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Review

A Review of the European Union Landing Obligation Focusing on Its Implications for Fisheries and the Environment

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Abstract: Discarding is a common practice in fisheries. Total discards are estimated to be about 30 million tons, representing around 23% of worldwide catches. Discarding is an undesirable practice, not only because of the waste of resources, but also because of its contribution to the overexploitation of fish stocks. Several countries have already established discard bans, to different extents (e.g., Norway, Iceland, Chile, New Zealand). The EU's landing obligation (discard ban) is a major measure of the latest reform of the Common Fisheries Policy for EU fisheries. It aims to reduce unwanted catches in EU fisheries, by incentivizing improved selectivity and restoring fish stocks to levels that can sustain the maximum production over time without harming the biodiversity and the capacity of future generations to obtain fish. However, banning discards will inevitably induce diverse short- and long-term ecological, economic, and social impacts, which may determine whether the landing obligation's objectives will be achieved.

Keywords: landing obligation; discards; discard ban; survival rate; MSY; undersized fish; minimum landing size; minimum conservation reference size; Common Fisheries Policy

1. Introduction

In fisheries, discards, or discarded catch, is that portion of the total organic material of animal origin in the catch which is thrown away, or dumped at sea for whatever reason. The discards may be dead, or alive [1]. The Food and Agriculture Organisation of the United Nations' (FAO's) code of conduct for responsible fisheries [2] identified discarding as a major problem and called for its reduction. However, knowledge of the extent of discarding suffers from data availability and data quality issues [3]. This is mainly because of the lack of systematic studies and the high variability in the proportions of the catch discarded in different fisheries using different fishing gears [4,5]. Indeed, discards can account for 80% of the catch in some fisheries. Alverson et al. [6] estimated worldwide discards to be about 27 million tons, whereas more recently, Nellemann et al. [7] reported total discards to be about 30 million tons, accounting for 23% of global catches.

Discarding occurs for both legal and economic reasons. Regulations often define the catch that can be legally caught and landed. Catches that (i) exceed a quota, (ii) are below a minimum legal size or (iii) do not meet catch composition rules cannot be retained on board and must be discarded. For economic reasons, catches could also be discarded if (iv) they comprise small individuals of commercial species that command low prices, (v) they are of poor quality (e.g., damaged, or not so fresh), (vi) they include species of low market value, or (vii) they are of non-commercial species [8–11].

The impacts of discarding in different fisheries depends on the survival rates of discards which are mainly linked to the species and the fishing gear [12]. For most species, survival rates are generally low and for some species and fisheries, the proportion of individuals that survive discarding is zero [12–14]. The expected survival rates are potentially higher for crustaceans and some elasmobranchs, e.g., skates/rays [14,15].

Discarding is an undesirable practice, since it results in:

- A waste of resources; catches disposed of at sea could be consumed or used in some other way [16].
- Undocumented (i.e., unreported) catch which can lead to increased uncertainty in determining optimal fishing mortality rates due to unaccounted mortality [12,17].
- Total Allowable Catches (TACs) and quota management systems not functioning as intended, since part of the catch is not registered.
- An increased risk of overexploitation.

According to the United Nations, the 2012 world population of more than 7 billion will rise to approximately 9 billion by 2030 and to 10 billion by 2050 [18]. Such rapid population growth will also give rise to a rapid increase in the global demand for additional food [19–22]. Hence, there is not only a need to increase food production sustainably, but also to ensure responsible consumption and to minimize food waste.

As a result, some countries (e.g., Norway, Iceland, Faroe Islands, Chile, New Zealand and now the EU) have established discard bans, i.e., the prohibition of discarding and the obligation to land all catches of species falling under such bans. However, the range of species to which a discard ban extends differs by country. Discard bans aim to make fishing more sustainable by encouraging more responsible practices through, for example, the development and deployment of more selective fishing gears [23,24].

2. Extent of Discarding in EU Fisheries

The EU landed almost 5 million tons of seafood products in 2015, of which almost 4 million tons came from the North-East Atlantic and 0.4 million tons from the Mediterranean and Black Sea [25].

In Europe discards are recorded via at-sea sampling organized by national institutions and the data are administered and stored by national authorities [3]. To date, discard information has primarily been collected and recorded to supply data to stock assessments. In the NE Atlantic, stock assessments are carried out by the International Council for the Exploration of the Sea (ICES).

Outside of stock assessment, a Fisheries Dependent Information (FDI) database containing data submitted by EU Member States under the Data Collection framework (DCF; Regulation (EU) 199/2008 [26]) has been assembled and is hosted by the European Commission's Joint Research Centre (JRC). The FDI database holds data from EU Member States on fishing effort, landings and discards by year and quarter, for selected fishing gear groups and FAO areas [27,28]. Under the DCF, EU countries report data for the NE Atlantic (including the Baltic and North Seas), and these data are assembled by the JRC, making them available from 2003 to 2016 through a dissemination website (https://stecf.jrc.ec.europa.eu/dd/effort [29]).

For the Mediterranean and Black Sea, data on total weight and abundance of discards by length classes and/or age by stock/métier (Métier: defined as a group of fishing operations targeting a similar assemblage of species, using similar gear, during the same period of the year and/or within the same area and which are characterized by a similar exploitation pattern, (Reg. (EC) N° 949/2008 [30]).) are collected by EU countries under the DCF and stored in a database hosted by the EU Commission JRC (https://stecf.jrc.ec.europa.eu/dd/medbs [31]). These data are used, for example, to evaluate the state of exploitation of the main demersal and small pelagic stocks [32,33].

Coverage of both JRC datasets is about 75%, i.e., both contain discard data related to almost ¾ of the EU landings from the area. Outcomes for the Mediterranean and Black Sea dataset suggest that

reported discards of EU fleets represent slightly less than 10% of total catches in the area for 2015, significantly less than the 19% estimated by Tsagarakis et al. [34]. The data for the NE Atlantic suggest that reported discards represent a significantly higher share of the catches than in the Mediterranean and Black Sea data [27]. These differences might be explained because discards in the Mediterranean and Black Sea area are primarily undersized catches, while in the NE Atlantic catch limits also play an important role. However, the data gaps and high variability across fisheries from all areas make it difficult to derive a precise estimate of discards and hence the potential impact of the landing obligation cannot be predicted with any certainty.

