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Contribution to the Themed Section: 'Bycatch and discards: from improved knowledge to mitigation programmes'

Original Article

Discarded fish in European waters: general patterns and contrasts

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To reduce the practice of discarding commercially fished organisms, several measures such as a discard ban and extra allowances on top of landings quotas ("catch quota") have been proposed by the European Commission. However, for their development and successful implementation, an understanding of discard patterns on a European scale is needed. In this study, we present an inter-national synthesis of discard data collected on board commercial, towed-gear equipped vessels operating under six different national flags spanning from the Baltic to the Mediterranean Seas mainly between 2003 and 2008. We considered discarded species of commercial value such as Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), European hake (*Merluccius merluccius*), and European plaice (*Pleuronectes platessa*). Comparisons of discard per unit effort rates expressed as numbers per hour of fishing revealed that in the Mediterranean Sea minimum size-regulated species such as hake are generally discarded in much lower numbers than elsewhere. For most species examined, variability in discard rates across regions was greater than across fisheries, suggesting that a region-by-region approach to discard reduction would be more relevant. The high uncertainty in discard rate estimates suggests that current sampling regimes should be either expanded or complemented by other data sources, if they are to be used for setting catch quotas.

Keywords: bycatch, Common Fisheries Policy reform, Data Collection Framework, discard reduction, Europe, monitoring.

Introduction

Discarding unwanted catch at sea in response to regulatory and/or market forces during commercial fishing is generally considered to be a waste of natural resources. It evades the eyes and often goes unrecorded. But, knowing how much is lost is important, for at least three reasons: first, discards might make up a large part of the total catch, possibly exceeding the amount of landings; second, stock viability and productivity may be compromised if large and unregistered numbers of organisms are removed periodically on top of the registered landings (Crowder and Murawski, 1998; Punt *et al.*, 2006); third, quantification of the magnitude of discarding is the first step in a framework to resolve it (Kennelly and Broadhurst, 2002).

In Europe, estimating the amount of discards is legislated via the Data Collection Framework ("DCF"; EEC, 2000). As part of nationally adopted onboard observer programmes, trained personnel collect the biomass, length, age, and species compositions of discards from their most important commercial fisheries (EEC, 2009), with the main aim to feed these data into stock assessments. This is done via at-sea sampling (ICES, 2011), and all the data are stored and administered by the respective national authorities. Although various analyses of these data have been done, many studies were restricted to regional fisheries (e.g. Stratoudakis *et al.*, 1999; Viana *et al.*, 2011; Feekings *et al.*, 2012; Madsen *et al.*, 2013). However, synthesizing discard data from as many different fisheries, regions, and countries as possible is required to facilitate European-wide management approaches. So far, such a synthesis was hampered by (i) the diversity of procedures in collecting and processing data, (ii) the disparate intensities of sampling compared with the total fishing effort across countries, (iii) the lack of a common data exchange format and storage facility, and (iv) national regulations which precluded sharing of detailed commercial catch data (STECF, 2006, 2008; Hinz *et al.*, 2013).

Considering that a reduction in discards is set to be a cornerstone of the European Common Fisheries Policy (CFP) reform (EEC, 2011), a comprehensive pan-European synthesis of discard data across species, fishing regions, and fleets is important. This may aid the decision-making process by providing input to questions such as on what level discard-reduction initiatives need to be implemented: species, fisheries, or region-based (i.e. fishing ground). An important component of the CFP-reform proposal is a landing obligation, or a discard ban, prohibiting the at-sea disposal of some commercially valuable species from 2014 on (Article 15; EEC, 2011, 2012a). Alternatively, the catch quota could substitute the current landings quota (EEC, 2011). In either case, the complete catch would need to be accounted for. Shifting from a landings to a catch quota management system would require that catch quotas are set based on the reliable estimates of discarded amounts and/or proportions. However, discard rates of a given species are likely to fluctuate within a fishery (e.g. Feekings *et al.*, 2012; Poos *et al.*, 2013) and/or across different fisheries, seasons, years, and regions (Stratoudakis *et al.*, 1999; Borges *et al.*, 2005, 2006). The starting point for designing mitigation measures and management plans to reduce discards is to describe and characterize these patterns.

In this study, onboard observer data from discard-intensive fisheries using towed gears from Denmark, England, France, Greece, The Netherlands, and Spain were compiled. These data were used to describe species-specific discard patterns among and between fisheries and regions. Owing to logistical and financial constraints, only a fraction of operations carried out by a fleet can be monitored, which will render extrapolations across the entire population of operations uncertain (Depestele *et al.*, 2011). Extrapolations require the use of raising or auxiliary variables such as landings or fishing effort. Following ICES (2011), this could be done "according to sampling theory [where] the standard raising procedure within a given stratum (e.g. quarter and area) should be: i) samples are raised to haul level based on sampled proportion; ii) sampled hauls are raised to trip level based on the proportion of hauls sampled; and iii) sampled trips are raised to métier level based on the proportion of trips sampled". But, the availability and quality of raising variables is not uniform and varies across countries (ICES, 2007), so that no single raising procedure can be recommended at the European level (ICES, 2011). For example, the total number of trips within a stratum may not be known or may be either over- or underestimated due to the switching of gears throughout a trip or depending on post-stratification methods (ICES, 2010). To circumvent these issues, discard estimates at the level of sampled trips are presented here.

