gurnards	<i>Triglidae spp</i>	7.0	0.5%
Others		20.5	1.5%
Total		1,339.5	

Table S.3. Discards classified by species for the fishing trip 2.

Common name	Scientific name	Weight (kg)	%	Reason
Blue whiting	<i>Micromesistius poutassou</i>	50.5	42.1%	VAL + QAL
European hake	<i>Merluccius merluccius</i>	40.2	33.5%	MLS + DAM
Atlantic horse mackerel	<i>Trachurus trachurus</i>	7.5	6.3%	DAM + VAL
Atlantic mackerel	<i>Scomber scombrus</i>	6.8	5.7%	VAL
Twaite shad	<i>Alosa falax</i>	5.1	4.3%	MAR
Common octopus	<i>Octopus vulgaris</i>	3.0	2.5%	VAL
Royale cucumber	<i>Parastichopus regalis</i>	2.5	2.1%	MAR
Horned octopus	<i>Eledone cirrhosa</i>	2.1	1.7%	DAM + VAL
Squids	<i>Loligo spp</i>	1.9	1.6%	VAL
Others		0.4	0.3%	
Total		120.1		

Table S.4. Retained catch classified by species for the fishing trip 2.

Common name	Scientific name	Capture (kg)	%
Atlantic horse mackerel	<i>Trachurus trachurus</i>	2,355.0	92.8%
European hake	<i>Merluccius merluccius</i>	130.0	5.1%
Atlantic mackerel	<i>Scomber scombrus</i>	40.0	1.6%
Monkfishes	<i>Lophius spp</i>	12.0	0.5%
Total		2,537.0	

Table S.5. Discards classified by species for the fishing trip 3.

Common name	Scientific name	Weight (kg)	%	Reason
Black-mouth catshark	<i>Galeus melastomus</i>	2,003.3	35.3%	NAL
Henslow's swimming crab	<i>Polybius henslowii</i>	1,324.4	23.4%	MAR
Blue whiting	<i>Micromesistius poutassou</i>	533.1	9.4%	VAL + QAL
Birdbeak dogfish	<i>Deania calceus</i>	365.9	6.5%	VAL
Lesser spotted dogfish	<i>Scyliorhinus canicula</i>	281.5	5.0%	VAL
Greater forkbeard	<i>Phycis blennoides</i>	173.6	3.1%	DAM + VAL
Atlantic horse mackerel	<i>Trachurus trachurus</i>	134.2	2.4%	DAM + VAL
Agassiz's flapjack octopod	<i>Opisthoteuthis agassizii</i>	95.2	1.7%	MAR
Softhead grenadier	<i>Malacocephalus laevis</i>	81.0	1.4%	MAR
Rabbit fish	<i>Chimaera monstrosa</i>	64.2	1.1%	MAR
Longfin gurnard	<i>Chelidonichthys obscurus</i>	53.3	0.9%	VAL
Roughsnout grenadier	<i>Trachyrincus scabrus</i>	47.7	0.8%	MAR
Squids	<i>Loligo spp</i>	44.9	0.8%	DAM + VAL
Angular roughshark	<i>Oxynotus centrina</i>	41.5	0.7%	NAL
Piper gurnard	<i>Trigla lyra</i>	40.9	0.7%	VAL
Blackbelly rosefish	<i>Helicolenus dactylopterus</i>	40.9	0.7%	VAL
European hake	<i>Merluccius merluccius</i>	37.4	0.7%	MLS + DAM
Mediterranean slimehead	<i>Hoplostethus mediterraneus</i>	30.2	0.5%	VAL
Leafscale gulper shark	<i>Centrophorus squamosus</i>	27.5	0.5%	VAL
Bluntnose sixgill shark	<i>Hexanchus griseus</i>	26.5	0.5%	NAL
Others		223.8	3.9%	
Total		5,671.1		

Table S.6. Retained catch classified by species for the fishing trip 3.

Common name	Scientific name	Capture (kg)	%
European hake	<i>Merluccius merluccius</i>	690.0	40.7%
Monkfishes	<i>Lophius spp</i>	457.0	27.0%
Blue whiting	<i>Micromesistius poutassou</i>	111.0	6.6%
Megrim	<i>Lepidorhombus spp</i>	79.0	4.7%
Horned octopus	<i>Eledone cirrhosa</i>	77.5	4.6%
Atlantic horse mackerel	<i>Trachurus trachurus</i>	60.0	3.5%
Squids	<i>Loligo spp</i>	59.5	3.5%
Rays	<i>Raja spp</i>	37.0	2.2%
Norwegian lobster	<i>Nephrops norvegicus</i>	33.0	1.9%
Greater forkbeard	<i>Phycis blennoides</i>	32.0	1.9%
Soles	<i>Solea spp</i>	18.0	1.1%
John dory	<i>Zeus faber</i>	15.0	0.9%
Pouting	<i>Trisopterus luscus</i>	9.0	0.5%
Edible crab	<i>Cancer pagurus</i>	8.0	0.5%
Others		8.2	0.5%
Total		1,694.2	

Table S.7. Discards classified by species for the fishing trip 4.