3. Fisheries Management under the CFP and the Landing Obligation

The EU's Common Fisheries Policy (CFP) has been designed with the aim of ensuring that EU fishing is environmentally, economically, and socially sustainable. Among the goals of the CFP are to foster a dynamic fishing industry and to ensure a fair standard of living for fishing communities. Whereas maximizing catches is of importance, the CFP must ensure that fishing practices do not harm the ability of fish populations to reproduce. The objectives of the current policy [35] are set out in Article 2 and although the term sustainable exploitation is not explicitly defined, a definition is implied in the context of the objectives specified in paragraph 2, of that article, which states: "*The CFP shall apply the precautionary approach to fisheries management, and shall aim to ensure that exploitation of living marine biological resources restores and maintains populations of harvested species above levels which can produce the maximum sustainable yield. In order to reach the objective of progressively restoring and maintaining populations of fish stocks above biomass levels capable of producing maximum sustainable yield, the maximum sustainable yield exploitation rate shall be achieved by 2015 where possible and, on a progressive, incremental basis at the latest by 2020 for all stocks*". Hence sustainable exploitation under the CFP equates to the exploitation rate that will restore and maintain populations of fish stocks above biomass levels capable of producing maximum sustainable yield.

The establishment of the landing obligation (discard ban) is a major provision of the latest reform of the CFP and aims to gradually eliminate discards of commercially exploited stocks (Article 15 of EU Reg. 1380/2013 [35]). In fact, the extensive practice of discarding in EU fisheries fostered by the EU quota system, has been identified as one of the reasons for the failure of the past CFP [36,37]. Discarding has prevented several fish stocks from recovering, despite low quotas [38]. Indeed, the obligation to land all catches and a better use of marine resources are in line with the EU's Europe 2020 Strategy objective of a more resource efficient economy [39].

The landing obligation prescribes that all catches of species which are subject to catch limits and, in the Mediterranean, also catches of species which are subject to minimum sizes caught during fishing activities in Union waters or by Union fishing vessels in international waters, shall be brought and retained on board the fishing vessels, recorded, landed and counted against quotas where applicable, except when used as live bait. In both sea areas, catches of fish below minimum conservation reference size (MCRS) that otherwise would have been discarded, cannot be sold for human consumption.

The landing obligation was introduced in 2015 and is being applied progressively across different stocks and fisheries, starting with fisheries for small and large pelagic species, fisheries for industrial purposes and fisheries for salmon in the Baltic Sea on the 1st of January 2015. The landing obligation will be fully enforced by the 1st of January 2019 [35]. This gradual introduction is to allow the fishing industry to adapt their fishing practices to comply with the changes introduced by the landing obligation. Furthermore, TACs are adjusted to allow for the anticipated increase in landings due to landings of that part of the catch that would previously have been discarded [40,41]. To put the timescale of the landing obligation introduction into context the Norwegian no discard policy started in 1987 covering two species (cod and haddock) and took until 2008 to gradually expand to cover 18 species. After the law was changed in 2009 to make an obligation to land all catches the norm, the number of species covered again expanded to reach 55 species by 2014 [24]. The obligation to land all catches does not apply to species for which fishing is prohibited under the CFP; species for which

scientific evidence demonstrates high survival rates (of discards); and species that fall under so-called *de minimis* exemptions. A *de minimis* exemption of up to 5% of the total annual catches of all species subject to the landing obligation may be granted for fisheries where scientific evidence indicates that increases in selectivity are very difficult to achieve, or where the costs of handling unwanted catches are disproportionate [35]. Requests for exemptions incorporated in discard plans [42] or multi-annual plans [43] and are considered on a case by case basis [44,45].

4. Factors Determining Success or Failure of the Landing Obligation Implementation

A discard ban will be beneficial if total removals are reduced [46] or if for the same amount of removals, an exploitation pattern closer to the optimal is achieved [45]. For given quotas, such reductions in removals can take place without any reductions in the weight of fish landed, by avoiding capture of undersized and non-commercial species and by avoiding over quota catches. However, reaping such benefits relies on strict compliance with the discard ban and on providing incentives for fishers to alter their fishing practices.

Discarding takes place because fishers expect to profit from this practice or because they are obliged to discard to comply with legal requirements. The landing obligation removes the legal requirement to discard, but fishers may still have an incentive to discard for economic reasons. For example, the desire to discard part of the catch may be related to the limited physical storage on board and high sorting costs relative to expected revenues. Thus, an effective implementation of the landing obligation will require stringent control and enforcement and/or economic incentives to land more of the catch [46,47]. However, fisheries control and enforcement is typically rather expensive [48,49]. Consequently, the required level of surveillance to ensure full implementation could prove to be extremely costly considering the size and diverse nature of the EU fleet [46].

From the incentive perspective, incentives to land the unwanted catch should not be significantly lower than the cost of landing to avoid illegal discarding or the deterioration of the fishers' economic performance. The main incentive to land fish that would otherwise be discarded is economic i.e., the ability to derive revenue from such landings. However, under the landing obligation, fish below minimum size cannot be used for direct human consumption, i.e., must be destined to other uses (e.g., fishmeal and fish oil production, bait, direct feed in aquaculture, fertilizers). This will often require the provision of necessary infrastructure on land for processing the discards, which is commonly lacking [50–52]. On the other hand, revenues from undersized fish should not be higher than the cost of landing, to avoid creating a (perverse) incentive to target undersized fish.

