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ECOSYSTEMS AND SUSTAINABILITY

Review Paper

Fishery discards and bycatch: solutions for an ecosystem approach to fisheries management?

Jose M. Bellido · M. Begoña Santos · M. Grazia Pennino · Xulio Valeiras · Graham J. Pierce

Abstract It has been widely acknowledged that fishery discard practices constitute a purposeless waste of valuable living resources, which plays an important role in the depletion of marine populations. Furthermore, discarding may have a number of adverse ecological impacts in marine ecosystems, provoking changes in the overall structure of trophic webs and habitats, which in turn could pose risks for the sustainability of current fisheries. The present review aims to describe the current state-of-the-art in discards research, with particular emphasis on the needs and challenges associated with the implementation of the Ecosystem Approach to Fisheries Management (EAFM) in European waters. We briefly review the international and European policy contexts of discarding, how discard data are collected and incorporated into stock assessments, selectivity in fishing and the main consequences of discarding for ecosystem dynamics. We then review implementation issues related to reducing discards under the EAFM and the associated scientific challenges, and conclude with some comments on lessons learned and future directions.

Keywords Discards · Bycatch · Ecosystem approach to fisheries management · EAFM

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J. M. Bellido (✉) · M. G. Pennino
Instituto Español de Oceanografía, Centro Oceanográfico de Murcia, Murcia, Spain
e-mail: josem.bellido@mu.ieo.es

J. M. Bellido · M. B. Santos · G. J. Pierce
School of Biological Sciences, University of Aberdeen, Aberdeen, UK

M. B. Santos · X. Valeiras · G. J. Pierce
Instituto Español de Oceanografía, Centro Oceanográfico de Vigo, Vigo, Spain

Introduction

Fisheries management has evolved over the years, from being uniquely concerned with single stocks and quotas to the realization that individual fisheries should be managed taking into account their effects on, and interactions with, the ecosystems to which the target species belong, and taking account the human dimensions of fisheries and their relationships with other marine and coastal zone activities, for example, by working in partnership with stakeholders. This has led to the coining of the term ‘Ecosystem Approach to Fisheries Management’ (EAFM). The EAFM (also named Ecosystem Approach to Fisheries, EAF and Ecosystem-Based Fisheries Management, EBFM) is defined as an integrated approach to management that considers the entire ecosystem, including humans. The goal is to maintain an ecosystem in a healthy, productive and resilient condition so that it can continue to provide the services that humans want and need (FAO Fisheries Glossary, http://www.fao.org/fi/glossary/default.asp).

Discarding is currently one of the most important topics in fisheries management, both from economic and environmental points of view (Alverson & Hughes, 1996; Alverson, 1997; Kelleher, 2005; Catchpole & Gray, 2010). The FAO Fisheries Glossary describes discards as 'that proportion of the total organic material of animal origin in the catch, which is thrown away or dumped at sea, for whatever reason. It does not include plant material and post-harvest waste such as offal. The discards may be dead or alive'. Discarding is an integral part of most fishing operations, since practically all fishing gears catch, at some time, species or specimens that are subsequently thrown back into the sea. Although the two concepts are obviously linked, it is nevertheless not necessarily the same as bycatch, which is the part of a catch that is 'taken incidentally in addition to the target species towards which fishing effort is directed. Some or all of it may be returned to the sea as discards, usually dead or dying'. Another related concept is 'slippage', a common practice in pelagic seine net fishing, whereby unwanted catches are released from the net and not taken on board. This is also destructive because the fish are often killed during the capture process (e.g. FAO, 2010; Huse & Vold, 2010).

Discarding involves a conscious decision made by fishers to reject some part of the catch. Discarding of target species can occur for reasons related to fishing regulations, e.g. if fish are below the minimum landing size or the fisher holds insufficient quota for the species or economic reasons: differences in market prices of different species and size-classes and limited availability of storage space can lead to so-called 'high grading', whereby less valuable species and size-classes are discarded to leave space for more valuable catch (e.g. Punt et al., 2006). Other reasons for discarding include damage or degradation of the catch and catching of non-commercial species. When the quota for a species is exceeded, the decision is often taken, especially in mixed fisheries, to continue fishing for other species even if this implies discarding individuals of the species for which the quota has been exceeded. In most EU fisheries, this is both legally permitted and economically justified (since the alternative would usually be to stop fishing), albeit clearly wasteful. It is generally illegal to sell under-sized fish or catches of protected species such as corals, some sharks or rays, and marine mammals.

Bycatch and discarding have numerous, generally undesirable, consequences. Clearly these are to some extent no different from the consequences of fishing per se, since all fishing causes mortality of marine animals and potentially also affects marine ecosystem structure and function. The main distinction to be drawn therefore is that discards (and any landed bycatch of no economic value) offer no obvious economic benefit to fishers and therefore represent additional 'unnecessary' mortality.

Kelleher (2005) estimated worldwide discards at an average of 7.3 million tonnes per year, or around 8% of the total catch, although the discard rate was much higher in certain fisheries. Thus, shrimp fisheries, particularly in tropical waters, had the highest total amount and highest proportion of discards with a weighted average discard rate of 62% (see Table 1, based on Kelleher, 2005). Demersal finfish trawling had a relatively low discard rate but because of its ubiquity contributed a substantial total amount of discards worldwide. The third most important contribution to total discards was from tuna longlines. Most other line fisheries have low or negligible discards although they may have significant bycatches of seabirds and turtles, an issue which gained prominence in the 1990s (e.g. Brothers, 1991; Cherel et al., 1996; Barnes et al., 1997; Hall et al., 2000). Fisheries with very low or negligible discards included small-scale and artisanal fisheries in general. However, although small-scale and artisanal fisheries usually have low levels of discards per vessel, in certain areas with very large artisanal fleets (e.g. the Mediterranean, some parts of Africa), the total amount of discards can still be very substantial (Stergiou et al., 2003; Nunoo et al., 2009).