To allow for an integration and comparison of discard data from various fisheries and national sampling programmes, an index has to be defined that takes into account the unit of fishing effort (i.e. DPUE, discards per unit of effort; Rochet and Trenkel, 2005). Fishing effort measured as the hours spent actually fishing is a commonly used effort descriptor among EU member states for towed gears. A DPUE index of abundance, hereafter called "discard rate", can be a useful tool for policy-makers to identify discard-intensive fisheries and improve discard management by developing mitigation strategies. Another useful measure is the ratio between discards and catch (discards and landings). Thus, in this study, we combined discard data from six different countries and several different regions (spanning from the Baltic to the Mediterranean Seas) to compare discard rates of commercially valuable species such as Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), European hake (*Merluccius merluccius*), and European plaice (*Pleuronectes platessa*). The aim was to contrast discard rates and ratios between fisheries or regions. We compared the coefficients of variation of discard rates and ratios across fisheries for a given region and across regions for a given fishery. If discard patterns were found to be more homogeneous across regions than fisheries, a fisheries-by-fisheries approach to discard reduction might be more relevant.

Material and methods

Dataset

A dataset was built from preprocessed and aggregated trip-level information that was provided by each partner detailing the mean ($\pm$ s.d.) number of discarded/landed species per hour from sampled trips per métier, and subarea within fishing region, together with the corresponding number of sampled trips from towed gears. Thereby, fishing activity was linked to the European level 5 métier definition, requiring data at the level of fishing region (hereafter "region"), gear type, and target species assemblage (e.g. demersal fish—hereafter "fish", small pelagic fish, cephalopods and fish, crustaceans, and crustaceans and fish; FAO, 1980; EEC, 2008; ICES, 2009). Hereafter, the term "fishery" is used to designate a gear type and target species assemblage combination. All biological data such as the numbers and weights (where available) of discarded and landed species were summarized by region, subarea per region (i.e. ICES Divisions or FAO areas of the Mediterranean Sea), métier, and vessel flag country (hereafter country) together with technical information (average trip duration, fleet size, and fishing effort). ICES Division "IIIa" was subdivided into Skagerrak and Kattegat to reflect the stock classifications used by ICES. A summary of a detailed comparison of each of the national discard sampling programmes is provided in Table 1.

Biological data were collected on a haul-by-haul basis and, for the majority of samples, consisted of landings and discard

Table 1. Sampling allocation schemes, species identification and measurement procedures, and raising units of national discard sampling programmes part of the European DCF.

Programme	Allocation[a]	Identification[b]	Measurement[c]	Raising unit[d]
Denmark				
All DCF fisheries	Random	Partial	Numbers/weights	Fishing operation
Spain				
Otter trawl (Med. Sea)	Opportunistic	Partial	Numbers/weights	Fishing operation
Otter trawl (Atlantic)	Random	Partial	Numbers/weights	Fishing operation
France				
All DCF fisheries	Opportunistic	All	Numbers/weights	Fishing operation
England				
All DCF fisheries	Random	All	Numbers	Fishing operation
Greece				
Otter trawl	Random	All	Numbers/weights	Fishing operation
The Netherlands				
Beam trawl	Opportunistic	All	Numbers	Fishing time

[a]Allocation of sampling effort. For example, how the units of the sampling frame (e.g. vessels, trips) were chosen: by a (stratified) random, opportunistic/cooperative design (ICES, 2011).
[b]Identification of either all or selected (partial) species within a catch sample.
[c]Measurement includes numbers and/or weights of discarded or landed species.
[d]Sampling unit includes the estimator used to raise species numbers/weights from haul to trip level.

observations of commercially valuable species (including invertebrates such as crustaceans, molluscs, and cephalopods). Numbers discarded, numbers landed (when these were registered), and lengths (cm) were recorded. To our study, numbers rather than weights were used, because species weights of catch and discards were not recorded in all national sampling programmes owing to the challenge of obtaining accurate weight measurements at sea. Although length–weight relationships may have allowed for transformations of available numbers-at-length into weights, this approach was not chosen, because it would have implied the mixing of measurements (available from $n = 4$ partners; Table 1) with estimated weights (theoretically available from $n = 2$ partners, Table 1) when combining data from different countries. All numbers were raised to the haul level (if a subsample was measured; based on the proportion between the total and the sampled fraction) and subsequently to the trip level (based on either the proportion of sampled fishing operations or fishing time; see Table 1 and ICES, 2011 for details). These raised numbers of landings and discards per species per sampled trip were standardized by sampled fishing time (i.e. tow duration, in hours) to derive a discard rate (i.e. DPUE), as the numbers landed or discarded per hour per sampled trip. The ratio between discards and catch (discards + landings) rates was used as the discard ratio. From all sampled trips, an average and an s.d. were then calculated for discard rates and ratios as follows.

Estimation of discard rates and ratios and their variability

To compare species-specific discard rates and ratios (at the level of sampled trips) across regions and fisheries, means and s.d. across countries and subareas within regions were combined. The most appropriate auxiliary variables, such as total fishing effort, were not available in comparable units at the required level of aggregation and desired quality from all countries. Therefore, discard rates were weighted by national sampling effort (i.e. number of observed trips) under the assumption that sampling effort was proportional to a fleet's activity. Thereby, the mean numbers of discarded or landed species per hour and trip were combined for a given fishery and region as:

$$M = \sum_{i \in I, k \in K} \frac{n_{i,k} m_{i,k}}{N}, \tag{1}$$

where M is the mean number of a discarded or landed species per given fishery and region; N the total number of sampled trips per given fishery and region; I the set of all subareas within the region; K the set of all countries; $n_{i,k}$ the number of sampled trips in subarea i, by country k, for the specified métier; and $m_{i,k}$ the mean number of a discarded or landed species in subarea i, by country k, for the specified fishery.