To help to assess the effectiveness of the landing obligation it will be important to monitor the relative catch profiles of different gear types and area combinations. Two significant issues make such monitoring problematic. Firstly, fishery-dependent data, including data on discards, is often collected at a much coarser level of aggregation than the categories of fisheries potentially of interest to managers [53]. Hence disaggregation into sub-categories can only repeat the recorded age or length profile [54]. Second, there is a tension between data used for scientific or compliance monitoring. Discards made in contravention of the landing obligation are unlikely to be reported on a voluntary basis. Any records obtained by national compliance organizations are unlikely to be made available to the wider scientific community. Already, member states have rejected the notion of a scientific database disaggregating "unwanted catch" into constituent parts (below minimum landing size, high survivability etc.) partly on the grounds this increases the likelihood the data can be used for compliance purposes and the pressure this creates to supply data that shows compliance [55].

5. Main Implications for Stock Sustainability, Biodiversity and Food Supply

Fishing has significantly impacted the marine ecosystem since ancient times. With the escalation in industrial fishing such impacts have been accentuated, leading to the collapse of some fish stocks, and discarding has become commonplace. Several studies point to the need of fisheries management to reduce fishing capacity and catches to rebuild fish stocks and biodiversity [56–58]. Discarding

has also impacted the marine ecosystem, especially during recent decades. With the introduction of discard bans, the amount of fish discarded should decline. However, the short- and long-term environmental effects together with their associated economic and social impacts of reducing discards remain uncertain.

5.1. Effects on Stock Sustainability

A landing obligation-induced improvement in fisheries size selectivity, driven both by gear modifications and by changes in the temporal and spatial allocation of fishing effort, could translate into a substantial improvement in sustainability of both fish stocks and fisheries. The yield-per-recruit theory [59] suggests that for every stock there is an optimal size at first capture (*Lopt*) that maximizes fisheries yields [60]. Fishing at sizes lower than this *Lopt* results in "growth overfishing" (Growth overfishing: Growth overfishing occurs when fish are harvested at an average size that is smaller than the size that would produce the maximum yield per recruit. A recruit is an individual that has lived long enough it can potentially be harvested by a fishery.). This is an issue particularly relevant to the Mediterranean Sea, where the majority of fisheries resources are captured before they realize their growth potential [61,62]. Conversely, increasing size at first capture results in higher maximum sustainable yields (MSYs), greater stock size and greater resilience of fish stocks to increased fishing pressure [63–68]. Gullestad et al. [24] report that the mean age of landing for Northeast Arctic cod (subject to a discard ban in Norwegian fisheries since 1987) in recent years is 1.5 years higher than in the 1970s, which translates, all other things remaining equal, to an 18% increase in annual yield. Additionally, since size in fish is closely linked to maturity, a landing obligation-induced improvement in size selectivity could reduce "recruitment overfishing" (Recruitment overfishing: Recruitment overfishing occurs when the mature adult population (spawning biomass) is depleted to a level where it no longer has the reproductive capacity to replenish itself—there are not enough adults to produce offspring.) as well. Sparing the juveniles and allowing more fish to spawn-at-least-once before they are captured has been shown to improve stock sustainability [69–71]. To reap all the benefits from improved size selectivity relies heavily on the provision of effective technical solutions and finding appropriate incentives that will encourage fishers to adopt more selective harvesting methods [23,50,72].

5.2. Effects on Fish Biology

Phenotypic shifts have been observed in several fish stocks. Although differentiating plastic (short term reversible) changes from genetic (heritable) changes is challenging, there is a body of evidence for fisheries-induced evolution in important commercial fish stocks [73,74]. The pressure exerted by fishing tends to induce maturation at younger ages and/or smaller sizes. In turn, lower size at maturation is linked with reduced fecundity and offspring fitness [75,76]. Severe fisheries-induced evolution has also been linked to reduction in genetic diversity, alteration of natural mortality rates and shifts in predator-prey interactions [77–79]. The two main factors affecting the rate of evolution are the size selectivity of fisheries and the intensity of the harvesting. The close-to knife-edge selection pattern of trawl gears has been estimated to enhance selection for early maturity [80] but a response to the landing obligation that reduces the selection of undersized and/or commercially less valuable smaller fish should in theory, ease such selection pressure.

5.3. Effects on Food Supply to Other Species

Bio-energetic and ecosystem models indicate that discards may have strong direct and indirect impacts across the whole food-web, which may have positive or negative impacts on populations, or even alter or simplify food webs [81–85]. Moreover, many seabirds in Europe depend, at least for part of their life cycle, on fisheries discards [86–88].

A direct and immediate consequence of banning discards will be a reduction in the food supply to opportunistic feeders (e.g., shrimps, *Nephrops*) and associated but as yet unknown effects on the

populations of such species. A reduction in the amount of fish discarded may also directly affect meso-pelagic scavengers, benthic fish, and invertebrates [82,89], although these processes are not well understood [90]. The extent of such effects will depend on species' ability to switch to alternative prey items, potentially causing cascading effects on other species through increased predation or competition. Top predators may be also affected by changes in their prey populations, which may lead to changes in the predation pressure exerted on the different trophic groups [91].

5.4. Effects on Food Security

In relation to the supply of food for human consumption, a negative short- to medium-term effect of the landing obligation is likely to be a reduction in landings. This could arise with more selective fishing practices and/or because of the need to cease fishing when quotas for the most restrictive "choke" species are exhausted [92]. In mixed fisheries, the extent of the effects of choke species will depend on fishers' capacity to avoid catching the species with the most restrictive quotas and their ability to take advantage of any quota-swapping mechanisms. In theory, closing fisheries prematurely will tend to reduce catches and hence exploitation rates on those species for which the quota has not been taken. Conversely, if catches of species that have a high discard survival rate are landed, fishing mortality on such species could increase, resulting in a reduction in population biomass [67,85]. However, species can be exempt from the landing obligation if scientific evidence demonstrates that such species have high survival, although to date, providing such evidence has proven to be problematic [93].