Global fishery discards have significantly declined in recent years (Kelleher, 2005; Zeller & Pauly, 2005; Davies et al., 2009). However, there are important exceptions, including (poorly regulated) deepwater fisheries in international waters and some of the most highly regulated fisheries, where severe quota restrictions have resulted in high grading (Kelleher, 2005). There is no unique and simple explanation for the overall decline, but it appears to have been due to, among other factors, improved selectivity of fishing technology and greater utilization of the bycatch for aquaculture and human consumption. Obviously, the

Table 1 Annual landings and discards in the main types of fisheries worldwide (in thousand tonnes), the percentage of discards to catch and the range of discard rates (based on Kelleher, 2005)

Fishery	Landings	Discards	Weighted average discard rate (%)	Range of discard rates (%)
Shrimp trawl	1126.3	1865.1	62.3	0–96
Demersal finfish trawl	16051.0	1704.1	9.6	0.5–83
Tuna and HMS longline (high migratory species)	1403.6	560.5	28.5	0–40
Midwater (pelagic) trawl	4133.2	147.1	3.4	0–56
Tuna purse seine	2679.4	144.2	5.1	0.4–10
Multigear and multispecies	6023.1	85.4	1.4	na
Mobile trap/pot	240.6	72.5	23.2	0–61
Dredge	165.7	65.4	28.3	9–60
Small pelagic purse seine	3882.9	48.9	1.2	0–27
Demersal longline	581.6	47.3	7.5	0.5–57
Gillnet (surface/bottom/trammel)	3350.3	29.0	0.5	0–66
Handline	155.2	3.1	2.0	0–7
Tuna pole and line	818.5	3.1	0.4	0–1
Hand collection	1134.4	1.7	0.1	0–1
Squid jig	960.4	1.6	0.1	0–1

latter is unlikely to have contributed much to reducing fishing mortality or reducing damage to ecosystems. Indeed, the growth of aquaculture potentially represents one of the greatest threats to marine ecosystems through the increased demand for fishmeal derived from so-called 'reduction fisheries'—although Asche & Tveterås (2004) argue that the threat can be avoided by efficient management of such fisheries.

At the time of writing, the European Commission is discussing the banning of discards as part of the reform of the CFP. In the present review, we examine the policy context of discarding in European fisheries and the current state-of-the-art in discards research. We discuss the main consequences of discarding for ecosystem dynamics, fishing exploitation and implications for management, with particular emphasis on the needs and challenges associated with the implementation of the Ecosystem Approach to Fisheries Management (EAFM) in European waters. We and then examine possible solutions to the issue in the context of the EAFM.

International regulations on discarding and bycatch

Before turning to focus on the situation in Europe, we here briefly outline the international context. As noted by Alverson et al. (1994) in their global assessment of fisheries bycatch and discards, awareness of discarding in fisheries can be seen in the bible, in parable of the net (Matthew 13: 47–48): 'Again, the Kingdom of Heaven can be illustrated by a fisherman—he casts a net into the water and gathers in fish of every kind, valuable and worthless. When the net is full, he drags it up onto the beach and sits down and sorts out the edible ones into crates and throws the others away…'. Alverson et al. also point out that incidental catches and discards have received most attention in the USA, relating to primarily to mortality of marine mammals in the Eastern Tropical Pacific purse seine fishery for tuna, high seas driftnetting fisheries (in which seabird and salmon bycatches were also a major issue) and the high level of discarding in shrimp fisheries in the Gulf of Mexico. Two significant pieces of national legislation resulted in the 1970s, the Marine Mammal Protection Act (1972) and the Endangered Species Act (1973). The USA also had a leading role in the adoption in 1989 of United Nations General Assembly Resolution 44/225, which recommended that all members of the United Nations agreed to a Moratorium on all large-scale pelagic driftnet fishing on the high seas by 30 June 1992. The United Nations Convention on the Law of the Sea (UNCLOS) was concluded in 1982, finally coming into force in 1994. This covers, for example, the requirement for fishing within the Exclusive Economic Zones of another country to respect conservation measures and other laws and regulations of the country.

In recent decades, the Fishery and Agriculture Organization of the United Nations (FAO) has provided a range of legislative instruments and guidelines for fisheries, including the 1995 Code of Conduct for Responsible Fisheries, the 1999 FAO International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (IPOA-Seabirds, FAO, 1999), the 1999 FAO International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks, FAO 1999), and the 2009 FAO Guidelines to Reduce Sea Turtle Mortality in Fishing Operations (FAO, 2009). Arising from a Technical Consultation held in Rome in December 2010, FAO issued International Guidelines on Bycatch Management and Reduction of Discards (FAO, 2010). These guidelines are intended to assist States and Regional Fisheries Management Organisations or Arrangements (RFMO/As) in the management of bycatch and reduction of discards in conformity with the FAO Code of Conduct for Responsible Fisheries. Among other initiatives, these Guidelines establish that States and RFMO/As should develop a framework for long-term cooperative work on bycatch management and discard reduction in association with stakeholders, management authorities at all levels, and other agencies and organizations, including providing accurate and timely information on bycatch-related issues, regulations and activities. They also establish the participation of scientists with appropriate expertise to conduct and evaluate bycatch and discard assessments, and propose mitigation strategies.

Discarding and fishery policy in Europe: towards an ecosystem approach

To the extent that obligatory discarding is part of a coherent management framework, it could be regarded as unfortunate but unavoidable collateral damage which nevertheless confers wider benefits for sustainability. In the European Union, however, such a viewpoint is increasingly untenable, not least because the European Common Fishery Policy has, at least in several important respects, failed to deliver sustainable fisheries. Important issues include fleet overcapacity, overexploitation of vulnerable species, wasteful practices such as discarding, environmental degradation and effects on non-target species: see Daw & Gray (2005) and Khalilian et al. (2010) for detailed critiques. Such failings are explicitly recognized in the Green Paper concerning the current process of CFP reform (EU COM, 2009). Some other countries, e.g. Norway, ban discarding and arguably also achieve more sustainable fisheries.