From the standard deviation that was associated with each mean number of a discarded or landed species per hour, the variance V was calculated per species, fishery, and region as follows, whereby $v_{i,k}$ is the variance for subarea i, by country k, for the specified fishery:

$$V = \sum_{i \in I, k \in K} \frac{v_{i,k}(n_{i,k} - 1) + (m_{i,k} - M)^2 n_{i,k}}{N - 1}. \tag{2}$$

In $n = 97$ cases, standard deviations (SD, square root of the variance) of discard rates were larger than the mean (M). Available length frequency distributions (Helmond and Uhlmann, 2011) were graphically examined and found to be positively skewed, which implies that a lognormal distribution would describe the data more appropriately than a normal distribution (Limpert *et al.*, 2001). Therefore, geometric means (GMs) and the multiplicative standard deviation (GSD) were calculated from the combined means (M) and standard deviations following Limpert *et al.* (2001):

$$\mathrm{GM} = \frac{M}{\sqrt{1 + (\mathrm{SD}/M)^2}} \tag{3}$$

$$\mathrm{GSD} = \exp\left(\sqrt{\log\left(1 + \left(\frac{\mathrm{SD}}{M}\right)^2\right)}\right). \tag{4}$$

Differences of discard and landings rates (i.e. per unit effort) between fisheries and regions are illustrated in bar plots with inferential error bars (Cumming *et al.*, 2007) calculated as:

$$\mathrm{GSE} = \mathrm{GSD}^{1/\sqrt{N}}. \quad (5)$$

The inferential error bars show a confidence interval (GM/GSE; GM × GSE) for the median of discarded or landed numbers. "Discard" or landing rate' hereafter refers to the GM of discarded or landed numbers per hour. Statistical significance at $p < 0.05$ was inferred when the gap between error bars was of the same size as the error bar itself with >10 sampled trips. For fewer trips, a greater gap is needed for a similar significant difference.

As a measure of the variability of discard rates and ratios across fisheries or regions, we computed the coefficient of variation for discards rates and ratios by fisheries and region. To calculate the respective CVs, the average and the s.d. of discard rates and ratios for a given fishery (across regions) or for a given region (across fisheries) were taken. All calculations were done using the statistical software R (R Development Core Team, 2005), with the aid of the "combinevar" function from the package "fishmethods" (Nelson, 2012).

Comparison of discard rates and ratios

The comparisons of discard rates and ratios were done specifically for towed-gear fisheries that operated under different national flags. These included otter (OTB) and beam trawlers (TBB) targeting crustaceans (CRU) or demersal fish ("fish", DEF; Table 2). Pelagic fisheries which require specific sampling procedures were not considered in this study. To make meaningful (i) inter-region (across fishing regions) and (ii) inter-fishery (across fisheries) comparisons of species-specific discard rates in the following section, we selected non-pelagic, minimum landing size (MLS)-regulated species which were listed in the CFP-reform proposal and were commonly discarded from the above-mentioned fisheries in many different regions, namely cod (MLS = 35 cm in all regions except Skagerrak/Kattegat, where MLS was decreased to 30 cm in 2008 and in the Baltic Sea where it was increased to 38 cm in 2003), haddock (30 cm in all regions apart from Skagerrak/Kattegat, where it is 27 cm), hake (27 cm in all regions apart from Skagerrak/Kattegat, 30 cm, and the Mediterranean Sea, 20 cm), and plaice (27 cm). Acknowledging the different species composition of discards in the Mediterranean Sea, for this region, the following list was nominated in accordance with the above criteria: bogue (*Boops boops*, 10 cm according to national legislation in Greece), red mullet (*Mullet barbatus barbatus*, 11 cm), and deep-water rose shrimp (*Parapenaeus longirostris*, 2 cm carapace length).

Results

Dataset

National discard sampling programmes are not standardized at the European level and exhibit differences in the way vessels are selected for observation, the level of detail that is recorded during biological sampling (e.g. species numbers, weights, age, and maturity), and what units of ratio estimators are used to scale up measured numbers (Table 1). Notwithstanding the above, sampling effort and landings and discard rates were compiled for 15 towed-gear fisheries and 11 major European fishing regions (22 ICES Divisions and 5 Mediterranean geographic subareas; see Helmond and Uhlmann, 2011 for details). Among these classified fisheries, there were differences in fleet size, fishing effort, and sampling effort between countries (Table 2). Apart from one Greek fishery, generally <1% of the number of days spent at sea were observed in any fishery (Table 2).

Comparison of discard rates and ratios

Discard rates varied from <5 up to >300 ind. h^{-1} based on observations between 4 and 776 sampled trips (Figure 1). Observations from <4 trips were not included to avoid using nonrepresentative values which in turn will increase the overall variance. The variability in sampling effort is reflected in the precision of the estimates (Figure 1). With <10 observations, the uncertainty is large, and even with many samples, some discard rates are difficult to estimate precisely owing to the large variability in discarding patterns (e.g. plaice discards by beam trawlers in the North Sea and Eastern Channel have a low precision, although 100 trips were observed; Figure 1d).

Table 2. List of discard-intensive, towed-gear fisheries for which data were provided by country; together with an indication of the range of fishing and sampling effort within a given period: number of registered vessels, annual total, and % observed fishing effort (days at sea, D.A.S.).

Fishery	Country	Period	Number of vessels	Total D.A.S.	% observed D.A.S.
Otter trawl for crustaceans	Denmark	2003–2008	221–350	15 719–28 152	0.29–0.55
	France	2003–2008	390–504	104 310–161 280	0.11–0.26
	England	2002–2008	NA	4 179–5 161	0.19–1.29
Otter trawl for fish	Denmark	2003–2008	476–809	27 706–57 687	0.22–0.71
	Spain[a]	2003–2007	167–210	109 683–294 673	0.05–0.12
	Spain[b]	2003–2008	182–188	23 512–34 664	0.12–0.19
	Greece	2003–2006	5–12	378–2 545	4.37–34.56
	Greece[c]	2003–2008	326–336	53 624–59 552	0.06–0.22
	France	2003–2008	1 530–1 832	550 800–616 600	0.05–0.17
	England	2002–2008	NA	31 612–50 578	0.17–0.51
Beam trawl for fish	Denmark	1997–2008	2–17	313–2 111	0.00–5.16
	France	2003–2005	42–79	15 120–27 876	0.09–0.15
	Netherlands	2003–2008	99–139	14 210–21 027	0.17–0.30
	England	2002–2008	NA	30 929–49 384	0.15–0.47

[a]Fishery active in Northeast Atlantic ICES Divisions: VIIb, VIIc, VIIj, VIIk, VIIg, VIIh, VIIc, and IXa.
[b]Fishery active in the Western Mediterranean Sea: GSA3701.
[c]Different otter trawl fleets in the Greek part of the Mediterranean Sea were considered as a single fishery.

