**Food and Agriculture
Organization of the
United Nations**

A third assessment of global marine fisheries discards

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by

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This Technical Paper, *a third assessment of global marine fisheries discards*, was prepared by Fishing Operations and Technology Branch, Fisheries and Aquaculture Policy and Resources Division, FAO Fisheries and Aquaculture Department. It is a part of the regular programme activities and contributes to the fulfilment of the Department's mandate by collecting, analyzing and disseminating information on the sector, in particular on global bycatch and discards, and different types of fishing-induced mortality from marine capture fisheries.

Sections of this document have been compiled by FAO staff and selected invited experts as indicated by the authorship. Petri Suuronen (former FAO Fishery Industry Officer, currently Head of research program at Natural Resources Institute Finland) was responsible for the general coordination while Amparo Pérez for technical editing of this document with the valuable assistance from Prof Pingguo He.

Abstract

This third update of FAO's global discard estimate adopted the 'fishery-by-fishery' approach employed in the second discards assessment published in 2005. The update included publicly available discard data in the last 20 years to establish a baseline of a time series of global marine fisheries discards. This is essential for monitoring the status and trends of discard management, which is the first step of the ecosystem approach to fisheries management cycle. In addition, the study developed a new fisheries data table incorporating landings data from the FAO Global Capture Production dataset (FishStat J) from 2010 to 2014, which allocated the landings to over 2 000 fisheries worldwide.

The current study estimated that the annual discards from global marine capture fisheries between 2010 and 2014 was 9.1 million tonnes (95% CI: 6.7 – 16.1 million tonnes). About 46 percent (4.2 million tonnes) of total annual discards were from bottom trawls that included otter trawls, shrimp trawls, pair bottom trawls, twin otter trawls and beam trawls.

The study included a synthesis of estimates of bycatch and discards of endangered, threatened and protected (ETP) species. Substantial advances have been made in quantifying fisheries interactions with such species so as to make informed decisions on their protection. However, many challenges remain, especially for small-scale fisheries. The development of standardized data collection techniques, risk-based sampling and sharing of data across agencies and regions will help to identify management priorities and allow implementation and enforcement of mitigation measures.

A review of previous research showed that discard practices were often related to a wide range of factors, so it is difficult to assess the effectiveness of fishery management actions on the amount and practice of discards. Many regulations are inconsistently enforced, and their implementation is often less strict than intended. Piecemeal approaches in many bycatch and discards management measures can result in unintended cross-taxa conflicts, where regulations designed to reduce bycatch and/or discards of one species or species group may increase bycatch and/or discards of another. Examination of approaches to accounting for and mitigating against pre-catch, post-capture and ghost fishing mortalities demonstrates that an understanding of the relative importance of factors affecting indirect fishing mortality is necessary for estimating total fishing-induced mortality and for designing and implementing mitigation measures.

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Abbreviations and acronyms

AIDCP	Agreement on the International Dolphin Conservation Program
ALDFG	abandoned, lost or otherwise discarded fishing gear
APFIC	Asia-Pacific Fishery Commission
BRD	bycatch reduction device
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CECAF	Committee for the Eastern Central Atlantic Fisheries
CFP	Common Fisheries Policy (EU)
CI	confidence interval
CNMI	Commonwealth of the Northern Mariana Islands
CO	country-based estimates
COFI	Committee on Fisheries (FAO)
CSV	comma-separated value
DCF	Data Collection Framework (EU)
DID	discard rate identifier (DiscardRates data table)
DTU	Technical University of Denmark
EEZ	Exclusive Economic Zone
EI	empirical estimates
EM	electronic monitoring
ETP	endangered, threatened, protected
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FFA	Pacific Islands Forum Fisheries Agency
FID	fishery identifier (FisheryTable data table)
FishStat	FAO Fisheries and Aquaculture Statistics
FRDC	Australian Fisheries and Development Corporation
GE	global gear-specific estimates
HDI	highest posterior density interval
ICES	International Council for the Exploration of the Sea
ID	identifier
IPOA	International Plan of Action
ISSCAAP	International Standard Statistical Classification of Aquatic Animals and Plants
ITQ	individual transferable quota
IUCN	International Union for Conservation of Nature
IUU	illegal, unreported, unregulated
LED	light-emitting diode
LFD	length frequency distributions
LME	Large Marine Ecosystem
LO	Landing Obligation
MA	management authority
MCRS	Minimum Conservation Reference Size
MSC	Marine Stewardship Council
N	number of records
NA	not applicable
NGO	non-governmental organization

NOAA	National Oceanic and Atmospheric Administration
NPOA	National Plan of Action
OECD	Organization for Economic Cooperation and Development
RFMO	regional fisheries management organization
SA	scientific authority
SAR	South Asia, excluding India
SAUP	Sea Around Us Project
SDG	Sustainable Development Goal
SPC	The Pacific Community
TAC	total allowable catch
UN	United Nations
USA	United States of America
VBA	visual basic for applications
WGMIXFISH	ICES Working Group on Mixed Fisheries Advice

Executive summary

Bycatch and discards threat sustainable fisheries by inflicting unnecessary mortalities. Sound management of bycatch and reduction of discards in capture fisheries will lead to healthy ecosystems and sustainable fisheries, contributing to long-term global food security, and alleviation of poverty, especially for coastal communities and Small Island Developing States which heavily depend on fish as food, fisheries as the main source of employment, and fishing as a way of life. Accurate and timely assessment of bycatch and discards provide necessary data for making sound management decisions and effective mitigation measures

This report includes three parts. Part I is an estimate of annual discards for the period 2010-2014 by marine commercial fisheries. Part II includes an evaluation and discussion of bycatch and discards of endangered, threatened and protected species, providing an updated overview of this specific dimension of the bycatch and discard issue. Part II also includes a review of current measures for managing bycatch and reduction of discards, as well as a discussion of other sources of fishing mortality, such as pre-catch loss, discard mortality and ghost fishing mortality. Part III is the conclusion of the whole report.