Any implementation of EAFM must consider discarding for several reasons: (a) it directly affects the balance, diversity and functioning of the ecosystem, (b) it potentially leads to reduced income from fisheries and (c) because it is widely perceived as being wasteful and ineffective, it undermines respect of fishers for the governance system and thereby leads to reduced compliance with, participation in and effectiveness of the regulatory system.

According to Hilborn (2011), there are 'core' and 'extended' aspects of EAFM. The 'core' consists of three primary features: (a) keeping fleet capacity and fishing mortality rates low enough to prevent ecosystem-wide overfishing, (b) reducing or eliminating bycatch and discards and (c) avoiding habitat-destroying fishing methods. The 'extended' EAFM takes into account trophic interactions and area-based management. Certainly such management objectives are not exclusive to EAFM and most fisheries management agencies around the world attempt to meet at least some of these objectives as part of existing single-species management regimes. In fact, the recent FAO International Guidelines on Bycatch Management and Reduction of Discards (FAO, 2010), in support of management measures to mitigate bycatch and discard problems, advised that 'States and RFMO/As should, where appropriate, map seabed habitats, distributions and ranges of species taken as bycatch, in particular rare, endangered, threatened or protected species, to ascertain where species taken as bycatch might overlap with fishing effort'.

It is evident that the good intentions of the CFP have not borne fruit. Thus, the current UK government stance (as of April 2011) is that 'The current Common Fisheries Policy is broken. It has not delivered its key objective of an economically viable fishing industry which minimizes impacts on marine ecosystems'. (http://www.defra.gov.uk/environment/marine/cfp/). A significant part of that problem appears to be that the scientific advice, which aims to address the CFP objectives, has been routinely ignored due to a decision-making process that clearly has rather different objectives, short-term political expediency being prominent among them. Cardinale & Svedang (2008) argued that, despite the limitations of using a deterministic single stock modelling framework for assessment, managers and politicians have had the necessary scientific instruments for managing stocks and avoid stock collapses (and by implication for achieving increased economic and social sustainability), but they failed to deliver since they tried to minimize the short-term negative impact of policy on those who are most affected (i.e. the fishing industry). The authors argued that is the practice of ignoring the scientific advice, more than the advice itself, which is to be blamed for the wasteful depletion of formerly abundant marine resources. Khalilian et al. (2010) offer similar arguments when discussing the failure of the CFP from biological, economical, legal and political perspectives. Excessive quotas set by the Council, regularly overriding scientific advice and payment of direct and indirect subsidies by both the EU and Member States, have resulted in too much fishing effort and excessive exploitation rates, leading in turn to low stock sizes, low catches and severely disturbed ecosystems. The lack of transparency of its regulations as well as insufficient control and enforcement of its provisions have contributed to the failure of the CFP. Khalilian et al. (2010) characterize the CFP as an opaque decision-making procedure with little approval by the public, which leads to a culture of non-compliance that undermines the CFP and the final goal of implementing sustainable fisheries management.

Several authors have argued that appropriate application of single-species management could actually achieve some of the goals of EAFM. Froese et al. (2008) show that setting fishing mortalities for several North Sea and Baltic species so as to achieve maximum sustainable yield (MSY) for individual stocks would be an improvement on the current regime, while taking only larger individuals (such that all fish are able to achieve maximum growth rate) would increase yield while at the same time rebuilding stocks and minimizing impact on the ecosystem. Although not specifying how catching smaller fish could be avoided, the authors point to fisheries elsewhere in the world where such objectives have been achieved (Hilborn, 2011). Hilborn (2011) raises the question ‘Would EAFM be unnecessary if we had implemented single-species management correctly?’ His answer is that successful single-species management could be a major step forward in many areas but, by itself, it is not sufficient because pure single-species management does not consider impacts on non-target species, trophic interactions among species and habitat-destroying fishing practices. However, he also notes that successful single-species management demands understanding of the ecosystem impacts of factors other than fishing, i.e. the need to deal with broader ecosystem concerns is already evident.

Nevertheless, even this latter analysis is based on the implicit assumption that the current assessment, management and governance system, whereby the different components are seen as independent, sequential, processes, is an appropriate framework. Environmental sustainability cannot be achieved in isolation from considerations of socioeconomic sustainability; the implementation of management measures must take into account the responses of the fishers. Thus, stock assessments must extend to offering predictions of stock trajectories under not only a range of possible management measures but a range of realistic outcomes in terms of compliance and enforcement of regulations. Furthermore, fisher buy-into the management and governance regime can itself be managed, through measures such as participatory management and co-management.

Collecting information on discards

Discards account for significant mortality in fisheries. However, few stock assessments take into account information on discards (Mesnil, 1996; Hammond & Trenkel, 2005; Punt et al., 2006; Aarts & Poos, 2009; Fernández et al., 2009). This is mainly due to limitations of the available data: long time series of onboard observation are not available for all the fleets involved in the exploitation of most stocks. In addition, a large amount of monitoring and research effort is needed to obtain this kind of information (Alverson et al., 1994; Kelleher, 2005).

One of the main problems with onboard observer data is the high spatial and temporal variation shown in discard patterns. Aside from the obvious difficulty of obtaining precise estimates for a highly variable phenomenon, if the sampling design does not account for it, this high variation could hide some bias in the estimation, which will be transferred and multiplied when raising estimates to the level of the whole fleet or stratum (Allen et al., 2001, 2002; Borges et al., 2004; Apostolaki et al., 2006). Rochet & Trenkel (2005) concluded that the factors underlying variation in discard rates are complex, noting that the amount of discards is rarely proportional to catch or effort, and commenting that although environmental conditions and fishing methods affect discards stratification, stratification of sampling to take this into account may not improve the precision of estimates.