Common name	Scientific name	Weight (kg)	%	Reason
Lesser spotted dogfish	<i>Scyliorhinus canicula</i>	366.3	34.8%	VAL
Henslow's swimming crab	<i>Polybius henslowii</i>	266.9	25.4%	MAR
Four-spot megrim	<i>Lepidorhombus boscii</i>	63.7	6.1%	MLS
Gastropods	<i>Gasteropoda spp</i>	45.7	4.3%	MAR
Atlantic mackerel	<i>Scomber scombrus</i>	45.6	4.3%	QUO
Dragonet	<i>Callyonimus lyra</i>	45.1	4.3%	MAR
Blue whiting	<i>Micromesistius poutassou</i>	40.5	3.9%	VAL
Hermit crabs	<i>Pagurus spp</i>	39.7	3.8%	MAR
Tub gurnard	<i>Chelidonichthys lucerna</i>	30.6	2.9%	VAL
Royale cucumber	<i>Parastichopus regalis</i>	23.1	2.2%	VAL
European hake	<i>Merluccius merluccius</i>	19.9	1.9%	MLS
Atlantic horse mackerel	<i>Trachurus trachurus</i>	12.0	1.1%	VAL
Thornback ray	<i>Raja clavata</i>	10.0	1.0%	NAL
Butterfly blenny	<i>Blennius ocellaris</i>	8.0	0.8%	MAR
Sea mice	<i>Aphrodita spp</i>	7.1	0.7%	MAR
Red gurnard	<i>Aspitrigla cuculus</i>	5.2	0.5%	VAL
Others		21.8	2.1%	
Total		1,051.4		

Table S.8. Retained catch classified by species for the fishing trip 4.

Common name	Scientific name	Capture (kg)	%
Atlantic horse mackerel	<i>Trachurus trachurus</i>	820	50.7%
Red gurnard	<i>Aspitrigla cuculus</i>	159	9.8%
Lesser spotted dogfish	<i>Scyliorhinus canicula</i>	133.2	8.2%
Megrim	<i>Lepidorhombus spp</i>	118	7.3%
Horned octopus	<i>Eledone cirrhosa</i>	67.6	4.2%
Soles	<i>Solea spp</i>	42.6	2.6%
Pouting	<i>Trisopterus luscus</i>	35	2.2%
John dory	<i>Zeus faber</i>	35	2.2%
Thickback sole	<i>Microchirus variegatus</i>	33.5	2.1%
Tub gurnard	<i>Chelidonichthys lucerna</i>	32	2.0%
Blue whiting	<i>Micromesistius poutassou</i>	23	1.4%
Gurnards	<i>Triglidae spp</i>	22	1.4%
Common octopus	<i>Octopus vulgaris</i>	21	1.3%
Red bandfish	<i>Cepola macrophthalma</i>	15.2	0.9%
European hake	<i>Merluccius merluccius</i>	15	0.9%
European conger	<i>Conger conger</i>	12.9	0.8%
Squids	<i>Loligo spp</i>	12.5	0.8%
Others		20.3	1.3%
Total		1,617.8	

Table S.9. Estimated retained and discards volumes of main species captured by the Galician trawling fleet operating in ICEAS areas 8c and 9a (2018)

Cod-FAO	Scientific name	Common name	TAC?	t retained/year	t discarded/year	% discard	
						Discard/Total Capture	
BOC	<i>Capros aper</i>	Boarfish	Y	0.00	215.19		100.00
HKE	<i>Merluccius merluccius</i>	Hake	Y	1,714.17	1,757.90		50.63
JAX	<i>Trachurus trachurus</i>	Horse mackerel	Y	1,038.20	3,919.83		79.06
LEZ	<i>Lepidorhombus spp</i>	Megrim	Y	2,819.23	1,993.76		41.42
MAC	<i>Scomber scombrus</i>	Atlantic Mackerel	Y	4,207.98	2,903.46		40.83
SRX	<i>Raja spp</i>	Skates	Y	255.39	80.90		24.06
WHB	<i>Micromesistius poutassou</i>	Blue whiting	Y	2,082.78	4,233.75		67.03
ARY	<i>Argentina sphyraena</i>	Argentine	N	11.32	25.12		68.93
BIB	<i>Trisopterus luscus</i>	Pout	N	293.44	60.95		17.20
BRF	<i>Helicolenus dactylopterus</i>	Blackbelly rosefish	N	384.36	563.82		59.46
GFB	<i>Phycis blennoides</i>	Greater forkbeard	N	89.28	33.78		27.45
GRV	<i>Macrouridae spp</i>	Rattails	N	1.97	399.46		99.51
GUX	<i>Triglidae spp</i>	Gurnard	N	296.40	1,341.44		81.90
MAS	<i>Scomber japonicus</i>	Pacific chub mackerel	N	0.00	2.29		100.00
SHO	<i>Galeus melastomus</i>	Blackmouth catshark	N	222.38	1,724.98		88.58
SYC	<i>Scyllorhinus canicula</i>	Small spotted catshark	N	228.12	653.24		74.12
UEX	<i>Munida spp.</i>	Squat lobster	N	0.00	73.40		0.00
QPH	<i>Polybius henslowii</i>	Henslow swimming crab	N	0.00	581.33		100.00
		Other invertebrates	N	0.00	28.22		100.00
Species subject to TAC/quota				12,117.75	15,104.77		55.49
Species not subject to TAC/quota				1,527.28	5,488.04		78.23
Total				13,645.03	20,592.81		