PART I – METHODOLOGY FOR ESTIMATING GLOBAL MARINE FISHERIES DISCARDS

The estimate of global discards used a similar approach to that of Kelleher (2005) in the second FAO global discard estimate, which was based on the assumption that the amount or rate of discards was a function of a particular fishery. A fishery is defined as a country fleet fishing in a defined area, using the same gear type and targeting the same species group. However, the method has been greatly refined to make it more robust and replicable by integrated data set development and transparent data analysis. The method to calculate global discards included three types of estimates that were applied in the following order:

i. <u>Country-based estimates</u>: country-level discard rates from the literature were applied to all fisheries of countries which either had a discard ban or which were believed to have extremely low discard rates.

ii. <u>Empirical estimates</u>: Where available, fishery-specific discard rates were applied to their respective fisheries. Such data was compiled from scientific publications, national or regional fisheries reports, grey literature, and correspondences with fisheries experts.

iii. <u>Global gear-specific estimates</u>: Global gear-specific mean discard rates and margin of error were estimated for 25 gear categories and applied to fisheries with no country-based or empirical discard rate estimates. Global gear-specific discard rates were estimated based on the empirical estimates from method ii.

The scope of the current assessment is similar to the 2005 study which included commercial marine and estuarine fisheries only. This assessment did not analyse which species were discarded; however, it is understood that species composition is an important issue that should be covered in future assessments. Knowing which species have been discarded and why they are discarded is critical for improved food security, better stock assessments, and sound fishery management.

THE ESTIMATES OF FISHERIES DISCARDS

The magnitude of annual discards in global marine capture fisheries was estimated to be 9.1 million tonnes (95% CI: 6.7 – 16.1 million), which represent 10.8% (10.1% –11.5%) of the annual average catch of 2010-2014. These estimates were based on a sample size of 1 854 fishery records (75.5 million tonnes of landings).

The gear type which contributed the most to annual levels of discards was bottom trawl with 4.2 million tonnes. Bottom trawl included otter trawls, shrimp trawls, pair bottom trawls, twin otter trawls and beam trawls.

From a regional perspective, the northwest Pacific (FAO Fishing Area 61) and northeast Atlantic (FAO Area 27) accounted for a combined 39% (3.6 million tonnes) of discards. Although the northwestern Pacific Ocean (FAO Area 61) had the highest discards, contributing more than 22% of global discards, it had the fifth lowest mean discard rate. The southwest Atlantic (FAO Area 41) had the highest mean discard rate, but it only contributed 7% of the total annual global discards.

Fisheries targeting tunas and other pelagic species had the lowest discard rates, while fisheries targeting crustaceans had the highest discard rates. Fisheries targeting demersal fishes produced the highest volumes of discards and fisheries targeting molluscs (excluding cephalopods) produced the lowest volumes.

PART II – BYCATCH AND DISCARD OF ENDANGERED, THREATENED AND PROTECTED SPECIES

A review of available data on estimating and mitigating fisheries interactions with endangered, threatened and protected (ETP) species in marine commercial and artisanal fisheries was provided. This review includes annual estimates of 1 million seabirds, 8.5 million turtles, 225 000 sea snakes, 650 000 marine mammals and 10 million sharks for a total of at least around 20 million individuals. Estimates of global discards are highly uncertain due to: (i) the occurrences of ETP species are often rare and controversial, and are frequently not recorded or reported; (ii) different protections are afforded to different ETP species in different countries and fisheries and; (iii) discarding practices vary greatly across spatio-temporal scales and according to individual fishing conditions and procedures, which affect discards mortalities.

Several recent initiatives provided information on such interactions, as well as the development of novel fishing methods and practices that may reduce ETP mortality. Reducing ETP interactions in many small-scale artisanal fisheries in developing countries remains a challenge. This will require comprehensive engagement of all stakeholders in order to facilitate regional and global scale bycatch assessments and mitigation initiatives.

MANAGING BYCATCH TO REDUCE DISCARDS

There are various types of measures to manage bycatch and to reduce discards, including modifications to fishing gear or fishing practice, spatial and temporal gear restrictions, bycatch quota, effort restriction, and discard ban (landing obligation). In addition, discards can be reduced through improved fleet communication, awareness-raising, training, better utilization, and economic incentives.

The range of policy options to reduce discards is determined both by the biological characteristics of the fishery and the socio-economic environment. Best practices in bycatch reduction are illustrated by a number of countries in the Organization for Economic Cooperation and Development (OECD), while many countries especially in Asia provide valuable experiences in utilization of bycatch. Increased bycatch utilization is now widespread in Asia, Africa and America leading to reduced discards.

PRE-CATCH, DISCARDS AND GHOST FISHING MORTALITIES

The International Guidelines on Bycatch Management and Reduction of Discards (FAO 2011) included recommendations for member States to identify, quantify and reduce impacts of mortality from pre-catch losses and ghost fishing and to maximize discards survival. All these components of mortality share the characteristic of being largely undetectable in the course of fishing operations. The relative proportions of these components vary by fishing gear and method, by fishery, and spatially, temporally and by vessel within a fishery.

Methods to avoid, minimize and offset pre-catch fishing mortality are similar to those for mitigating capture and discard mortality. These include modifications to the gear, for example, by using circle instead of J-shaped hooks in pelagic longlines to reduce the injury to organisms escaped or discarded. While, methods to reduce ghost fishing mortality can be preventative such as gear marking to identify the owner and discourage abandonment and discarding of gear, remedial such as using less durable and biodegradable gear, or mitigative such as removal and recovery of derelict gear.

PART III – CONCLUSION

This report contains two new outcomes on bycatch and discards in global marine capture fisheries: (i) an annual discard quantity of around 9.1 million t, or 10.1% of annual catches, and (ii) an annual estimate of fisheries interactions with at least 20 million individuals of endangered, threatened and/or protected species.

It is difficult to quantify the progress made in reducing discards but this report indicates that in the last 10 years there has been a greater scrutiny of such issues via the public reporting of discards.

Regarding fisheries interactions with endangered, threatened and/or protected species (ETP), there is a lack of solid data for many fisheries and for many parts of the world. Therefore, more effort is needed to better quantify fisheries interactions with such species, and to implement measures to reduce interactions and mortality in the future.

This report also summarized other related issues concerning bycatch and discarding, including (i) current measures to manage bycatch and discards and (ii) challenges associated with estimating cryptic sources of fishing mortality such as pre-catch, discards and ghost fishing mortality.

Background

FAO is required to report periodically to the United Nations General Assembly on progress with regard to UN resolutions on fisheries. A number of these resolutions refer to monitoring bycatch and discards, including various provisions in international fisheries instruments calling for assessment of bycatch hand discards and their impact on the sustainable use of living marine resources.