A reduction in landings for sale for human consumption could also result from undersized fish now counting against quota. To counter this possible reduction in landings, the choke species problem and adverse economic impacts as fishers adapt to the new regime, "TAC adjustments" have been adopted [44,45]. Sometimes referred to as "TAC top-ups" such adjustments are intended to account for that part of the expected catch that in the absence of the landing obligation, would have been discarded. Before the introduction of the landing obligation, TACs were set to limit that part of the catch that could be legally landed so in setting TACs for stocks under the landing obligation, the predicted landings from a stock are inflated. In theory, the TAC adjustments are neutral regarding their impact on the stocks, because the expected catch (amount of fish removed from the sea) remains the same. However, discarding of unwanted catches continues, or unwanted catches are substantially reduced or avoided through changes to fishing practices, the adjusted TACs will provide additional opportunities to land more of the desired catch thereby increasing fishing pressure on stocks concerned, at least in the short-term.

6. Use of Undersized Catches that Otherwise Would Be Discarded

The emphasis of the landing obligation has been placed on reducing unwanted catches (through increased selectivity), rather than utilizing the catch that otherwise would be discarded [41]. Previously discarded catches can be mostly used as bait, feed for the aquaculture sector, pet-food, and fishmeal for the aquaculture, agriculture, and livestock sectors. Depending on the demand for these previously discarded individuals, fishers may be able to sell them, e.g., to fishmeal processing plants. However, to meet this demand, an appropriate infrastructure needs to be in place. Thus, making use of catch that would formerly have been discarded may imply changes to markets and the processing sector which may take time to occur, as they need to adapt to accommodate a wider range of catch components, and maybe even be incentivized to do so. Yet, the EU landing obligation, focuses on commercially regulated species and prohibits the use of undersized catches for human consumption, thus limiting their effective use [41].

The landing obligation, together with greater public awareness, should also encourage more responsible fishing practices and consumption to reduce food waste. FAO estimates that annually a third of all food produced for human consumption (i.e., 1.3 billion tons) is wasted [94]. Although fisheries represent less than 2.5% of overall food production in weight, most world regions lose about

30% to 35% of the fish and seafood production, and losses in industrialized regions are mostly due to discards (between 9–15% of catches) [94]. (These discards estimates are based on Kelleher [95] data, who estimated global discards to be 7.3 million tons, representing about 8% of the total catch, and consequently they are much lower than the most recent data from Nellemann et al. [7]. Therefore, food loses in the fish and seafood production in industrialized countries could be beyond 50% globally. In developing countries discards are only between 6–8% of the catches, and higher losses are suffered in the distribution process [94]).

In terms of responsible consumption, the landing obligation is not enough, and other steps need to be taken to avoid any kind of food loss and waste in the whole supply chain. For example, from balancing our consumption with our needs (i.e., avoiding overconsumption) and consuming more local food, to promoting the consumption of currently low-value by-catch species (non-regulated, and not subject to the landing obligation) from sustainable sources. Consumption is often more selective (i.e., picky) in wealthier communities than in poorer ones where a wider spectrum of species and sizes are landed and consumed [34]. In case of the failure to incentivize the consumption of low value species in economically developed countries, exporting this, perfectly edible, food to less economically developed countries where there is relevant demand should be considered.

7. Future Prospects

The EU landing obligation will be fully implemented in 2019 and at present, there are few data available to assess whether discard plans that have been implemented since 2015 have affected the fisheries and species concerned. Moreover, in general, discard data contain significant gaps and high variability across fisheries [96], which make it difficult to derive a precise estimate of discards and hence the potential impact of the landing obligation cannot be predicted with any certainty.

In principle, the EU's landing obligation is a step towards achieving more sustainable fisheries. For it to succeed in doing so, it should result in both a reduction in the volume of discarded catches and associated reductions in fishing mortality rates. The longer-term goal is to rebuild fish stocks to levels that can deliver MSY, which in many cases will allow an increase in overall catches above current levels.

However, to ensure compliance with the landing obligation will require high levels of surveillance (i.e., high cost of enforcement) and/or creation of economic incentives to land all catches [46]; without them, the success of the policy is at risk [97,98]. Different fleet sectors (targeting different species and using different fishing gears) will face different degrees of difficulty in achieving greater selectivity. Thus, policies to support the landing obligation will need to be tailored and capable of adaptation. This places an importance on monitoring the selectivity of fleets, despite the high costs of sampling at sea and the difficulties of ensuring detailed data collection for scientific purposes.

Moreover, the landing obligation has multiple dimensions, creating short- and long-term ecological, environmental, economic, and social impacts that may be considerable. The landing obligation could not be considered successful if fish stocks recover, but we lose the fishers. In the short- to medium-term, the landing obligation will impose a cost (or loss of revenue) to fishers, while it is uncertain whether and when they would be compensated by its medium to long-term benefits. Thus, to ensure compliance with the landing obligation, but also to try to mitigate the fishers' costs, it is important to further involve fishers, since they are the ones taking the decisions on whether to discard [97].

In summary the potential benefits of the landing obligation are considerable as are the challenges that must be overcome if it to be judged a success. The landing obligation is a step towards achieving more responsible fishing practices and the reduction of food waste at the production level. Nevertheless, further steps are necessary to encourage responsible consumption and further reduction of food waste in the commercialization and consumption stages.