The above-mentioned conclusions notwithstanding, one solution is to identify and measure auxiliary variables (e.g. environmental, biological, regulatory, market factors) which affect the nature and extent of discarding and use statistical modelling to control for these effects. For example, Stratoudakis et al. (1998) analysed sources of variation in proportions of three gadid species discarded at length by fishers using demersal gears in the North Sea. They found clear differences between inshore and offshore fishing areas (with more high grading observed in the latter) but also showed that discarding practices for haddock and cod were consistent over time and across gears—although discarding of (the less valuable) whiting was more variable and depended on catch composition. Borges et al. (2005) investigated both the best sampling unit and auxiliary variables for estimating discards in Irish fisheries. Their results showed that use of fishing trip rather than haul as sampling unit reduced the overall variability of estimates. Use of different auxiliary variables resulted in different estimates and although the authors observed that number of fishing trips is probably reported more reliably than hours fishing or weight of landings reliable, there was no reason to favour one estimate over another.

While spatial stratification of discard sampling is routinely undertaken (as described, for example, in Stratoudakis et al. 1998), it is worth considering that spatial patterns of discarding can occur at several scales and may differ between species. Such patterns can be quantified using spatial statistical methods, as shown by Sims et al. (2008) and Lewison et al. (2009) in relation to fishery bycatch. In the context of bycatches of megafauna, these authors point out the importance of considering bycatch relative to target catch as well as the relevance of identifying spatial patterns in bycatch to management and mitigation of bycatches. These are conclusions which are equally relevant to discarding.

Another aspect requiring more attention is the change of discarding behaviour over time, e.g. seasonally or over the course of a fishing trip, the latter being particularly important in distant water fleets that make long trips. Several factors, e.g. availability of storage space, temporal variation in abundance of target species or even changes in market price during the fishing trip can lead to changing decisions about which part of the catch to retain. Bellido & Pérez (2007) evaluated alternative sampling strategies for discarding by Spanish trawlers using computer resampling (bootstrapping) and identifying the strategy that minimized the coefficient of variation. They suggested sampling at least one vessel and one trip per vessel, monthly, sampling between 30 to 50 hauls within a trip, and sampling 8–15 hauls at the beginning, middle and end of the trip. Gray et al. (2005) reported seasonal differences in discard rates in an Australian estuarine commercial gillnet fishery. These differences were attributed to a seasonal difference in fishing regulations such that nets could be left in the water only 3 h during summer but could be set overnight in the winter. Although the discarding rate was generally low, the authors concluded that reducing maximum soak time (as well as increasing mesh size) would reduce the discard rate.

Most of the studies cited thus far have involved data collection by on-board observers. Observer programmes are generally thought to be essential for accurate quantification of discards in most fisheries. However, some authors have questioned whether observer at-sea trips can be used to make inferences about catch composition and discards. Thus Benoît & Allard (2009) highlight two issues, 'deployment' bias resulting from non-random distribution of observers among sampling units and observer effects due to changes in fishing practice or location when observers are on board.

A major limitation is the expense of using on-board observers to record discard data. Allard & Chouinard (1997) proposed using a combination of on-board and shore-based sampling, with the latter making use empirically determined changes in the length-frequency distribution of catches when discarding had taken place. The advent of on-board camera technology offers the prospect of a more comprehensive (if perhaps less detailed) picture of discarding practices. FAO (2010) recommend that management of bycatch and reduction of discards should be supported by technological development both in the harvest and the post-harvest and valorization sector.

Incorporating discard data into assessments

The omission of discard data from the stock assessment process may result in underestimation of fishing mortality and can lead to biased assessments, hampering achievement of sustainable resource use (e.g. Punt et al., 2006; Aarts & Poos, 2009). Some progress has been made recently on inclusion of discard data and survival estimates into stock assessment. For example, in the case of the Norwegian lobster (*Nephrops norvegicus*), one of the most valuable crustaceans landed in Europe, with most of the catches taken by bottom trawls, estimates of 25% discard survival rate have been used in the assessment of the stocks by the International Council for the Exploration of the Sea (ICES, 2010).

Several authors have used statistical modelling to estimate discards, based on the assumption that the main driver for discarding is minimum landing size regulations (e.g. Casey, 1996; Cotter et al., 2004; Punt et al., 2006). One limitation in such models has been the assumption that gear selectivity is constant. Aarts & Poos (2009) developed a statistical catch-at-age model with flexible selectivity functions to reconstruct historical discards of plaice in the North Sea and estimate stock abundance. Fernández et al. (2009) developed a Bayesian age-structured stock assessment model for the southern stock of European hake (*Merluccius merluccius*) and showed that incorporating information on discards into the model had an important effect on predicted stock trajectories.

Punt et al. (2006) point out that inclusion of discard data can also permit detection of strong year-classes before they are apparent in landings data—while stressing that discarding remains a poor use of the resource and that conducting pre-recruit surveys is a more appropriate way to predict future recruitment. The few fish stock assessments that include discards assume that all discarded fish die, which is not necessarily the case. Mesnil (1996) incorporated various levels of discard survival into stock assessments based on Virtual Population Analysis (VPA) and showed that this could significantly affect estimates of fishing mortality and stock size. The author also suggests that, from a management point of view, measures to improve the survival of released fish (if feasible and effective) might be as effective as increasing mesh size and potentially more acceptable to fishers. Although the inclusion of discard data into stock assessment models is a major improvement, most of the above-mentioned examples are based mainly on a single-species approach.