In 1994, FAO published the first estimate of global discards in marine fisheries (Alverson *et al.,* 1994) which indicated that 27 million tonnes, or approximately 27% of global fishery catch, was discarded annually. This initial estimate was considered to be a major achievement, providing an order of magnitude estimate of global discards and illustrating the difficulty in their estimation, as indicated by the wide range of the estimate (17.9-39.5 million tonnes). The 1994 assessment also brought the attention to fishing industries and managers on the magnitude of the issue and therefore may have helped to reduce discards over the ensuing two decades.

However, in 1996, an FAO Technical Consultation on *Reduction of wastage in fisheries* (FAO, 1997a) identified a number of issues with the methods used in the Alverson *et al.* (1994) assessment, which were considered to have possibly contributed to an overestimate of global discards. In response to these concerns, a revised estimate of 20 million tonnes of global discards was presented in the FAO State of World Fisheries and Aquaculture 1996 report (FAO, 1997b), which was based on revised estimates for selected FAO statistical areas that were examined in the 1996 Technical Consultation (FAO, 1997a).

A decade later, in 2005, FAO provided an update of the estimate of global discards from marine fisheries (Kelleher 2005) at 8%. Based on this rate, annual average discards were estimated to be 7.3 million tonnes between 1992 and 2001- substantially less than that given in the 1994 and 1997 reports.

The methodological approach used in the 2005 study differed substantially from that used in the 1994 assessment. The 1994 report was based on discard/catch ratios according to targeted species, or species groups. These ratios were applied to FAO's FishStat nominal catch statistics for the 1988-1990 period to derive the global estimate. In contrast, the 2005 study used a fishery-based approach by compiling an inventory of the world's fisheries, their respective catches and used any available discard studies to estimate rates. As discard rates were not available for all fisheries, the ratio of discards to catch was assumed for those fisheries based on information from similar fisheries or based on expert opinion. The quantity of discards for each fishery was then calculated by raising (extrapolating) discard rates by the total recorded landings for the fishery, as extracted from national fisheries statistics and other sources. The 2005 report suggested a substantial reduction in discards compared to the 1994 estimate. The major reasons for such reduction were believed due to a reduction in unwanted bycatch through the use of bycatch reduction technologies and increased utilization of previously-assumed discarded organisms.

A number of policy issues were discussed in the 2005 report. These include a 'no discards' approach to fisheries management; the need for balance between bycatch reduction and bycatch utilization initiatives; and concerns arising from incidental catches of marine mammals, seabirds and reptiles. The study advocated the development of more robust methods for estimating discards, allowances for discards in fishery management plans, development of bycatch management plans and the promotion of best practices for bycatch reduction and mitigation of incidental catches.

In this context, FAO developed the International Guidelines on Bycatch Management and Reduction of Discards (FAO, 2011) that were endorsed during the twenty-ninth session of FAO's Committee on Fisheries (COFI) in 2011.

At the Thirtieth Session of COFI in 2012, the Committee recommended continued attention to bycatch and discards to ensure that they were addressed comprehensively in conservation and management assessments, within an ecosystem approach. It was considered important to have timely information on how world fisheries are performing in reducing discards and seafood wastage, in the context of how countries are contributing to enhancing the world's food security.

In 2014, FAO considered it timely and prudent to conduct another update on this vital fisheries and food security issue. The first step in the development of this updated assessment of global discards was an Expert Workshop (Casablanca, Morocco, 26-28 May 2015) to develop the scope, timeline, methodology and deliverables for such an update. It was noted that, compared to the situation in 1994 and 2005, the monitoring and reporting of bycatches and discards in fisheries has improved throughout the world, including more observer programs and initiatives such as electronic monitoring, electronic logbooks and smartphone reporting. However, a detailed analysis of the species composition of discarded catch is only possible in relatively few fisheries. Therefore, it was decided that the species composition of discards would not be included in the scope of the new assessment.

There has been significant difficulty in reaching an agreement on a globally-accepted, standard definition of the term "bycatch", which may, depending on the jurisdiction, include: general discards, retained, released or discarded endangered, threatened or protected (ETP) species, sold "by-product" species, juveniles, trash fish, pre-catch losses, slipped fish, mortalities due to ghost fishing, discarded fish heads, frames and offal, and even broader ecosystem and habitat impacts of fishing (FAO, unpublished). Notwithstanding this variety of definitions, the most commonly used definitions tend to settle on "bycatch" being the unintended, non-targeted organisms caught while fishing for particular species (or sizes of species). This bycatch is then most commonly divided into those non-target organisms that are kept and eaten/sold ("landed bycatch" or "by-product") and "discards" which are those animals thrown back (alive or dead) into the sea (and can also include "slipped releases"). It is this latter subset of bycatch (discards) which is the usual focus of studies that seek to report on bycatch, including two previous global reports on bycatch by FAO, because it is this subset that results in wastage of resources, impact on ETP species, and threats biodiversity, all of which have caused significant attention and controversy.

This new global assessment on discards is intended to provide a comprehensive update of Kelleher's (2005) estimates using a similar approach (i.e. a fishery-based approach using discard ratios by fishery and/or fishing method). The current study compiled available discard rates from the last 20 years as well as a list of the world fisheries which includes 2,089 fishery records covering 99% of global landings. These data have been placed online to establish a baseline time series of global marine fisheries discards which will be used to monitor the status and trends of discard management into the future (this is step 1 of the Ecosystem Approach to Fisheries management cycle).

In addition to estimating discards in the world's fisheries, it was also the purpose of this study to provide an update on three other major issues concerning discards: (i) estimates of fishing interactions with ETP species, (ii) measures to manage bycatch and reduce discards, and (iii) current knowledge on mortality due to pre-catch, discards and ghost fishing losses.

This report is an output of an ongoing FAO initiative that focuses on the magnitude of discards, trends in discarding, practices associated with discards, and measure to reduce discards. However, readers should be aware that all assessments of discards are just estimates with simple assumptions to explain a highly complex subject.

Ultimately, FAO's work on bycatch and discard management issues contribute towards Sustainable Development Goal (SDG) 14 - conserve and sustainably use the oceans, in particular SDG 14.2 – to sustainably manage and protect marine and coastal ecosystems, avoiding significant adverse impacts, and SDG 14.4 – to end destructive fishing practices, restoring fish stocks in the shortest time possible.