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References

1. FAO (Food and Agriculture Organization of the United Nations). *Report of the Technical Consultation on Reduction of Wastage in Fisheries. Tokyo, Japan, 28 October–1 November 1996*; FAO Fisheries Report, No. 547; FAO: Rome, Italy, 1996; 27p.
2. FAO (Food and Agriculture Organization of the United Nations). *Code of Conduct for Responsible Fisheries*; FAO: Rome, Italy, 1995.
3. Uhlmann, S.S.; van Helmond, A.T.M.; Kemp Stefánsdóttir, E.; Sigurðardóttir, S.; Haralabous, J.; Bellido Millán, J.M.; Carbonell, A.; Catchpole, T.; Damalas, D.; Fauconnet, L.; et al. Discarded fish in European waters: General patterns and contrasts. *ICES J. Mar. Sci.* **2014**, *71*, 1235–1245. [CrossRef]
4. Rochet, M.-J.; Trenkel, V.M. Factors for the variability of discards: Assumptions and field evidence. *Can. J. Fish. Aquat. Sci.* **2005**, *62*, 224–235. [CrossRef]
5. Martinet, V.; Thébaud, O.; Doyen, L. Defining viable recovery paths toward sustainable fisheries. *Ecol. Econ.* **2007**, *64*, 411–422. [CrossRef]
6. Alverson, D.L.; Freeberg, M.H.; Murawski, S.A.; Pope, J.G. *A Global Assessment of Fisheries Bycatch and Dicards*; FAO Fisheries Technical Paper, No. 339; FAO: Rome, Italy, 1994; 233p.
7. Nellemann, C.; Mac Devette, M.; Manders, T.; Eickhout, B.; Svihus, B.; Prins, A.G.; Kaltenborn, B.P. (Eds.) *The Environmental Food Crisis—The Environment's Role in Averting Future Food Crises. A UNEP Rapid Response Assessment*; United Nations Environment Programme; GRID-Arendal; UNEP/Earthprint: Stevenage, UK, 2009.
8. Pascoe, S. *Bycatch Management and the Economics of Discarding*; FAO Fisheries Technical Paper. No. 370; FAO: Rome, Italy, 1997; 137p.
9. Hall, M.A.; Alverson, D.L.; Metuzals, K.I. By-catch: Problems and solutions. *Mar. Pollut. Bull.* **2000**, *41*, 204–219. [CrossRef]
10. Catchpole, T.L.; Frid, C.L.J.; Gray, T.S. Discards in North Sea fisheries: Causes, consequences and solutions. *Mar. Policy* **2005**, *29*, 421–430. [CrossRef]
11. Damalas, D.; Maravelias, C.D.; Osio, G.C.; Maynou, F.; Sbrana, M.; Sartor, P.; Casey, J. Historical discarding in Mediterranean fisheries: A fishers' perception. *ICES J. Mar. Sci.* **2015**, *72*, 2600–2608. [CrossRef]
12. Davis, M.W. Key principles for understanding fish bycatch discard mortality. *Can. J. Fish. Aquat. Sci.* **2002**, *59*, 1834–1843. [CrossRef]
13. Hill, B.J.; Wassenberg, T.J. Fate of discards from prawn trawlers in Torres Strait. *Mar. Freshw. Res.* **1990**, *41*, 53–64. [CrossRef]
14. STECF (Scientific, Technical and Economic Committee for Fisheries). *Landing Obligation in EU Fisheries (STECF-13-23)*; JRC Scientific and Policy Reports JRC 86112; EUR 26330 EN; Publications Office of the European Union: Luxembourg, 2013; 118p.
15. International Council for the Exploration of the Sea (ICES). *Report of the Workshop on Methods for Estimating Discard Survival 3 (WKMEDS 3), 20–24 April 2015, London, UK*; ICES CM 2015\ACOM:39; ICES: Copenhagen, Denmark, 2015; 47p.
16. Stockhausen, B.; Officer, R.A.; Scott, R. Discard mitigation–what we can learn from waste minimization practices in other natural resources? *Mar. Policy* **2012**, *36*, 90–95. [CrossRef]
17. MRAG. *Impact Assessment of Discard Policy for Specific Fisheries*; European Commission Studies and Pilot Projects for Carrying out the Common Fisheries Policy. No. FISH/2006/17—Lot 1; European Commission: Brussels, Belgium, 2007; 289p. Available online: http://ec.europa.eu/fisheries/documentation/studies/impact_assessment_discard_policy_2007_en.pdf (accessed on 17 January 2018).