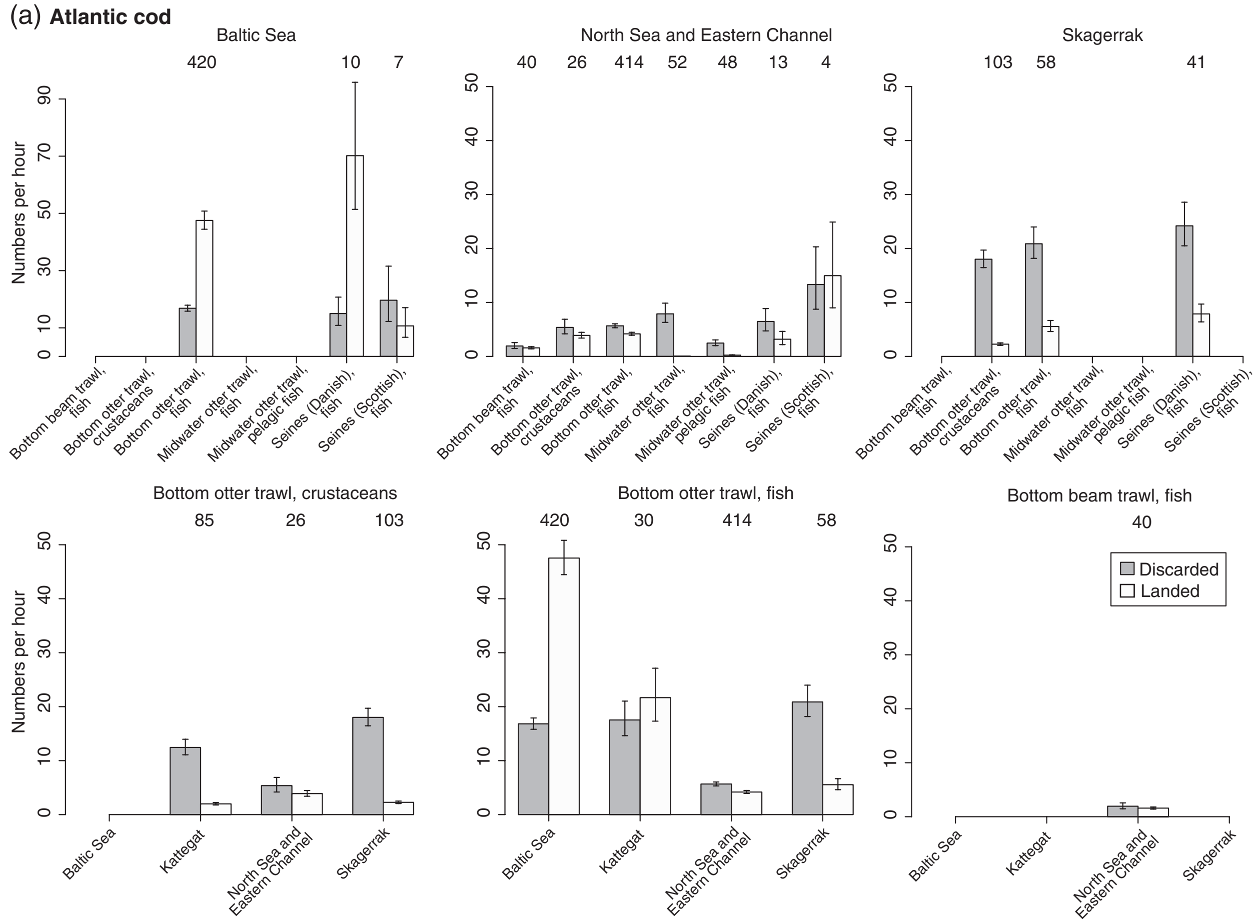

Figure 1. Discard and landings rates (with inferential error bars) of commercially valuable species across fisheries for a given region (inter-fishery, top row) and across regions for a given fishery (inter-region, bottom row of plots): (a) Atlantic cod, (b) haddock, (c) European hake, and (d) European plaice, when combined across countries and ICES Divisions, and (e) red mullet, (f) deep-water rose shrimp, and (g) bogue, when combined across countries fishing in the Mediterranean Sea. To improve visibility of bar plots, the *y*-axis scaling was broken where large differences between landings and discard rates existed. The number above each bar represent the number of observed trips (if ≥4).

Discard rates of cod and haddock (Figure 1a and b) were generally lower than those of hake and plaice (Figure 1c and d). Some of the Mediterranean species such as red mullet and deep-water rose shrimp exhibited the lowest rates (Figure 1e and f). In general, there were distinct patterns when comparing species-specific discard rates across fisheries and regions (Figure 1). For example, discard rates of Atlantic cod were found to be homogenous across fisheries, but were higher in the Skagerrak than in other areas (Table 3; Figure 1a). For haddock, differences of discard rates between regions were larger than between fisheries (Table 3; Figure 1b). Hake discard rates were relatively low and similar between different fisheries and regions, except for bottom-otter trawlers targeting fish in the Celtic Sea or crustaceans in the Bay of Biscay (Table 3; Figure 1c). For plaice, the differences of discard rates between fisheries seemed to be of the same order of magnitude than between regions (Table 3; Figure 1d). Notably, discard rates of plaice differed greatly between beam and otter trawls in the North Sea, but were much more homogenous across fisheries in the Irish Sea (Table 3; Figure 1d). In general, otter trawlers targeting crustaceans were observed to discard the majority of the cod, hake, and plaice compared with those targeting fish (Figure 1a–d).