PART I – ESTIMATE OF GLOBAL MARINE FISHERIES DISCARDS

1. Introduction

This third update of FAO's global discard estimates took the 'fishery-by-fishery' approach adopted by Kelleher (2005) in the second update and improved it by cross-matching with FAO's FishStat J landing dataset (FAO, 2016). FishStat J is software for fishery statistical time series with access to a variety of fishery statistical datasets (http://www.fao.org/fishery/statistics/software/fishstatj/en). FishStat J landings data from 2010 to 2014 were allocated to over 2 000 fisheries worldwide. Data on discarding rates from over 530 fisheries were then applied to 1 854 the fisheries in this dataset to calculate global discarding rates.

There are many advantages to this new FishStat J-based approach. The most important one is that it is easily replicable. The fishery data table can be refined and then updated against the latest FishStat J landings data, and the discard rates data table can be updated with new information as it is generated. Secondly, the data are highly transparent. As both tables are open source, it is encouraged that they are further developed and refined.

It is also notable that the fishery data table, whose fields include landings attributed to flag state, FAO area and Large Marine Ecosystem (LME), gear type, water depth and target species, is the first of its kind and is of significant potential use to fisheries scientists and managers in its own right.

1.1.   SCOPE, DEFINITIONS AND TERMINOLOGY

The scope of the assessment was as follows:
- Discards from marine and estuarine fisheries only. This includes coastal lagoons that have a predominately marine ichthyofauna but excluded freshwater fisheries.
- Commercial fisheries only. It excludes recreational and subsistence fishing.
- The time reference period was from 2010 to 2014.

As with the 2005 assessment, the definition of discards used in this study is adapted from FAO Fisheries Report No. 547 (FAO, 1997b).

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. It does not include plant materials and post-harvest waste such as offal. The discards may be dead, or alive.

Therefore, for this global discard estimation, discards <u>exclude</u>:
- Post-harvest offal.
- Fish deliberately slipped from nets for commercial or safety reasons. This source of mortality is considered in other sections of this report.
- Carcasses of sharks or other animals where some body parts have been removed and retained (e.g. fins). Some aspects of this component of discards are considered in Section 5 of this report.
- Certain other living (corals, sponges, seaweeds / sea grasses and other sessile organisms), and non-living elements (sand, rocks, dead coral, marine litter, etc.).

Definitions of other key terms that are used in this assessment include:
- **Bycatch:** the catch of organisms that are not targeted. This includes organisms that are outside legal-size limits, over-quotas, threatened, endangered and

protected species, and discarded for whatever other reasons, as well as non-targeted organisms that are retained and then sold or consumed.

- **Bycatch reduction device (BRD)**: devices inserted in fishing gear to reduce unwanted bycatch. The most common BRDs are in shrimp trawls, close to the codend, to encourage live escape of unwanted species, sizes, or threatened, endangered and protected species.
- **Catch**:
    - (verb) Any activity that results in capturing and bringing any fish, alive or dead, on board a vessel.
    - (noun) The biomass of marine resources that are landed on a vessel, discarded, consumed on board or used as bait.
- **Commercial fisheries**: fishing activities that are conducted for revenue through the sale of retained catch.
- **Country (flag)**: the State under the responsibility of which a boat is legally registered.
- **Discard levels/quantity/volume**: the biomass of discards from a particular fishery over a defined period of time e.g. metric tonnes (hereafter, t) per year. For most discards, this is usually expressed as weight, but for ETP species, this is usually expressed as number of individuals.
- **Discard rate**: the proportion of the total catch that is discarded, expressed either as proportion (0-1) or as a percentage (0-100%). The formula to calculate discard rate is as follows:

Discard Rate = Discards / (Landings + Discards)

- **Fishery**: A grouping of fishing effort, combined according to a fishing area or zone, a fishing gear, and one or more target species. Fishery is used as the principal unit of account for discard rates and fishery data tables.
- **Gear (fishing gear)**: a tool used to catch fish, such as hook and line, trawl, gillnet, trap, spear, etc.
- **Landed catch**: the retained catch that is landed for use ashore.
- **Management authority**: the organization which makes decisions on how the fishery is regulated, and is also usually responsible for all ancillary services, such as statistics gathering, assessment, consultation with fishers and other stakeholders, resource allocation and determining the conditions of access to the fishery.
- **Non-target species**: species for which the gear and fishing effort is not specifically intended to catch, although they may have immediate commercial value and be a desirable component of the catch, but in many cases, they are discarded.
- **Scientific authority**: the organization tasked with identifying research and monitoring needs for the management of a fishery and leading its implementation and delivery.
- **Target species**: those species that are primarily sought in a particular fishery and are the subject of directed fishing effort in a fishery. Target species may also be discarded due to landing size limits, over-quota, low quality as a result of depredation, scavenging or spoilage, or safety issues.

2.   Methods

2.1   DEVELOPMENT OF A FISHERIES-BASED DISCARD DATASET

The development of a fisheries-based discard dataset that can be updated as new FishStat J landings data becomes available and that is based on robust discard rates for a variety of different fisheries, requires allocation of the FishStat J landings data to specific fisheries. This allows the inference of actual catch and discarding volumes. In order to achieve this, a nine-step process (Figure 1) was developed.

This process was initially done (Steps 1-5) in Microsoft Excel. Various methods, such as Visual Basic for Applications (VBA) routines, use of drop-down lists and various cross-checking tools, were used to ensure analytical rigor and assisted in quality control. To validate the data, estimate discard rates, and allow easy reproduction of the method for review and updating, an R "markdown" (http://www.fao.org/fishery/static/TP633/script.Rmd) file was produced with full code and explanation (Steps 6-9). The code would read data tables and produce a single joined table-output containing landing and discard estimates.

1. Downloading FishStatJ landings: Global fish landings data were obtained from FishStat J (version 3.01.0), using (i) the FAO Global Fishery and Aquaculture dataset v2016.1.2 and the FAO Regional capture fisheries dataset v2016.1.0 (the latter for CECAF and SE Atlantic only). Annual species-specific landings volumes by country and FAO fishery area for the period 2010 – 2014 (n=14 563) were downloaded and compiled in Excel (see FishStat data table).