18. Gerland, P.; Raftery, A.E.; Ševčíková, H.; Li, N.; Gu, D.; Spoorenberg, T.; Alkema, L.; Fosdick, B.K.; Chunn, J.; Lalic, N.; et al. World population stabilization unlikely this century. *Science* **2014**, *346*, 234–237. [CrossRef] [PubMed]
19. Duarte, C.M.; Holmer, M.; Olsen, Y.; Soto, D.; Marbà, N.; Guiu, J.; Black, K.; Karakassis, I. Will the oceans help feed humanity? *BioScience* **2009**, *59*, 967–976. [CrossRef]
20. Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C. Food security: The challenge of feeding 9 billion people. *Science* **2010**, *327*, 812–818. [CrossRef] [PubMed]
21. Garcia, S.M.; Rosenberg, A.A. Food security and marine capture fisheries: Characteristics, trends, drivers and future perspectives. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **2010**, *365*, 2869–2880. [CrossRef] [PubMed]
22. Béné, C.; Barange, M.; Subasinghe, R.; Pinstrup-Andersen, P.; Merino, G.; Hemre, G.I.; Williams, M. Feeding 9 billion by 2050–Putting fish back on the menu. *Food Secur.* **2015**, *7*, 261–274. [CrossRef]
23. Bellido Millán, J.M.; Carbonell Quetglas, A.; García Rodriguez, M.; García Jiménez, T.; González Aguilar, M. *The Obligation to Land All Catches—Consequences for the Mediterranean: In-Depth Analysis*; Policy Department B: Structural and Cohesion Policies; European Parliament: Brussels, Belgium, 2014.
24. Gullestad, P.; Blom, G.; Bakke, G.; Bogstad, B. The "Discard Ban Package": Experiences in efforts to improve the exploitation patterns in Norwegian fisheries. *Mar. Policy* **2015**, *54*, 1–9. [CrossRef]
25. FAO (Food and Agriculture Organization of the United Nations). Global Capture Production 1950–2015. 2018. Available online: http://www.fao.org/figis/servlet/TabSelector (accessed on 17 January 2018).
26. European Commission (EC). Commission Regulation (EC) No 665/2008 of 14 July 2008 laying down detailed rules for the application of Council Regulation (EC) No 199/2008 concerning the establishment of a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy. *Off. J. Eur. Union* **2008**, *L186*, 3–5.
27. STECF (Scientific, Technical and Economic Committee for Fisheries). *Fisheries Dependent Information—Classic (STECF-17-09)*; JRC 107598; Publications Office of the European Union: Luxembourg, 2017; 848p. ISBN 978-92-79-67481-5. [CrossRef]
28. STECF (Scientific, Technical and Economic Committee for Fisheries). *Fisheries Dependent Information—Classic (STECF-17-09) ADDENDUM*; JRC 109483; Publications Office of the European Union: Luxembourg, 2017; 11p. ISBN 978-92-79-67481-5. [CrossRef]
29. Joint Research Centre—STECF (Scientific, Technical and Economic Committee for Fisheries). 2017—Fisheries Dependent Information. Available online: https://stecf.jrc.ec.europa.eu/dd/effort (accessed on 17 January 2018).
30. European Commission (EC). Commission Decision of 12 July 2016 (2016/1251/EU) on Adopting a multiannual Union programme for the collection, management and use of data in the fisheries and aquaculture sectors for the period 2017-2019 (notified under document C(2016) 4329). *Off. J. Eur. Union* **2016**, *L207*, 113.
31. Joint Research Centre—STECF (Scientific, Technical and Economic Committee for Fisheries). 2017—Mediterranean and Black Sea. Available online: https://stecf.jrc.ec.europa.eu/dd/medbs (accessed on 17 January 2018).
32. STECF (Scientific, Technical and Economic Committee for Fisheries). *Mediterranean Assessments 2016—Part 2 (STECF-17-06)*; JRC 106582; Publications Office of the European Union: Luxembourg, 2016; 430p. ISBN 978-92-79-67478-5. [CrossRef]
33. STECF (Scientific, Technical and Economic Committee for Fisheries). *Mediterranean Stock Assessments 2017 Part I (STECF-17-15)*; JRC 109350; Publications Office of the European Union: Luxembourg, 2017; 432p. ISBN 978-92-79-67487-7. [CrossRef]
34. Tsagarakis, K.; Palialexis, A.; Vassilopoulou, V. Mediterranean fishery discards: Review of the existing knowledge. *ICES J. Mar. Sci.* **2014**, *71*, 1219–1234. [CrossRef]
35. EU. European Council Regulation 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. *Off. J. Eur. Union* **2013**, *L354*, 22–61.
36. Salomon, M.; Holm-Muller, K. Towards a sustainable fisheries policy in Europe. *Fish Fish.* **2013**, *14*, 625–638. [CrossRef]

37. Borges, L. The evolution of a discard policy in Europe. *Fish Fish.* **2015**, *16*, 534–540. [CrossRef]
38. European Commission. Green Paper on the Reform of the Common Fisheries Policy. Brussels, 22.4.2009, COM(2009) 163 Final. 2009. Available online: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0163:FIN:EN:PDF (accessed on 17 January 2018).
39. European Commission. *COM 2020/2010. Communication from the Commission EUROPE 2020. A Strategy for Smart, Sustainable and Inclusive Growth*; European Commission: Brussels, Belgium, 2010.
40. EU. Council Regulation (EU) 2016/72 of 22 January 2016 fixing for 2016 the fishing opportunities for certain fish stocks and groups of fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters, and amending Regulation (EU) 2015/104. *Off. J. Eur. Union* **2016**, *L22*, 1–165.
41. Borges, L.; Cocas, L.; Nielsen, K.N. Discard ban and balanced harvest: A contradiction? *ICES J. Mar. Sci.* **2016**, *73*, 1632–1639. [CrossRef]
42. European Commission. Discarding and the Landing Obligation. Available online: https://ec.europa.eu/fisheries/cfp/fishing_rules/discards_en (accessed on 17 January 2018).
43. European Commission. Multi-Annual Plans. Available online: https://ec.europa.eu/fisheries/cfp/fishing_rules/multi_annual_plans_en (accessed on 17 January 2018).
44. STECF (Scientific, Technical and Economic Committee for Fisheries). *50th Plenary Meeting Report (PLEN-15-03)*; JRC 98672; Publications Office of the European Union: Luxembourg, 2015; 90p. ISBN 978-92-79-54011-0. [CrossRef]
45. STECF (Scientific, Technical and Economic Committee for Fisheries). *Methodology and Data Requirements for Reporting on the Landing Obligation (STECF-16-13)*; JRC 102672; Publications Office of the European Union: Luxembourg, 2016; 95p. ISBN 978-92-79-56790-2. [CrossRef]
46. Condie, H.M.; Grant, A.; Catchpole, T.L. Incentivising selective fishing under a policy to ban discards; lessons from European and global fisheries. *Mar. Policy* **2014**, *45*, 287–292. [CrossRef]
47. Bellido, J.M.; Santos, M.B.; Pennino, M.G.; Valeiras, X.; Pierce, G.J. Fishery discards and bycatch: Solutions for an ecosystem approach to fisheries management? *Hydrobiologia* **2011**, *670*, 317–333. [CrossRef]
48. Willman, R.; Kelleher, K.; Arnason, R.; Franz, N. *The Sunken Billions: The Economic Justification for Fisheries Reform*; World Bank: Washington, DC, USA; FAO: Rome, Italy, 2009; 100p.
49. Cicuendez Perez, J.; Alvarez Alvarez, M.; Heikkonen, J.; Guillen, J.; Barbas, T. Efficiency analysis of the use of remote sensing to mitigate IUU fishing: Application to the Mediterranean Bluefin tuna fishery. *Fish. Res.* **2013**, *147*, 24–31. [CrossRef]
50. Villasante, S.; Pierce, G.J.; Pita, C.; Pazos Guimeráns, C.; Garcia Rodrigues, J.; Antelo, M.; da Rocha, J.M.; García Cutrín, J.; Hastie, L.C.; Veiga, P.; et al. Fishers' perceptions about the EU discards policy and its economic impact on small-scale fisheries in Galicia (North West Spain). *Ecol. Econ.* **2016**, *130*, 130–138. [CrossRef]
51. Mangi, S.C.; Catchpole, T.L. Using discards not destined for human consumption. *Environ. Conserv.* **2014**, *41*, 290–301. [CrossRef]
52. Catchpole, T.L.; Ribeiro-Santos, A.; Mangi, S.C.; Hedley, C.; Gray, T.S. The challenges of the landing obligation in EU fisheries. *Mar. Policy* **2017**, *82*, 76–86. [CrossRef]
53. ICES. *Report of the Working Group on Commercial Catches (WGCATCH), 7–11 November 2016, Oostende, Belgium*; ICES CM 2016/SSGIEOM:03; ICES: Copenhagen, Denmark, 2017; 142p.
54. European Commission. *Report on the STECF Expert Working Group 17-12 Fisheries Dependent Information: 'New-FDI'*; JRC Technical Report; Publications Office of the European Union: Luxembourg, forthcoming.
55. STECF (Scientific, Technical and Economic Committee for Fisheries). *56th Plenary Meeting Report (PLEN-17-03)*; JRC 109344; Publications Office of the European Union: Luxembourg, 2017; 162p. ISBN 978-92-79-77297-9. [CrossRef]
56. Pauly, D.; Christensen, V.; Guénette, S.; Pitcher, T.J.; Sumaila, U.R.; Walters, C.J.; Watson, R.; Zeller, D. Towards sustainability in world fisheries. *Nature* **2002**, *418*, 689–695. [CrossRef] [PubMed]
57. Worm, B.; Hilborn, R.; Baum, J.K.; Branch, T.A.; Collie, J.S.; Costello, C.; Fogarty, M.J.; Fulton, E.A.; Hutchings, J.A.; Jennings, S.; et al. Rebuilding global fisheries. *Science* **2009**, *325*, 578–585. [CrossRef] [PubMed]
58. De Leo, F.; Miglietta, P.P.; Pavlinović, S. Marine ecological footprint of Italian Mediterranean fisheries. *Sustainability* **2014**, *6*, 7482–7495. [CrossRef]