Selective fishing

More selective fishing should reduce discards by avoiding unwanted catches and maximizing the marketable portion of the catch. Zhou et al. (2010) refer to six types of selective fishing: by species, stock, size, sex, season and/or space. Increased selectivity is generally favoured by fishers, as they are by nature selective and do not want to catch fish that cannot be sold or that will create sorting difficulties. Recent work in this field covers topics such as mesh size regulation (Suuronen et al., 2007), technical measures (Catchpole et al., 2008; Enever et al., 2009a), mesh size and selectivity modifications (Revill & Holst, 2004; Guijarro & Massuti, 2006; Revill et al., 2007; Massuti et al., 2009), cost-benefit analysis (Macher et al., 2008), new designs to improve escapement of unwanted fish (Graham, 2003; Revill et al., 2006; Catchpole et al., 2007; Moore et al., 2009; Yamashita et al., 2009) and devices to reduce the impact of trawls on benthic communities (Revill & Jennings, 2005). There have also been important advances in reduction of bycatches of marine mammals and seabirds in gears such as purse seines, gill nets and long-lines. National Research Council (1992) describe how a combination of modified fishing gear, modified procedures and education of skippers dramatically reduced dolphin bycatches in the Eastern Tropical Pacific tuna fishery. Several studies have shown that acoustic alarms (pingers) can reduce porpoise bycatch in gill nets (e.g. Gearin et al., 2000), although their efficacy is by no means universally accepted and there is a need to monitor the success of deploying pingers. Goetz et al. (2011)

describe trials of modifications to long-lines to reduce seabird bycatches (see also references therein).

Although bycatch reduction has been achieved in some fisheries by modifying the gear, some well-publicised cases have not been successful. The fishery for Baltic cod (*Gadus morhua*) has been subject to a great number of technical regulations, with the aim of reducing juvenile mortality. However, a large increase in selectivity introduced in a single step may not be commercially acceptable and in this case the measures resulted in substantial short-term economic losses. Suuronen et al. (2007) note that fishers' willingness to comply with new regulations depends largely on their ability to deal with such short-term reductions in catch. When losses are too large, gears will be manipulated and rules will be circumvented. Apparently, a gradual increase in mesh size (or gradual introduction of any restrictive measure) would often be more acceptable to the fishers (Suuronen et al., 2007). In addition, fishers usually prefer mesh size regulations to fishing effort regulation, probably because the former still allows them the opportunity to apply the deep knowledge they have on fishing gears and the way they operate.

Although more selective fishing is always suggested as a key factor in reducing discards, Zhou et al. (2010) argue that less selective fishing gears may help to maintain diversity and functioning in certain marine ecosystems (although they do also point to the importance of the protection of vulnerable species and the need for regulation of fishing effort). This potential inconsistency between promoting more selective fishing and the 'ecosystem approach' requires attention from both theorists and practitioners in order to formulate the best scientific advice (Kelleher, 2005). Hall & Mainprize (2005) recommend diversifying our harvest and learning to utilize a wider variety of products, although they stress that this is not intended as a justification of extending fishing activity to other species, rather it should involve reduced fishing pressure on current target species.

On the impact of fishing and discards in the ecosystem

Knowledge of the impacts of bycatch and discarding at the community and ecosystem levels becomes increasingly necessary in the context of the multi-species and ecosystem-based approaches to fisheries management (Borges et al., 2001).

Disturbance by trawling is well known to affect the species composition and structure of marine benthic communities. Several authors have suggested that trawling disturbance is 'farming the sea'; ploughing the seabed to boost production. To others, trawling is assumed to damage key functional processes (Jennings & Kaiser, 1998). Also, the physical disturbance of the sediment by trawl nets could expose endobenthic organisms which can then be predated by carnivores (Jenkins et al., 2004). However, the effects on ecosystem structure and function (biodiversity, community structure, trophic links) of returning biomass directly to the ecosystem though discarding are not so well known (Dayton et al., 1995; Jennings & Kaiser, 1998; Lindeboom & de Groot, 1998; Hall, 1999; Collie et al., 2000; Kaiser & de Groot, 2000; Borges et al., 2001; Erzini et al., 2002). The effects of discarding on the stability of trophic webs may have negative consequences for commercial stocks due to the disruption of species interactions and cascading effects throughout the trophic chains (Monteiro et al., 2001). Tsagarakis et al. (2008) showed that the composition and/or trophic level of discards in relation to the marketed catch seemed to be indicative of the exploitation state of the demersal community.

Various seabird species use discards and offal as trophic resources, and some species are believed to have increased in numbers as a result of availability of food via discards (Furness, 2003; Valeiras, 2003; Votier et al., 2004). However, Grémillet et al. (2008) argue that, at least for gannets, fishery waste is basically 'junk food' and has a negative impact on growth rates of chicks.

Another fraction of the discards sinks in the water column and its fate is poorly known but some midwater scavengers such as sharks (Sánchez et al., 2005) may benefit from them. Finally, the remaining discarded biomass ends up on the seabed and is consumed by the benthic fauna (Jennings & Kaiser, 1998; Jenkins et al., 2004). The biomass made available by fisheries discards returning to the seabed may produce good conditions for a short-term increase of scavenger benthic species, including fish, crabs, shrimps and other invertebrates.

Long-term studies of the benthos communities in the southern and central North Sea suggest that biomass and production have increased (Kroncke et al., 1998). This could be a response to trawling disturbance, climate change and/or eutrophication (Rijnsdorp & van Leeuwen, 1996; Kroncke et al., 1998). The decrease in abundance of vulnerable species such as elasmobranchs, echinoderms, corals and sponges due to seafloor disturbance caused by trawling could be followed by increases of other benthic species.

Many elasmobranch species are thought to be threatened by bycatch and discarding, and it is also a serious issue for various species of turtles and seabirds (caught on long-lines), and marine mammals (caught in purse seines, gillnets and trawls). Elasmobranch fish have been reported to be more resistant to capture than teleosts, with several species of sharks and rays having a high probability of survival after being discarded from trawlers. Rodríguez-Cabello et al. (2005) quoted a mean survival rate of 78% for spotted catshark *Scyliorhinus canicula* in the Cantabrian Sea, while Enever et al. (2009b) found a short-term rate of survival of 55% for skates discarded in the skate fishery in the Bristol Channel.