2. Fishery Table (no landings allocated): A data table was developed on a country-by-country basis, identifying the main fisheries (n=2,089) being prosecuted by each flag state in its own exclusive economic zone (EEZ), in the high seas and in others' EEZs. This included the following data fields (**bold** fields were mandatory):

- **Country**
- **Fishery name / description** (e.g. Southern Adriatic trammel fishery)
- **FAO area**
- **Ocean**
- **Large Marine Ecosystem (LME)**
- **Target** species group(s)
- **Gear** code
- **Reference / data origin**
- Managing authority (e.g. regional fishery management organization, RFMO)
- Scientific authority
- Water depth
- Location (e.g. Estuarine, inshore, offshore)
- Vessel length
- Selectivity
- BRD used (yes / no)
- BRD type

FIGURE 1

Nine-step process to develop a fisheries-based discard dataset. In parenthesis are the names of the data tables (light blue boxes) and the dataset (dark blue box)

1 FAO FishStat J Database (FishStat)
- Country (flag state)
- FAO statistical area
- Species
- Landings (2010-2014)

2 Fishery table (FisheryTable) Landing volumes unallocated
- Country (flag state)
- Fishery Name
- FAO statistical area
- Gear type
- Target Species group
- Reference

3 Species volume allocation

4 Fishery table (FishStatLink) Matrix where landing volumes are allocated
- Country
- Fishery Name (columns)
- Species (rows)
- FAO statistical area (rows)
- Landed quantity (rows)

5 Discard Rates table(DiscardRates)
- Country (flag state)
- Fishery Name
- FAO statistical area, LME
- Gear type
- Target Species group
- Robustness
- Discard rate (and range if any)
- Reference

6 Country specific discard rates table (CountrySpecificDR)
- FAO statistical area
- Country (flag state)
- Year
- Discard rate
- Type
- Source

7 (DiscardLink)

8 Global discard rate estimates (gear based)

9 Fisheries-based discard dataset (LandDisc):
- Country (flag state)
- Fishery Name
- FAO statistical area
- Gear
- Landings (tonnes)
- Discards (tonnes)
- Total catch (tonnes)

The original basis for this data table were the fisheries compiled by Kelleher in his 2005 assessment. This was updated by a number of regional teams, using available literature, national and RFMO fisheries statistics or personal communication with the flag state authorities involved. Common descriptors were used where appropriate (e.g. gear codes, etc.) to avoid duplication and enforce standardization of common data groups. A description of the codes used in the data tables and dataset is in Annex A.2. At this stage no landings data were assigned to each fishery record.

3. Species volume allocation: A tool was developed in VBA to allocate species-specific landings by flag state from the FishStat J landings data table to the individual fisheries record in the Fishery table. This was done by a number of regional specialists using a variety of sources such national fisheries statistics and databases (where available), published information on individual fisheries types, Marine Stewardship Council (MSC) public certification reports (which usually have detailed information at a fisheries level), etc.

4. Fishery Table (with landings allocated): Following the species allocation in Step 3 above, a revised Fishery Table from Step 2 was produced. As before, these fisheries are defined by their location, target species and gear type but now include the volumes of each species by flag state for each fishery.

5. Discard rates table: a new data table was compiled with records of discard rates from around the world. This included the following data fields (**bold** fields were mandatory):

- Gear type and code
- FAO area
- Flag state
- Discard rate and range
- **Data origin** (expert opinion/port records/logbook/observer/survey (research))
- **Robustness** (low/medium/high)
- **Reference**

- Fishery name / description (e.g. Southern Adriatic trammel fishery)
- Large Marine Ecosystem (LME)
- Water depth
- Period when discard rate was recorded
- Target species group(s)
- Vessel length
- Management type (input controls/ output controls/market controls/ bycatch management)

These records were primarily sourced from official observed discard data as published by fisheries management administrations (MAs) and their scientific authorities (SAs). In addition, other peer reviewed estimates were used. Where this was not possible, other sources of information, e.g., industry estimates or non-governmental organization (NGO) observations were used. A total of 530 records were included. The majority were for bottom (including shrimp) trawls, with the rest mainly from purse seines, boat seines (mainly Danish seine) and pelagic longlines. All these gear type records made up the 60% of total discard rate records. Discard rates from 71 flag states were compiled, with USA, Australia and EU countries providing the majority of data (57% of total discard rate records).

6. Country-specific discard rates table: Assumed (and low) discard rates were applied to domestic (locally-based) fisheries of certain countries which either have a discard ban (Norway and Iceland) or which were believed to have extremely high bycatch utilization rates (Bangladesh, Cambodia, China, India, Indonesia, the Democratic People's Republic of Korea, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand, and

Viet Nam). This additional country-specific data table fed into the final fisheries-based discard dataset in Step 9.

7. DiscardLink data table: this links the Fishery Table records with the relevant Discard Rates records where such a link was identified. The data table contained several attributes of both Discard Rates and Fishery Table data tables to assist matching as these were not explicitly matched on data entry. However, the fields of interest were just the discard rate ID (DID) and the fishery ID (FID) as these would provide the link between the two data tables.

8. Global discard rate estimation: discard rates were assumed for a large number of fisheries for which no discard rates were observed or estimated. In these cases, global gear-specific discard rates were estimated using the method described in Subsection 2.3.1.

9. Fisheries-based discard dataset: the final product derived from Steps 6, 7 and 8 included estimated discard rates. To check the data, estimate discard rates, and allow easy reproduction of the method for review and updating, a RStudio "markdown" file (script.Rmd) was produced with full code and explanation. The code would read the data files, produce summary statistics to check the data consistency and outputs a single joined table containing fishery-by-fishery landings and discard estimates (http://www.fao.org/fishery/static/TP633/landdisc.csv). The system was designed so that any data correction or updates can be incorporated by running two routines, the VBA routine for producing the CSV files from each data table, and the "DiscardCalculations.Rmd" in RStudio. In all, seven data tables were created to produce the discard estimates (see Table 1).

TABLE 1
Data tables (Excel spreadsheets) defined for estimating discards

Spreadsheet	Description
FishStat	Landings data taken from the FAO FishStat J datasets. No changes were made to these records, which consisted of the raw landings data by species category as reported by each country.
FisheryTable	All fishing fleets operating under the flag of each country that landed the fish quantities defined in FishStat.
FishStatLink	It links each FishStat record to the relevant Fishery Table records, with a percentage allocation. It consists of three fields: the FishStat and Fishery Table IDs and an integer percentage (1-100).
DiscardRates	It includes all discard rate estimates collected from publicly available sources (national observer programs, scientific journals, grey literature, etc.).
DiscardLink	It links the Fishery Table records with the relevant Discard Rates records where such a link has been identified. The table contained several attributes of both Discard Rate and Fishery tables to help with matching as these were not explicitly matched on data entry. However the only fields of interest were the discard rate ID (DID) and the fishery ID (FID) as these provide the link.
GearSpecificDiscard	Estimated global discard rates by gear type (see Section 2.3.1 for details on how they were estimated).
CountrySpecificDR	Country-specific discard rates for countries with discard bans or where almost all catches were believed to have been utilised, resulting few discards.