Both discard rates and ratios were lower in the Mediterranean Sea than in other regions (Tables 3 and 4; Figure 1e–g). In the Mediterranean Sea, landings rates largely exceeded those of discard rates (Figure 1c, e, and f), except for bogue (Figure 1g). Discard ratios of hake were more homogenous than discard rates (Tables 3 and 4). The discard ratios of hake varied more in the Mediterranean Sea than in the Celtic Sea, where hake discards exceeded landings, although it is a target species by the fleet operating there (Table 4; Figure 1c).

Discussion

Our study highlights the variability of species-specific discard rates at a European scale. A stark contrast was observed between rates in the Mediterranean Sea and the other fishing regions. Further, we found that discard rates were more homogeneous across fisheries than regions, suggesting that discard management measures may be devised at a regional level; for example, by removing quota and catch composition rules (e.g. EEC, 2012b) and incentivising the use of more selective gears. In any case, differences in discard rates between species will also require species-specific approaches to discard reduction such as improvements to gear selectivity parameters.

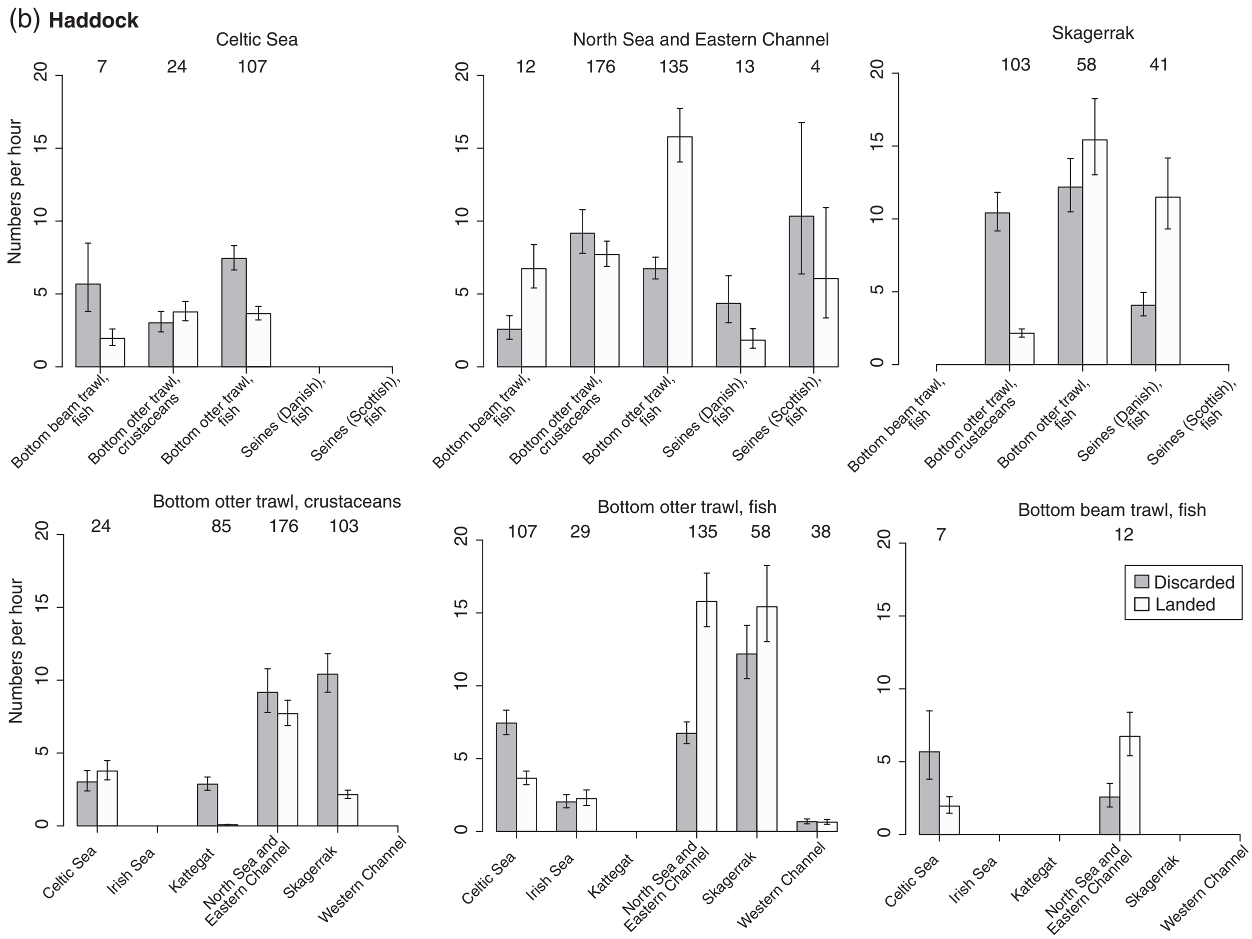

Figure 1. Continued

The low level of discarding of MLS-regulated species among Mediterranean otter trawl fisheries may be a consequence of smaller MLS (e.g. hake), a lack of MLS compliance and the absence of over-quota discards in a quota-independent management system of Greek demersal trawl fisheries (Catchpole *et al.*, 2013; Damalas and Vassilopoulou, 2013). Although undersized hake, for example, are being caught by demersal otter trawlers, the proportion (in weight) of discarded individuals is small (Damalas and Vassilopoulou, 2013). The fast-growing, smaller, and highly diverse fish fauna (Stergiou *et al.*, 1997) together with the existence of local markets for small fish and the low probability of prosecution for retaining undersized fish (Damalas and Vassilopoulou, 2013) may be further reasons why a tendency to retain most of the catch exists in this area.