59. Beverton, R.J.H.; Holt, S.J. *On the Dynamics of Exploited Fish Populations*; Series II; United Kingdom Ministry of Agriculture and Fisheries, Fishery Investigations: London, UK, 1957; Volume XIX.
60. Froese, R.; Stern-Pirlot, A.; Winker, H.; Gascuel, D. Size matters: How single-species management can contribute to ecosystem-based fisheries management. *Fish Res.* **2008**, *92*, 231–241. [CrossRef]
61. Colloca, F.; Cardinale, M.; Maynou, F.; Giannoulaki, M.; Scarcella, G.; Jenko, K.; Bellido, J.M.; Fiorentino, F. Rebuilding Mediterranean fisheries: A new paradigm for ecological sustainability. *Fish Fish.* **2013**, *14*, 89–109. [CrossRef]
62. Vasilakopoulos, P.; Maravelias, C.D.; Tserpes, G. The alarming decline of Mediterranean fish stocks. *Curr. Biol.* **2014**, *24*, 1643–1648. [CrossRef] [PubMed]
63. Scott, R.D.; Sampson, D.B. The sensitivity of long-term yield targets to changes in fishery age-selectivity. *Mar. Policy* **2011**, *35*, 79–84. [CrossRef]
64. Raveau, A.; Macher, C.; Méhault, S.; Merzéréaud, M.; Le Grand, C.; Guyader, O.; Bertignac, M.; Bertignac, M.; Fifas, S.; Guillen, J. A bio-economic analysis of experimental selective devices in the Norway lobster (*Nephrops norvegicus*) fishery in the Bay of Biscay. *Aquat. Living Resour.* **2012**, *25*, 215–229. [CrossRef]
65. Cardinale, M.; Hjelm, J. Size matters: Short term loss and long term gain in a size-selective fishery. *Mar. Policy* **2012**, *36*, 903–906. [CrossRef]
66. Guillen, J.; Macher, C.; Merzéréaud, M.; Bertignac, M.; Fifas, S.; Guyader, O. Estimating MSY and MEY in multi-species and multi-fleet fisheries, consequences and limits: An application to the Bay of Biscay mixed fishery. *Mar. Policy* **2013**, *40*, 64–74. [CrossRef]
67. Guillen, J.; Macher, C.; Merzéréaud, M.; Fifas, S.; Guyader, O. The effect of discards and survival rate when choosing between landings or catches as yield in the Maximum Sustainable Yield estimation: Application to the nephrops fishery in the Bay of Biscay. *Mar. Policy* **2014**, *50*, 207–214. [CrossRef]
68. Vasilakopoulos, P.; O'Neill, F.G.; Marshall, C.T. The unfulfilled potential of fisheries selectivity to promote sustainability. *Fish Fish.* **2016**, *17*, 399–416. [CrossRef]
69. Myers, R.A.; Barrowman, N.J. Is fish recruitment related to spawner abundance? *Fish. Bull.* **1996**, *94*, 707–724.
70. Myers, R.A.; Mertz, G. The limits of exploitation: A precautionary approach. *Ecol. Appl.* **1998**, *8* (Suppl. 1), S651–S691. [CrossRef]
71. Vasilakopoulos, P.; O'Neill, F.G.; Marshall, C.T. Misspent youth: Does catching immature fish affect fisheries sustainability? *ICES J. Mar. Sci.* **2011**, *68*, 1525–1534. [CrossRef]
72. De Vos, B.I.; Döring, R.; Aranda, M.; Buisman, F.C.; Frangoudes, K.; Goti, L.; Macher, C.; Maravelias, C.D.; Murillas-Maza, A.; van der Valk, O.; et al. New modes of fisheries governance: Implementation of the landing obligation in four European countries. *Mar. Policy* **2016**, *64*, 1–8. [CrossRef]
73. Olsen, E.M.; Heino, M.; Lilly, G.R.; Morgan, M.J.; Brattey, J.; Ernande, B.; Dieckmann, U. Maturation trends indicative of rapid evolution preceded the collapse of northern cod. *Nature* **2004**, *428*, 932–935. [CrossRef] [PubMed]
74. Kuparinen, A.; Merilä, J. Detecting and managing fisheries-induced evolution. *Trends Ecol. Evol.* **2007**, *22*, 652–659. [CrossRef] [PubMed]
75. Hutchings, J.A. Life history consequences of overexploitation to population recovery in Northwest Atlantic cod (*Gadus morhua*). *Can. J. Fish. Aquat. Sci.* **2005**, *62*, 824–832. [CrossRef]
76. Jørgensen, C.; Fiksen, Ø. State-dependent energy allocation in cod (*Gadus morhua*). *Can. J. Fish. Aquat. Sci.* **2006**, *63*, 186–199. [CrossRef]
77. Jennings, S.; Greenstreet, S.; Reynolds, J. Structural change in an exploited fish community: A consequence of differential fishing effects on species with contrasting life-histories. *J. Anim. Ecol.* **1999**, *68*, 617–627. [CrossRef]
78. Conover, D.O. Darwinian fishery science. *Mar. Ecol. Prog. Ser.* **2000**, *208*, 303–306.
79. Heino, M.; Gadø, O.R. Fisheries-induced selection pressures in the context of sustainable fisheries. *Bull. Mar. Sci.* **2002**, *70*, 639–656.
80. Hutchings, J.A. Avoidance of fisheries-induced evolution: Management implications for catch selectivity and limit reference points. *Evol. Appl.* **2009**, *2*, 324–334. [CrossRef] [PubMed]
81. Fulton, E.A.; Smith, A.D.M.; Punt, A.E. Which ecological indicators can robustly detect effects of fishing? *ICES J. Mar. Sci.* **2005**, *62*, 540–551. [CrossRef]
82. Catchpole, T.L.; Frid, C.L.J.; Gray, T.S. Importance of discards from the English Nephrops norvegicus fishery in the North Sea to marine scavengers. *Mar. Ecol. Prog. Ser.* **2006**, *313*, 215–226. [CrossRef]