2.2 ANALYTICAL METHODS FOR THE PROCESSING OF THE DISCARD DATASET

2.2.1 Estimate Gear-Specific Mean Discard Rates

Using the empirical discard rates records gathered (see Discard Rates table), posteriori mean discard rates and 95% credible intervals were estimated for 25 gear types (see Table B.1 in annex B) from gear-specific zero-inflated beta regression models (Ferrari and Cribari-Neto, 2004; Grun *et al.*, 2012; Liu and Eugenio, 2018) fitted within a Bayesian inferential framework (as employed by Gilman *et al.*, 2018).

2.2.2 Dataset Processing

The LandDisc file contains pooled data from the FishStat and Fishery Table data tables.

Methods of estimating discard rates

One of three methods for estimating discard rates was employed for each fishery:

i. <u>Country-based estimates (CO)</u>: Discard rates from the literature (see CountrySpecificDR data table) were applied to all fisheries of countries which either had a discard ban (Norway and Iceland) or which were believed to have extremely low discard rates: Bangladesh, Cambodia, China, India, Indonesia, the Korean Democratic People's Republic, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand, and Viet Nam. This method has been applied to more than 45% of global landings.

ii. <u>Empirical estimates (EI)</u>: Fishery-specific discard rates obtained from observed discard rates, with records entered in the Discard Rate data table, were applied to their respective fisheries in the Fishery Table. If more than 1 observed discard rate estimates were available for a fishery, the average of the observed rates was used, recognizing that calculating a mean of rates may result in highly uncertain results. This method has been applied to less than 20% of global landings.

iii. <u>Global gear-specific estimates (GE)</u>: Global gear-specific discard rates were estimated using the method described in Section 2.2.1 above. This method has been applied to less than 35% of global landings.

For individual gear type and ocean region estimates, the 95% confidence interval was constructed assuming a uniform prior distribution and that the original estimate was derived from a binomial likelihood with an effective sample size of 100. In some cases, the maximum likelihood estimate (e.g. 0 discard rate) falls outside this range, so the median Bayes estimate was also calculated. For the gear-based estimates, the 95% confidence interval from the model was used. To indicate relative precision, the estimate's standard error was calculated from the confidence interval range scaled to the equivalent standard error for the normal distribution.

Dataset processing steps

i. Removed records from LandDisc.csv file with Fishery ID = "0" and "NA" for ocean region, target species and fishing gear fields. These were entries in FishStat which had not been allocated to a "fishery". Many landed catch records with ID=0 likely belonged to gear types with relatively small discard rates, e.g., spearfishing, hand collection, coastal gillnet, handline, and troll. But there are some obvious exceptions, e.g., thresher shark spp., albacore, and swordfish reported by American Samoa, Guam, Commonwealth of the Northern Mariana Islands (CNMI), which were classified as mesopelagics and assigned fishery ID=0, should have been allocated to pelagic longline fisheries.

ii. Confirmed that the field "Gear" contained one of the 26 categories that were previously identified.

iii. Confirmed that the field "Target" contained one of the 7 codes that were agreed.

iv. Confirmed that the field "Ocean" contained one of the 16 categories. However, for Ocean=AO, Antarctic / Southern Ocean fisheries, some of the records might not be Antarctic fisheries, e.g., the Korea distant water pelagic longline and trawl fisheries.

v. Eliminated records with a gear type of "MIS" for which neither an empirical discard rate (EI) was estimated nor a country-based discard rate (CO) have been applied. Some fisheries (those that have been eliminated in this step), were tagged with miscellaneous (MIS) gear type because the gear type used was unknown or not included in the other 25 gear-type categories. As a consequence, these "fisheries" were removed from the assessment, as they did not meet the definition of a fishery, i.e. a fleet using a defined gear type, targeting the same species group in a specific area. The final number of fisheries included in the global estimate at this step was 1 854.

vi. Calculate 95% CI discard levels as follows:

  (i). Sort the LandDisc processed file by DRsource.
  (ii). Use the CO high and low 95% CI rates for DRsource=CO. Same for DRsource=GE and DRsource=IE.
  (iii). Calculate: <u>low discard level = low CI discard rate x landed t/ (1-low rate)</u>. Same for high discard level.

vii. Calculate 95% CI catch levels in the LandDisc processed file: lowest catch level = Disc Lo and Landings, and highest catch levels = Disc Hi + Landings.

viii.Use pivot tables to sum 95% low and high discard and catch levels for each unique FisheryId record.

Results tables and figures
Results (Section 3.1) reports discard levels and rates employing different methods for estimates. The global discard rate was estimated using the two input values (discard level, catch level) and rescaling by 10 000 because they are such large numbers, and sampling the rate from a binomial data likelihood coupled with a Bayes-Laplace beta prior (Gelman *et al.*, 1997; Tuyl *et al.,* 2008).

The summed discard levels were then calculated using the delta method (Jackson, 2011; Oehlert, 1992).

The discard rates by FAO Area and target species categories were estimated using summed discard levels and summed catch levels using a binomial (x=discard, n=catch) in a Bayesian framework to produce expected and 95% highest posterior density intervals (HDIs).

2.3   ASSUMPTIONS AND ISSUES RELATED TO THE METHOD
Discard rates were assumed for some fisheries, based on rates that were available for similar fishery types (i.e. similar target species, gear types and area). The advantage of this approach is that the results can be fine-tuned over time as fisheries allocations and the discard rate data tables are refined. However, it is fully accepted that this first attempt will have methodological and data allocation weaknesses that will need to be addressed in future runs.

The key assumptions and issues were:
- A linear *relationship between landings and discards* within fisheries was assumed, which is a common practice for the extrapolation of sample discard rates to total discards.
- The *identification of key fisheries at a national level* was based on a combination of national and regional fisheries statistics and sector reviews. In many countries, the structure of key commercial fisheries e.g. gear and vessel types, target species,

location, etc. (see Step 2 in Figure 1) are well known, but not in others. For example, many of the distant water activities of some flag states are not well characterized. Characterizing multi-gear inshore fisheries that are common in many parts of the world was also difficult. In countries where the knowledge of specific fisheries was low, we assumed a fisheries structure based upon similar countries in the same region, the composition of landed species, and discussions with national fisheries authorities where possible. See Annex A.1 for further information on countries which are not included in the assessment.