Further important related issues that still need further research include the impact of abandoned gears (ghost fishing) and slippage of catches in pelagic fisheries. This is highlighted in the FAO International Guidelines on Bycatch Management and Reduction of Discards (FAO, 2010) which dedicates a section to pre-catch losses and ghost fishing, establishing that States and RFMO/As should consider measures to address the impact of pre-catch losses and ghost fishing on living aquatic resources. Recommendations include development methods for estimating pre-catch losses by various gear types, modification of gears and fishing methods, identification of gear ownership, reduction of gear losses, development of gear retrieval procedures and programs, and reducing, and where possible eliminating, fishing power of lost gear, e.g. through the use of degradable materials. FAO (2010) also remind us that abandoned and discarded gears should be considered as marine pollution and that

> States and RFMO/As should take account of current work at the International Maritime Organization on the revision of Annex V of the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78) and the Guidelines for the Implementation of Annex V in relation to reducing the impact of lost fishing gear.

Brown & Macfadyen (2007) reports that ghost fishing in depths shallower than 200 m is not a significant problem and declines rapidly once nets have been lost. This is due to lost, discarded, and abandoned nets have a limited fishing life, because many static-net fisheries take place in shallow water, where storm and tide action can quickly roll up the nets, and bio-fouling reduces their catching efficiency (Erzini et al., 1997; Pawson, 2003; Revill & Dunlin, 2003). Large et al. (2009) carried out retrieval exercises to recover lost and abandoned nets from deep-water gillnet fisheries in the Northeast Atlantic. They towed a retrieval gear that basically consisted of three grapnels connected by chains to a steel bar and towed at a speed of 1–2 knots, a technique called ‘creeping’. In terms of mitigation, they suggested that information should be collected from fishers and fisher organizations, and creeping should then be carried out at locations where fishers have reported incidences of lost or abandoned nets.

Huse & Vold (2010) showed that (short-term) mortality of mackerel in purse seines could be reduced by avoidance of ‘excessive crowding’ of the fish. Studies by Stratoudakis & Marcalo (2002) on sardine (*Sardine pilchardus*) taken by purse seiners in Portugal and for another sardine species (*Sardinops sagax*) taken with the same gear in western Australia (Mitchell et al., 2002) indicate that slippage mortality could be much higher in the long-term as, although fish are still alive when released, many are believed to have suffered physical damage (loss of scales, skin abrasions) by contact with other fish and the walls of the net.

Implementation of policy

Pikitch et al. (2004) state that the overall objective of EAFM is to sustain healthy marine ecosystem and the fisheries they support. EAFM is generally considered more conservative and more protective of marine ecosystems than is single-species management. Hilborn (2011) comments that he suspects the general public and legislators believe that if we can manage every species to its MSY level, there would be no significant ecosystem impacts. However, we should be aware that a healthier ecosystem does not automatically imply more productive fisheries. Additionally, EAFM objectives are quite often vague enough that different interpretations could lead to drastically different outcomes. The current legislative frameworks for EAFM often lack clarity, and management agencies will have insufficient guidance on appropriate policy unless international agreements and national legislation are made more specific.

Given that fisheries and conservation tend to be the responsibilities of different and independent government departments, it is perhaps unsurprising that some of the most important contributions to EAFM have arisen from non-fisheries legislation. Hall & Mainprize (2005) review several examples, including the US Marine Mammal Protection Act, which sets monitoring requirements and imposes tough and rigorously enforced limits on fishery bycatch of marine mammals. Other examples include the US Endangered Species Act which limits the incidental capture of the short-tailed albatross in Alaska and the Environmental Protection and Biodiversity Conservation Act in Australia, which requires fisheries to undertake 'threat abatement plans' if they impact on certain marine species, and to become accredited as ecologically sustainable. Aside from illustrating the power of non-fisheries legislation to effect changes in fishing practices, an important precautionary note is that these are all non-European examples. In the European context, it is apparent that fishery and conservation may be contradictory (e.g. the CFP and the Habitats Directive), and indeed, because national governments cede power to regulate fisheries beyond their immediate coastal waters to the European Union, they may be legally powerless to fulfil their species protection obligations under the Habitats Directive (Khalilian et al., 2010).

There is a clear need to take account of the interdependence of stocks and the effects on species associated with or dependent upon harvested species, with a view to maintaining or restoring populations of such associated or dependent species above levels at which their reproduction may become seriously threatened. The 1980 Convention on the Conservation of Antarctic Marine Living Resources provides that 'ecological relationships between harvested, dependent and related species must be maintained'. This principle often refers specifically to endangered, threatened or protected species. A key-related objective is to minimize bycatch and discards. As it is impossible to optimize the exploitation for all species at the same time, compromise solutions will need to be found, reflecting decisions on which species may be more negatively affected. Optimal harvest strategies for multi-species fisheries have for some time been a focus of ICES work. A variety of mathematical approaches has been developed, among which the Fcube (Fleet and Fishery Forecast) model is particularly promising (J. Castro-Pampillon, pers. Comm.)

The Ecosystem Approach to Fisheries Management (EAFM) will provide some impetus to this process, in that it aims for an integral ecosystem-based management of fisheries. One of the main challenges of the EAFM is to understand the trade-offs resulting when a particular approach is chosen, and to develop the institutional and legislative frameworks that recognize and account for these trade-offs (Hall & Mainprize, 2005). While a measure may, at first glance, appear entirely reasonable and may well make fishery managers and conservationists feel better, the complexities of ecological systems and the biology and population dynamics of the species within them, the difficulty of measuring the outcomes, the inability or unwillingness on the part of the fishers to comply with the measure, and the inability of the regulatory agency to enforce compliance, can often conspire against good intentions and render a measure ineffective, unexpectedly costly or simply impossible to evaluate. As with most complex decisions, there are trade-offs that must be carefully weighed.

As is increasingly obvious across the spectrum of different fishery management measures, it is essential to engage fishers and stakeholders in the management system to find appropriate and agreed solutions. Furthermore, as the potential interactions between fisheries and other uses of the seas are increasingly recognized (and captured within concepts such as integrated coastal zone management, marine spatial planning and integrated marine management), there may be a need to involve experts and stakeholders from other management areas.