Apart from removing quotas and catch composition rules, incentives to increase the use of more selective gears may be another option to reduce discards. One of the more selective gears and fishing methods in our study, where the majority of the target catch was landed, were Danish seines catching cod in the Baltic Sea and plaice in the North Sea (Figure 1b and d). Scottish seines seem equally selective for other target species such as megrim (*Lepidorhombus whiffiagonis*; Borges *et al.*, 2006). Some gears and methods have become more selective in recent years (beyond the period investigated here) in some areas (e.g. Kattegat and Skagerrak), and their uptake throughout the fishing community was partly promoted by incentives such as an increased quota share, access rights, and more fishing days (Madsen and Valentinsson, 2010).

A shortcoming of the current DCF, which complicated the inter-national synthesis of discard data, was the difficulty to agree upon common métier definitions. For example, target species assemblage of a level 5 métier could be defined either before the commencement of a trip or after a trip's completion (i.e. by determining its landings compositions). If we had followed the latter rule, it would have resulted in such a large number of métiers, at least among some countries, that it would have rendered an analysis of combined data meaningless. Alternative sampling units other than métiers may be considered for the selection of a sampling frame as part of at-sea monitoring programmes, e.g. vessels (ICES, 2012). This will also facilitate the standardization of discard sampling approaches (ICES, 2011). Another shortcoming, which hampered our analysis, was the inability to combine both raw data of fishing effort and catch statistics, partly due to the requirements of a data harmonization software for species weights which were not routinely collected in all programmes (Anon., 2009; ICES, 2010, 2011) and partly due to confidentiality concerns of releasing detailed, non-aggregated data to a third party (ICES, 2009); the latter is an issue which has hampered also other scientific analyses (Hinz *et al.*, 2013). The lack of recording a species' subsampled and total weight in some sampling

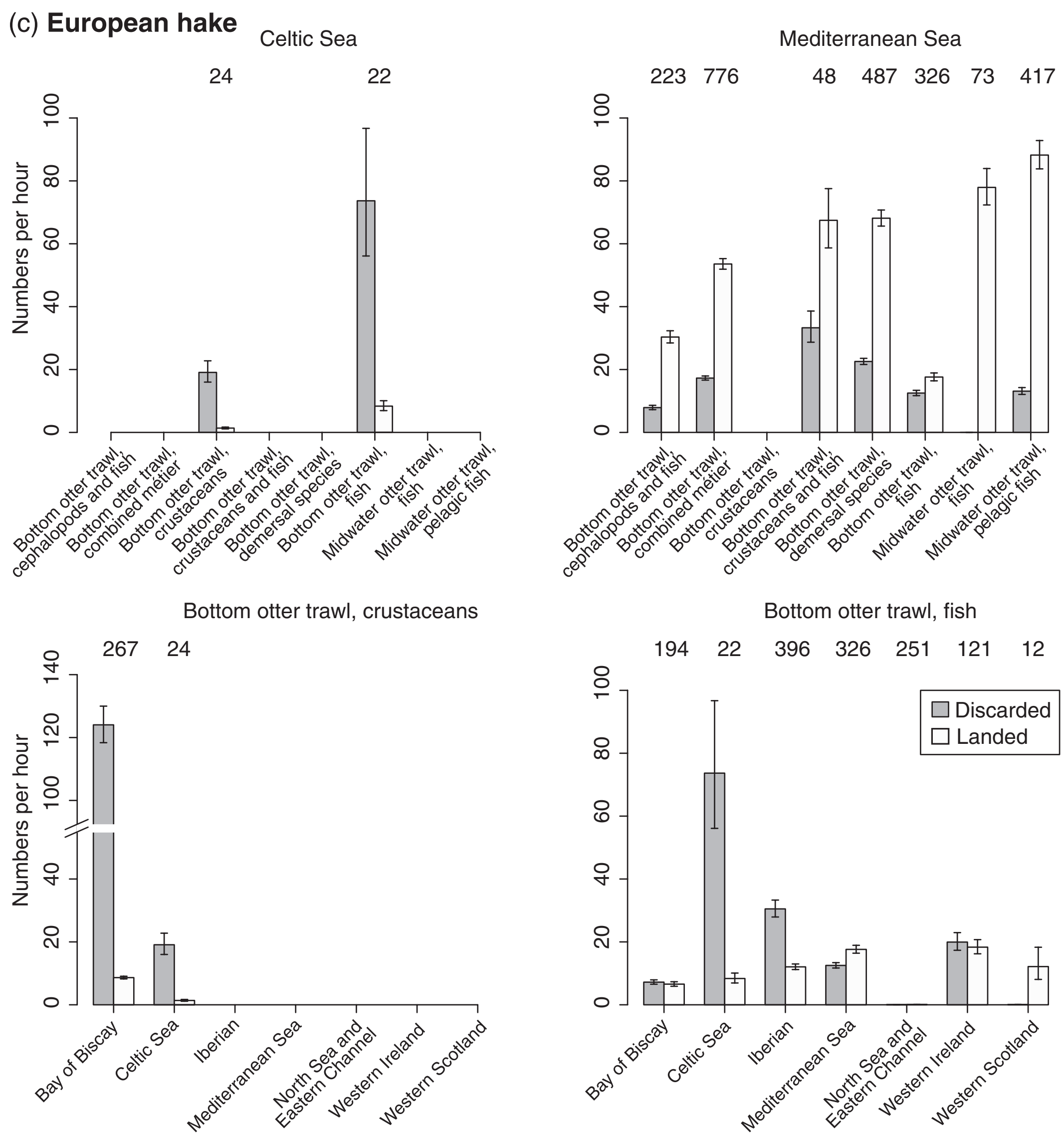

Figure 1. Continued

programmes precluded the use of the COST software (Anon., 2009; ICES, 2010).