- The *allocation of species to these fisheries* from the national FishStat J landings data table (see Steps 3-4 in Figure 1) is also vulnerable to error. Although many countries provided fish landing statistics for key commercial fleets, many did not. In such cases, the regional teams used fisher's knowledge, MSC and other third-party certification reports, and other published sources to make the allocation decision. Where there were no published data, assumptions were made on the susceptibility of certain species to specific gear types in inshore and offshore fisheries. These cases appeared in the Fishery Table data table as "Expert Opinion" records (field "RefNotes").

The Discard Rates data table compiled records from a wide range of published scientific and industry studies. Many of these estimates were from robust analyses based on large sample sizes, often as part of long-term discard monitoring, especially in Europe and the North America. However, many other areas lacked a robust discard monitoring scheme (e.g., SE Asia and sub-Saharan Africa). Although some gear types had been the focus of discard monitoring (e.g., mobile bottom gears), there was relatively little information on widely used gears such as purse seines and ring nets, specific types of bottom trawls (other than otter trawls) and pelagic gillnets.

We attempted to estimate relative quality of the discard estimates by labelling each as being high, medium or low robustness based on their source, sample sizes, level of peer review, etc. Approximately 55% of the discard data records were ranked as highly robust, 24% medium, and 20% low.

3. Results

3.1   GLOBAL DISCARDS

The estimate of annual discards in global marine capture fisheries for 2010-2014 was around 9.1 million t (95% credible interval: 6.7 – 16.1), not accounting for the unknown discards from some countries and fisheries that account for approximately 6.5% of global landings (see Annex A.1). The global discard rate (t of discards / t of total catch) was 0.108 (95% highest posterior density interval or HDI: 0.101 – 0.115). These estimates were based on a sample size of 1 854 fishery records, with an estimated total annual catch of 84.6 million t (95% CI: 82.2 – 91.6) and annual landed (retained) catch of 75.5 million t.

3.2   DISCARDS BY GEAR TYPE

Discard rates vary widely among gear types (Figures 2, 3 and Tables B1 and B2 in Annex B). About 45.5 percent (4.2 million t) of total annual discards were from bottom trawls that included otter trawls, shrimp trawls, pair bottom trawls, twin otter trawls and beam trawls. The average discard rate (t of discards*100 / t of total catch) of bottom trawls was 21.8%. Boat seines only accounted for 0.48 million t of discards, but it had a high average discard rate of 23.5%. Dredges made up 2% of total discards (0.2 million t) with an average discard rate of 13.6%.

Gillnet fisheries produced 0.80 million t of discards with an average discard rate of about 10.1%. The main part of gillnet discards came from bottom gillnets. Longline fisheries accounted for 0.36 million t of discards with an average discard rate of 12.3%. Likewise, bottom longlines produced the most discards from all longline fisheries.

Relatively high discard volumes were associated with purse seines (1.02 million t) and midwater trawls (0.9 million t). Discard rates in these fisheries, and in particular in purse seines, were however relatively low (3.9%). The high overall quantity of discard was a result of large catch volumes of pelagic species in purse seines.

3.3   DISCARDS BY OCEAN REGION

Discard levels and discard rates varied by geographic region (i.e., FAO Major Fishing Area; Figure 4, 5 and Table B3 in Annex B). The northwest Pacific (Area 61) and northeast Atlantic (Area 27) together accounted for 39% (3.57 million t) of the estimated global discards. Some regions with relatively high discard rates had relatively low discard levels, and vice versa. For instance, the southwest Atlantic (Area 41) had the highest mean discard rate. This region, however, only contributed less than 7.5% of the total annual global discards. While the northwest Pacific Ocean (Area 61) had the greatest amount of discards, contributing 22% of the total annual global discards, but it had the fifth lowest mean discard rate.

3.4   DISCARDS BY TARGET SPECIES

Discards and discard rates varied by target species of fisheries that they pursued (Table 2). Fisheries targeting tunas and other pelagic species had the lowest discard rates, while fisheries targeting crustaceans had the highest discard rates. Fisheries targeting demersal fish had the highest discard levels, while fisheries targeting molluscs (excluding cephalopods) had the lowest discards levels.