In very broad terms, there are two different approaches for managing discards in the world: regulating what it is allowed to be caught and regulating what can be retained on board and landed, with the latter being more easily enforceable since it requires inspection only at the landing port. In addition, the full utilization of the catch may be promoted, for example, by developing markets for 'non-commercial' species (e.g. Portela et al., 2004).

Measures to reduce may include modifications of gear and or fishing practices. While it is impossible to legislate against bycatch occurring, it can be discouraged by imposing penalties. Thus, in relation to marine mammal bycatch, measures available under the US Marine Mammal Protection Act include fishery-specific limits on bycatches, time and area closures, gear modifications and deployment of pingers (the latter being a measure originally proposed by the fishers, Bache, 2001). Bisack & Sutinen (2006) explored the idea of introducing Individual Transferable Quotas for porpoise bycatch and argue that it is a potentially more efficient measure than area closures.

One option for regulating discards is to pursue a no-discard policy, as implemented in, for example, Norway, Iceland and New Zealand, whereby all catches, desirable and non-desirable must be landed. However, unless combined with measures to reduce catches of unwanted fish and/or to provide for their utilization, the benefit in terms of environmental conservation and sustainable marine and coastal zones management may be limited or negative. Rather than ensuring zero waste, the policy potentially transfers the problem of marine waste onto the land, where its safe disposal becomes a problem for local authorities. If such waste is stored adjacent to the coast, there is the risk of pollution in the coastal and littoral area. A partial solution (at least providing benefits onshore) may be the development of processing facilities and markets to make use of fish waste, e.g. to produce feed and fertilizer. Catchpole et al. (2005) note that discard bans can create markets for incidental catches. While there may be cases for the development of markets for particular species or size classes, where there is pressure on resources and threats to sustainable fishing activities, the main objective must be reducing the capture of potential discards rather than their utilization. The above discussion highlights the importance of careful analysis before a measure is adopted.

The European Commission is at present reconsidering its discard policy, which represents a major shift in European fisheries management (Green Paper, EU COM, 2009). This is taking place in the context of a bigger and fascinating challenge, to develop holistic approaches to manage the use of the sea and its resources as a whole, as envisaged under EU Marine Strategy (Apitz et al., 2006; Jensen, 2006). EAFM thus represents the 'fishery' component within holistic marine management.

A no-discard policy changes the focus of management from landings to catches, in other words from production to total fishing mortality. This is exemplified in the contrasting Norwegian (it is prohibited to *catch*…) and EU legislation (it is prohibited to *have on board*…). This means that many of the no-discards management measures are designed to ensure that unwanted fish is not caught. Thus, the choice is not between returning unwanted fish to the sea and obligatory landings for fishmeal or animal feed, but between catching and not catching unwanted fish.

While the EU sees reducing excessive fishing effort as the main way to reduce the level of unwanted catch, other measures, already enforced in no-discard countries, should also be considered (Green Paper, EU COM, 2009): (a) temporary area closure for spawning stocks, vulnerable habitats or protecting juveniles; (b) real-time movement of vessels to another fishing area once their unwanted catches exceed a certain level; (c) adapting fishing gear so that threatened species or sizes can escape from nets and (d) reviewing existing management measures which may lead to discarding. The discard ban could be implemented progressively, for example, starting with a discard ban for pelagic species (mackerel, herring, blue withing, etc.) in the first year of the new CFP, and continuing with demersal target (cod, hake, nephrops, sole, etc.) and associated species (haddock, whiting, hake, plaice, etc.) as well as a discard ban in Mediterranean fisheries in the second year of the new CFP (EU High Level Meeting on banning discards, Brussels 1st March 2011).

Scientific challenges to implement an EAFM

How can scientists provide answers and tools to meet such a huge challenge? Hilborn (2011) suggests that EAFM needs to be set in the context of risk analysis. The FAO guidelines for bycatch and discards reduction (FAO, 2010) also identify the need for 'a risk assessment to identify the specific nature and extent of bycatch and discard problems in the fishery as a basis for prioritization and planning'. However, before we can conduct risk analyses, the specific objectives of EAFM must be clear.

It is evident that complete knowledge of fisheries, and the ecosystems in which they take place, is impossible. For example, in some multispecies, multigear fisheries, reporting the full species composition of catches may not be practical. Consequently, alternative methods, such as reporting on indicator species or other suitable proxies, may be necessary. Levin et al. (2009) propose an Integrated Ecosystem Assessment (IEA) as a framework for organizing science in order to inform decisions in marine EAFM at multiple scales and across sectors. IEA comprises five key stages: scoping, indicator development, risk analysis, management strategy evaluation and ecosystem assessment. It develops ecosystem indictors through synthesis and quantitative analysis of information on relevant natural and socioeconomic factors, in relation to specified ecosystem management objectives, and integrates them into management measures.

Implementation of spatial management, with zoning for different kinds of fishing activity and use of seasonal or temporary closures, can be a useful tool for reducing discard rates and controlling effort exerted. Spatial management measures must be underpinned by a good knowledge of the biology, spatial distribution and abundance of both resource species and other species impacted by fisheries, including protected species. The effects of fleet displacement must also be understood, otherwise spatial management results can be disappointing.

There is a huge literature on the pros and cons of marine protected areas (MPAs). In the context of fisheries, successes have been decidedly mixed. Catchpole et al. (2005) note that temporary closure, through establishment of the 'Plaice Box', failed to protect the main nursery grounds for plaice in south-eastern North Sea, even after closure was made permanent, whereas a Norwegian system of temporary closures used in the Barents Sea is regarded as having an important contribution to the recovery of cod and haddock stocks. Robb et al. (2011) comment that 'no-take' MPA, in which all fishing is prohibited, can result in greater productivity of fish stocks. However, they highlight the need for effective management to ensure that only permitted activities occur within MPAs. The authors found that all but one of 161 MPAs on the Pacific coast of Canada are open to some kind of commercial fishing and attribute the mismatch between intent and practice to a lack of coordination between management of protected areas and management of fisheries.