Data incompatibility and confidentiality were also the reasons why we ended up contrasting aggregated data at the sampled trip as opposed to the fleet level. However, some inferences from patterns at the trip to the fleet level are possible. For example, the greater variability in discard rates between regions than fisheries may be a consequence of the region-specific quota and landings regulations, if acting as the main drivers of discarding (Catchpole *et al.*, 2013). For example, the main reason for discarding cod by Danish otter trawlers in the Baltic Sea was catches below MLS, whereas in the North Sea and Eastern Channel cod discards were also driven by a lack of sufficient quotas (Catchpole *et al.*, 2013). Regional differences in MLS regulations may also be associated with higher discard rates of hake from bottom-otter trawlers in the Celtic Sea (MLS = 27 cm), compared with lower rates by the same fishery in the Mediterranean Sea (MLS = 20 cm; Figure 1).

Nevertheless, the interpretation of differences between discard rates based on the available dataset is difficult for two reasons: first, not all species are caught and discarded in significant amounts in all regions; thus, for each region, we did not necessarily have data on the same species from all countries. Second, an additional problem is that the specific reason as to why a species is discarded can often be difficult to disentangle; especially if similar drivers such as quota and MLS regulations exist in different regions or target species vary throughout seasons and fisheries. For example, we have almost exclusively considered CFP-reform-listed fish as opposed to invertebrate crustacean species (other than deep-water rose shrimp) in our analysis. Thereby, we essentially mix comparisons of discard rates of non-target with those of target species. For bottom-otter trawlers targeting crustaceans, discarded fish typically exceeded their landings rates during those sampled trips, whereas for those targeting fish the opposite patterns was eminent (Figure 1a–d). Furthermore, the exact reasons why some fish with an associated landings quota were discarded above MLS can only be inferred (Catchpole *et al.*, 2013); unless fishers (or observers, for example, in the US Northeast Fisheries observer programme;