Table S.10. Estimations of mortality rates intervals of unwanted organisms generated by different trawling fleets and related discards volumes of the Galician trawling fleet obtained by applying these values.

Cod-FAO	Scientific name	Common name	Taxon	Discard mortality		Volume of death discards to sea (t/year)		References
				Min	Max	Min	Max	
BOC	<i>Capros aper</i>	Boarfish	Teleosts	16%	99%	34.43	213.04	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
HKE	<i>Merluccius merluccius</i>	Hake	Teleosts	16%	99%	281.26	1,740.32	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993); Benoit et al. (2010)
JAX	<i>Trachurus trachurus</i>	Horse mackerel	Teleosts	16%	100%	627.17	3,919.83	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993); Adao et al. (2018)
LEZ	<i>Lepidorhombus spp</i>	Megrim	Teleosts	27%	100%	538.31	1,993.76	van Beek et al. (1990); Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993); Huse and Vold (2010)
MAC	<i>Scomber scombrus</i>	Atlantic Mackerel	Teleosts	16%	99%	464.55	2,874.43	Lapikhovsky (2004); Enever et al. (2009); Mandelman et al. (2013); Depesle et al. (2014); Knotek et al., (2018)
SRX	<i>Raja spp</i>	Skates	Elasmobranchs	29%	99%	23.46	80.09	Berghahn et al., (1992); Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
WHB	<i>Micromesistius poutassou</i>	Blue whiting	Teleosts	65%	100%	2,751.94	4,233.75	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
ARY	<i>Argentina sphyraena</i>	Argentine	Teleosts	16%	99%	4.02	24.87	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993); Depesle et al. (2014)
BIB	<i>Trisopterus luscus</i>	Pout	Teleosts	16%	100%	9.75	60.55	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
BRF	<i>Helicolenus dactylopterus</i>	Blackbelly rosefish	Teleosts	16%	99%	90.21	558.18	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
GFB	<i>Phycis blennoides</i>	Greater forkbeard	Teleosts	16%	99%	5.41	33.45	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
GRV	<i>Macrouridae spp</i>	Rattails	Teleosts	16%	99%	63.91	395.47	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
GUX	<i>Trigloa spp</i>	Gurnard	Teleosts	16%	99%	214.63	1,328.03	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
MAS	<i>Scomber japonicus</i>	Pacific chub mackerel	Teleosts	16%	99%	0.37	2.27	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993)
SHO	<i>Galeus melastomus</i>	Blackmouth catshark	Elasmobranchs	10%	82%	172.50	1,414.48	Stobutzki et al. (2002); Broadhurst and Cullis (2020)
SYC	<i>Scyllorhinus canicula</i>	Small spotted catshark	Elasmobranchs	0%	95%	0.00	620.58	Stobutzki et al. (2002); Castro et al. (2003); Revill et al. (2005); Eddy et al. (2016); Adao et al., (2018); Barragán-Méndez et al. (2019)
QPH	<i>Polybius henslowii</i>	Henslow swimming crab	Crustaceans	0%	54%	0.00	313.90	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993); Bergmann and Moore (2001)
		Other invertebrates	Molluscs Echinoderms Gastropods	0%	10%	0.00	2.82	Wassenberg and Hill (1993); Kaiser and Spencer (1995); Currie and Parry (1999); Gasper et al. (2001)
UEX	<i>Munida s pp.</i>	Squat lobster	Crustaceans	16%	32%	11.74	23.49	Wassenberg and Hill (1989); Hill and Wassenberg (1990); Wassenberg and Hill (1993); Bergmann and Moore (2001)
TOTAL						5,293.67	19,833.68	
						25.71%	96.31%	
TOTAL DISCARDS						20,592.81	20,592.81	