83. Kaiser, M.J.; Hiddink, J.G. Food subsidies from fisheries to continental shelf benthic scavengers. *Mar. Ecol. Prog. Ser.* **2007**, *350*, 267–276. [CrossRef]
84. Heath, M.R.; Cook, R.M.; Cameron, A.I.; Morris, D.J.; Speirs, D.C. Cascading ecological effects of eliminating fishery discards. *Nat. Commun.* **2014**, *5*, 3893. [CrossRef] [PubMed]
85. Sardà, F.; Coll, M.; Heymans, J.J.; Stergiou, K.I. Overlooked impacts and challenges of the new European discard ban. *Fish Fish.* **2015**, *16*, 175–180. [CrossRef]
86. Bicknell, A.W.J.; Oro, D.; Camphuysen, K.C.J.; Votier, S.C. Potential consequences of discard reform for seabird communities. *J. Appl. Ecol.* **2013**, *50*, 649–658. [CrossRef]
87. Votier, S.C.; Bicknell, A.; Cox, S.L.; Scales, K.L.; Patrick, S.C. A bird's eye view of discards reforms: Bird-borne cameras reveal seabird/fishery interactions. *PLoS ONE* **2013**, *8*, e57376. [CrossRef] [PubMed]
88. Casey, J. Birds, discards and decision-making. *Br. Birds* **2016**, *109*, 250–251.
89. Bozzano, A.; Sardà, F. Fishery discard consumption rate and scavenging activity in the northwestern Mediterranean Sea. *ICES J. Mar. Sci.* **2002**, *59*, 15–28. [CrossRef]
90. ICES. *Report of the Working Group on the Ecosystem Effects of Fishing Activities (WGECO), 8–15 April 2014, Copenhagen, Denmark*; ICES: Copenhagen, Denmark, 2014.
91. Kopp, D.; Robert, M.; Chouvelon, T.; Méhault, S. Some expected impacts of the Common Fishery Policy on marine food webs. *Mar. Policy* **2016**, *66*, 8–14. [CrossRef]
92. Baudron, A.R.; Fernandes, P.G. Adverse consequences of stock recovery: European hake, a new "choke" species under a discard ban? *Fish Fish.* **2015**, *16*, 563–575. [CrossRef]
93. STECF (Scientific, Technical and Economic Committee for Fisheries). *Landing Obligation in EU Fisheries—Part 3* (STECF-14-06); JRC Scientific and Policy Reports JRC 89785; EUR 26610 EN; Publications Office of the European Union: Luxembourg, 2014; 56p.
94. Gustavsson, J.; Cederberg, C.; Sonesson, U.; Van Otterdijk, R.; Meybeck, A. *Global Food Losses and Food Waste*; FAO: Rome, Italy, 2011; 38p.
95. Kelleher, K. *Discards in the World's Marine Fisheries: An Update*; FAO Fisheries Technical Paper. No. 470; FAO: Rome, Italy, 2005; 131p.
96. Catchpole, T.L.; Elliott, S.; Peach, D.; Mangi, S.C.; Gray, T.S. How to deal with the EU landing obligation: Lessons from an English discard ban sea trial. *ICES J. Mar. Sci.* **2017**, *75*, 270–278. [CrossRef]
97. Eliasen, S.Q.; Papadopoulou, K.-N.; Vassilopoulou, V.; Catchpole, T. Socio-economic and institutional incentives influencing fishers' behavior in relation to fishing practices and discard. *ICES J. Mar. Sci.* **2014**, *71*, 1298–1307. [CrossRef]
98. Sigurðardóttir, S.; Kemp Stefánsdóttir, E.; Condie, H.; Margeirsson, S.; Catchpole, T.L.; Bellido, J.M.; Eliasen, S.Q.; Goñi, R.; Madsen, N.; Palialexis, A.; et al. How can discards in European fisheries be mitigated? Strengths, weaknesses, opportunities and threats of potential mitigation methods. *Mar. Policy* **2015**, *51*, 366–374. [CrossRef]