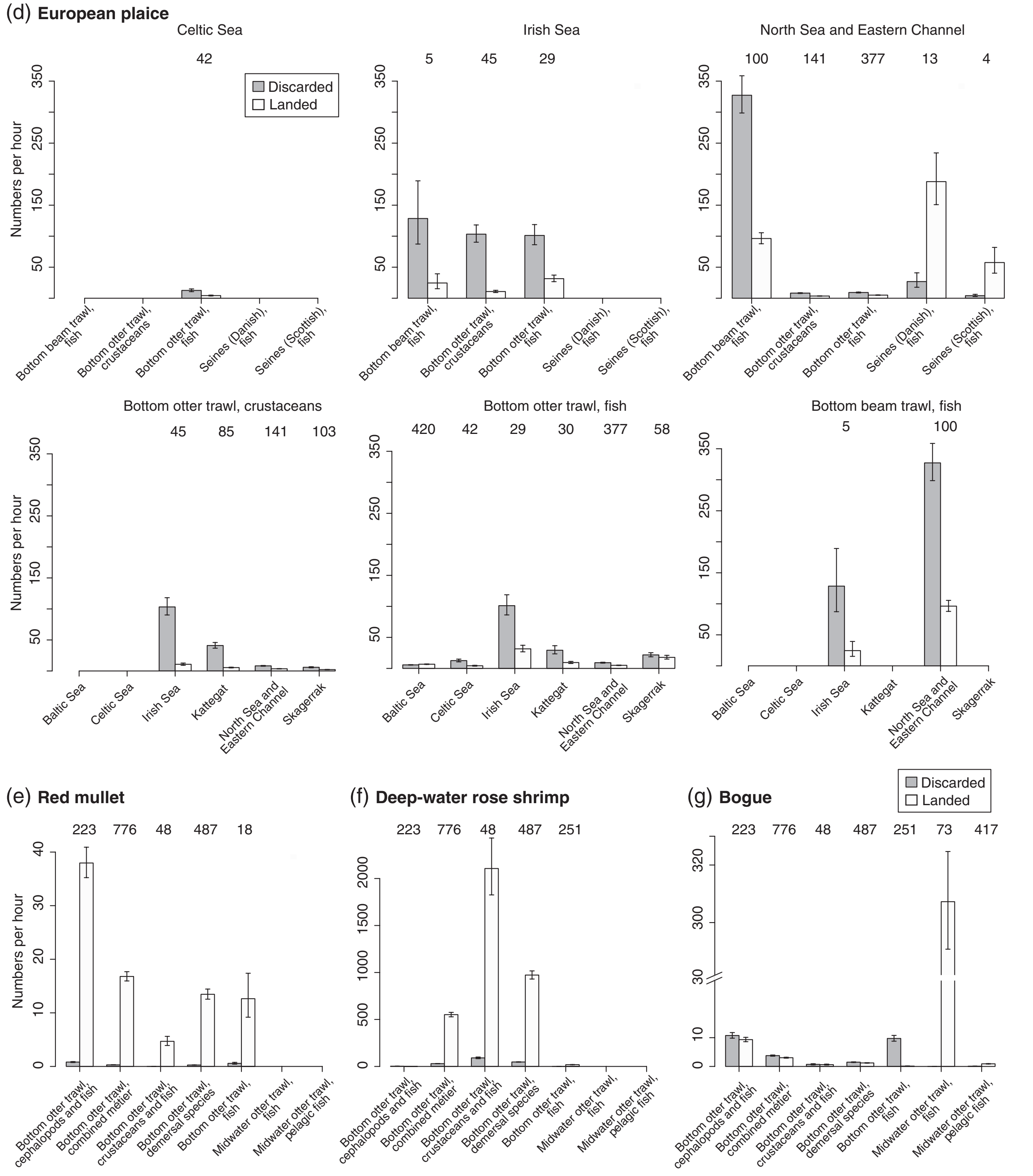

Figure 1. Continued

Wigley *et al.*, 2012) note why they chose to discard some fish over others (e.g. lack of quota, low market prize, or poor quality). Such reasons together with a plethora of likely other biological, technical, environmental, and socio-economic factors will contribute to fluctuating discard rates between species (Borges *et al.*, 2006), regions (Stratoudakis *et al.*, 1999; Eliasen *et al.*, 2013), gears, and years (Borges *et al.*, 2005), among others.

Introducing a discard ban or landing obligation in combination with catch limits across 27 Member States, 11 fishing regions, 27 species, and ~84 000 registered vessels (EEC, 2011; Eurostat, 2012) may compromise the profitability of some discard-intensive fisheries at least in the short term. A discard ban in isolation would increase the costs and decrease the income if the catch includes significant proportions of unwanted

Table 3. Coefficients of variation (%) of discard rates, where applicable, for selected species calculated across fisheries for a given region (inter-fishery) and across regions for a given fishery (inter-region).

	Atlantic cod	Haddock	European hake	European plaice	Red mullet	Deep-water rose shrimp	Bogue
Inter-fishery							
Baltic Sea	14						
Celtic Sea		84	83				
Irish Sea				14			
Mediterranean Sea			70		80	109	121
North Sea	62	77		188			
Skagerrak	15	48					
Inter-region							
Otter trawls (crustaceans)	53	63	104	114			
Otter trawls (fish)	43	79	126	120			
Beam trawls (fish)		53		62			

Table 4. Coefficients of variation (%) of discard ratios, where applicable, for selected species calculated across fisheries for a given region (inter-fishery) and across regions for a given fishery (inter-region).

	Atlantic cod	Haddock	European hake	European plaice	Red mullet	Deep-water rose shrimp	Bogue
Inter-fishery							
Baltic Sea	69						
Celtic Sea		25	3				
Irish Sea				9			
Mediterranean Sea			60		76	183	71
North Sea	29	40		73			
Skagerrak	9	57					
Inter-region							
Otter trawls (crustaceans)	22	35	<1	13			
Otter trawls (fish)	43	28	63	19			
Beam trawls (fish)		65		6			

organisms (H. M. Condie *et al.*, unpubl. manuscript). But, if the benefits of non-compliance still outweigh the costs of sanctions (Batsleer *et al.*, 2013), there may be little incentive for those with increased costs to comply with the desired outcome of reduced discards. Thus, the introduction of a discard ban will also require ancillary management measures such as catch quotas to stimulate more selective fishing practices (Condie *et al.*, 2013). For the allocation of catch quotas it will be important, as the European Commission noted, that these "need to reflect as much as possible the actual fishing patterns of vessels and their likely catch composition" (EEC, 2012c). This study provides at a European scale a first portrayal of the fishing and discarding pattern for some of the considered species, fisheries, and regions.

Our analysis of patterns in discard rates and ratios are based on measured numbers-at-length as opposed to length–weight relationship-estimated weights. If weights were used, patterns may have differed depending on the proportion of small and light-weight individuals in discarded fractions. For example, 100 discarded cod would have translated into a much greater weight than 100 discarded bogue or plaice, owing to differences in MLS (e.g. cod, <38 cm in the Baltic Sea, vs. bogue, <10 cm in the Mediterranean, or plaice, <27 cm) and their body morphology (flat vs. round shapes).

Our analysis is based on the assumption that all the sampling programmes considered here have a similar degree of bias. Such bias may be associated with the selection of vessels on a voluntary basis, deployment of observers, and their sampling procedures. Deployment and observer bias (Benoît and Allard, 2009) are inherent to sampling programmes and difficult, if not impossible, to quantify. However, some of the sampling programmes used in this study were evaluated based on surrogate measures, such as comparing the relative biomass of marketable fish between observed and unobserved trips gleaned from logbooks (Tsagarakis *et al.*, 2008); the representativeness of sampled trips vs. total effort in time and space (ICES, 2011); or selecting vessels for sampling from randomly generated lists and where sampling effort was allocated in proportion to the fisheries' annual fishing effort in the preceding year (Catchpole *et al.*, 2011). Despite these shortcomings, on-board observer programmes remain the most complete source of information on all components of the catch by fishing vessels.

The variability across samples resulted in wide confidence intervals for many discard rate estimates. If discard estimates are to be used in the future to set species-specific catch quotas within reasonable confidence limits, observations from a much greater number of fishing trips will be needed to more precisely estimate discard amounts. Alternative, innovative sampling techniques (e.g. self-sampling, Uhlmann *et al.*, 2011; vessel monitoring by satellite systems, Hintzen *et al.*, 2012; and closed-circuit TV, Kindt-Larsen *et al.*, 2011) may be necessary to overcome the high costs of observers and resulting small sample sizes. Otherwise, the number of species for which target precision levels can be achieved will remain small.

Onboard observer programmes, in their complexity require, like any other scientific survey, uniform sampling standards or at least their detailed description (Cotter and Pilling, 2007;

ICES, 2011) to allow for the inter-national integration of data. These programmes need to be continuously adapted because of perpetual changes in fishing activities. Despite some institutional inertia, the national efforts and the international coordination have allowed significant progress to be made. This study contributes to further improvements.

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