Recent fisheries research has focused on the development of indicators that might underpin the implementation of an EAFM. Such indicators would provide information on the state of the ecosystem, the extent and intensity of effort or mortality and the progress of management in relation to objectives (Jennings, 2005). Papers on ecosystem or ecological indicators in the context of fisheries have flourished over the last 10 years (see, for example, Piet & Jennings, 2005; Piet et al., 2008; Cotter et al., 2009; Rochet & Trenkel, 2009; Van Hoey et al., 2010; Greenstreet et al., 2011). Trenkel et al. (2007) proposed such an approach for the assessment of two anglerfish (*Lophius piscatorious* and *L. budegassa*) stocks in the Bay of Biscay and the Celtic Sea. The authors used a set of indicators derived from scientific survey data and compared the results between traditional model-based and the indicator-based methods. Although their results were somewhat inconclusive, it is clear that the progressive implementation of an EAFM will need to be based on the behaviour of ecological indicators (Piet et al., 2008). Regarding discard and bycatch issues, some relevant pressure indicators have been suggested to address how fishing impacts on the ecosystem. The discarding rates of commercially exploited species and discard rates in relation to landings value have been suggested as pressure indicators to use as measures of the relative environmental impact of different fisheries (Piet et al., 2007). Indicators should guide the management of fishing activities that have led to, or are most likely to lead to, unsustainable impacts on ecosystem components or attributes (Jennings, 2005; Rice & Rivard, 2007).

Currently, the implementation of the Marine Strategy Framework Directive (MSFD Directive 2008/56/EC) is providing a new impetus to the process of indicator development. It calls for completion of an initial assessment of the current environmental status of EU waters and the environmental impact of human activities by 2012 and envisages EU Member States achieving (or maintaining) good environmental status (GES) across all European waters by 2020. In relation to fisheries, populations of commercially exploited fish and shellfish should be within safe biological limits and elements of marine food webs should occur at normal abundance and diversity. Reduction of bycatches and discarding should contribute to both objectives.

Heymans et al. (2011) modelled the deep-sea ecosystem of the Rockall area (200 miles off the west of Scotland) using Ecopath with Ecosim. They identified the lack of discard data from deepwater fisheries in the area as an important limitation and potentially a substantial source of error in the model. This emphasises the importance of having a deep knowledge and good quantification of discards throughout EU waters. This is needed to assess ecosystem status, as required for the implementation of EAFM and the MSFD. A common database of discarded species for different fishing gears and areas would provide a good starting point. Data are needed to make rational decisions, evaluate fisheries performance in relation to management objectives and fulfil regional, national and international obligations. The extent to which management objectives are achieved is assessed using indicators, which are generated from data. Appropriate indicators can be developed which measure the state of the resource, the performance of fishing controls, economic efficiency and social value (e.g. to coastal communities).

Conclusions and future directions

The history of fisheries management, like that of many human endeavours, is a tale of an increasingly detailed and sophisticated understanding of what we are doing wrong, while, on the whole, solutions are developed at a much slower pace. In the case of the EAFM, we increasingly recognize that the damage caused by fishing spreads far beyond the target fish population, and we are developing a range of metrics and indicators to quantify these negative effects and to help identify optimal states (good environmental status). However, it is arguable that (at least so far), we have been much less successful at devising management measures and governance systems that can deliver on these objectives.

There is also a common agreement that reduction of discarding will greatly benefit the health of marine ecosystems. The 'discards problem' is a key point in the EAFM. It is far from being an easy issue to solve, as it involves the 'hard core' of fishing operations, from economic, legal and biological points of view. Assuming that discards are unavoidable, the question of an acceptable level of discards has a moral dimension in addition to the more obvious biological and economic criteria (Kelleher, 2005). Additionally, the legal requirement (as under the current CFP) to carry out such an obviously wasteful practice undermines the legitimacy of the regulatory/management system. However, in spite of all these difficulties, there is a common and positive perception from all sides (citizens, NGOs, the fishing sector, policymakers, scientists, etc.) that discards are negative for all us. We all should work to find a better solution.

Of course, that desirable solution will most probably not come about implementing a few simple management measures, and it would require substantial changes in many fisheries, possibly with substantial economic consequences. Here we suggest the principles and goals that should be met to achieve a reduction of discards and finally a better and healthier marine environment as well sustainable fishing exploitation under the framework of the EAFM:

1. A better balance between fishing intensity exerted and the carrying capacity of the ecosystem: This requires, firstly, a deeper and more detailed knowledge on ecosystem dynamics, including spatial distribution, abundance patterns and fish behaviour, secondly supplementary discards-directed management measures within the EAFM framework, such as requirements to change fishing ground and real-time closures. The basic implementation principle is to regulate what is caught in the first place rather than to regulate landings.
2. Better selectivity without altering biodiversity and ecosystem functioning: Progressive introduction of discard reduction devices and encouragement to improve the selectivity of fishing gears but with a focus on maintaining the functionality of the ecosystem and the protection of vulnerable species or sizes.
3. Establishment of clear, simple and rapid indicators as fishery management tools: Ecosystems are complex and ecological indicators can help describe them in simpler terms that can be

understood and used by non-scientists to make management decisions. The use of indicators has not yet been fully developed in the context of discards and bycatch, but indices related to the species- and size-composition and amount of bycatch and discards could be useful indicators to support an EAFM.

4. Public engagement: Finally, as we commented above, (almost) everybody agrees that discarding is a bad thing. However, greater public awareness of the issues could prove to be the most crucial driver for change. Fox (1992, cited by Alverson et al., 1994) noted that aside from its economic, conservation and legal facets, discarding is a public ethics issue, the latter being the most overlooked as a driving force but undoubtedly important for the establishment of the Marine Mammal Protection Act in the USA. Cod may not be as charismatic as dolphins, but public opinion could also be crucial for success in tackling the discard and bycatch problem in Europe.

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