FIGURE 2
Mean discard rates and 95% credible intervals for 25 gear types, estimated from gear-specific zero-inflated beta regression models fitted within a Bayesian inferential framework. Discard rates are expressed in tonnes of discards per tonnes of total catch. The solid dots represent mean discard rates for different gear types, and their sizes are proportional to their sample sizes
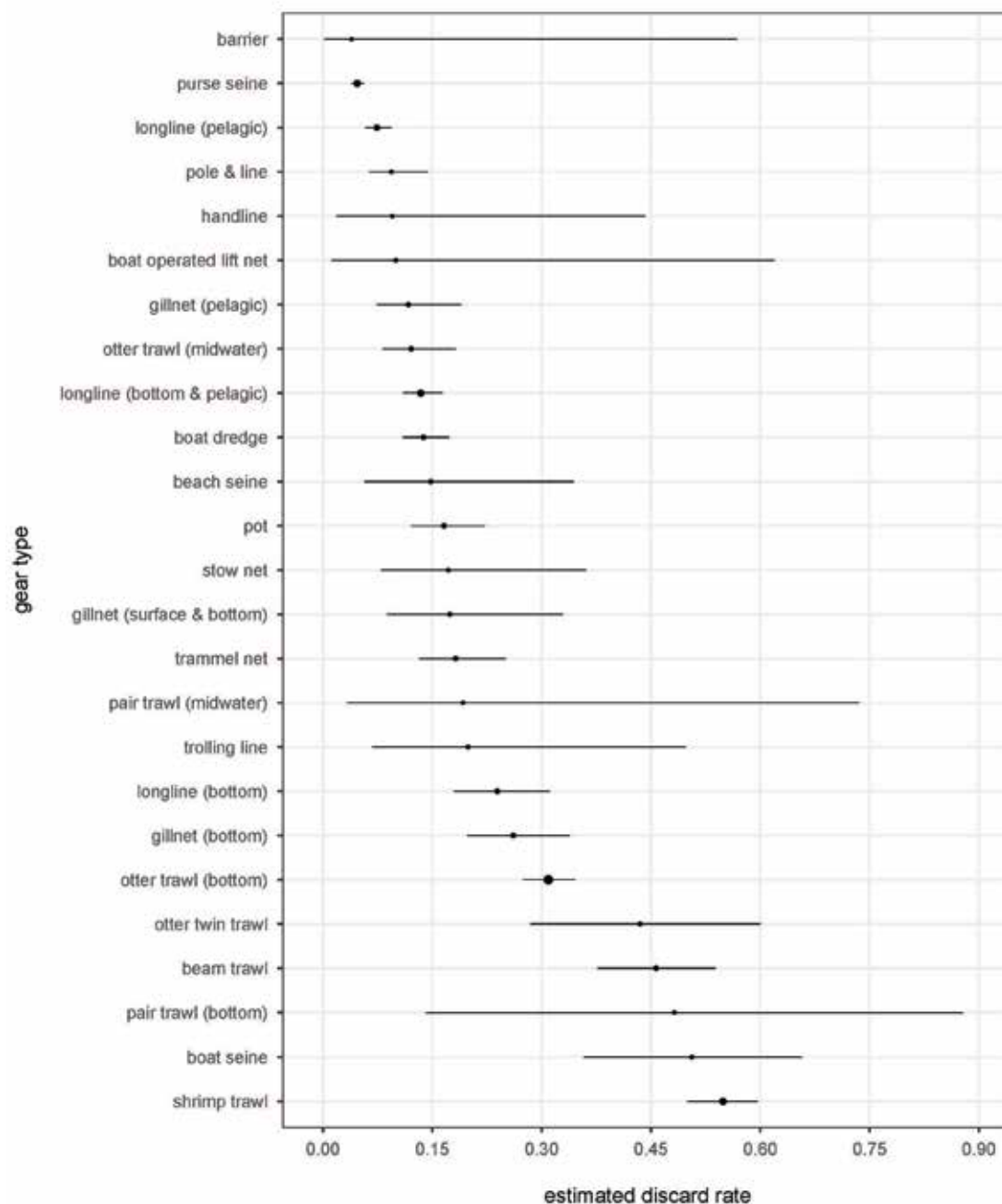
FIGURE 3
**Mean discard levels (thousand tonnes) and 95% confidence intervals by gear type.
The solid dots represent mean discard levels for different gear types, and their sizes
are proportional to their sample sizes**
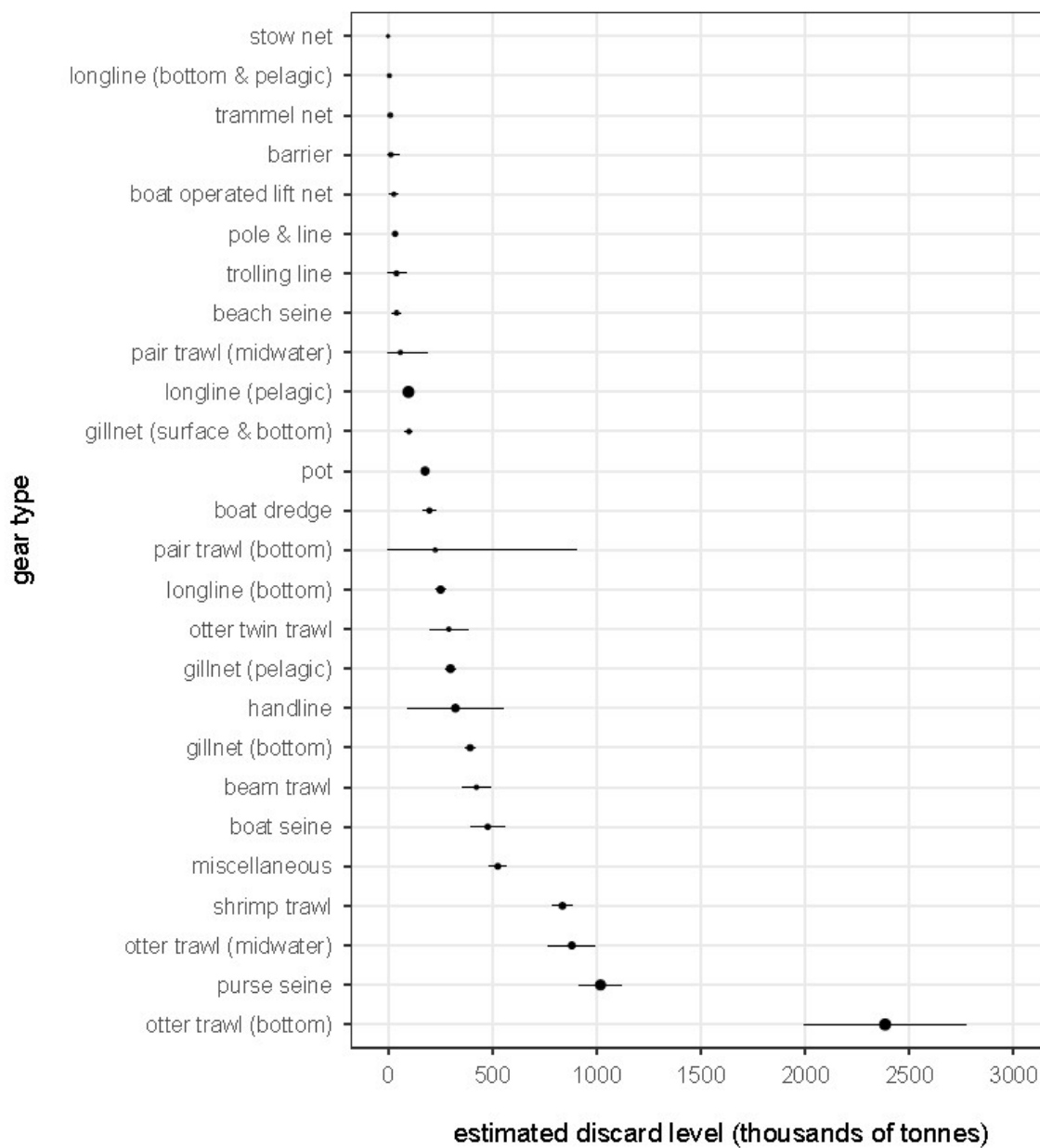
FIGURE 4
Global fisheries discard levels by region. The solid dots represent mean discard levels for different regions, and their sizes are proportional to their sample sizes
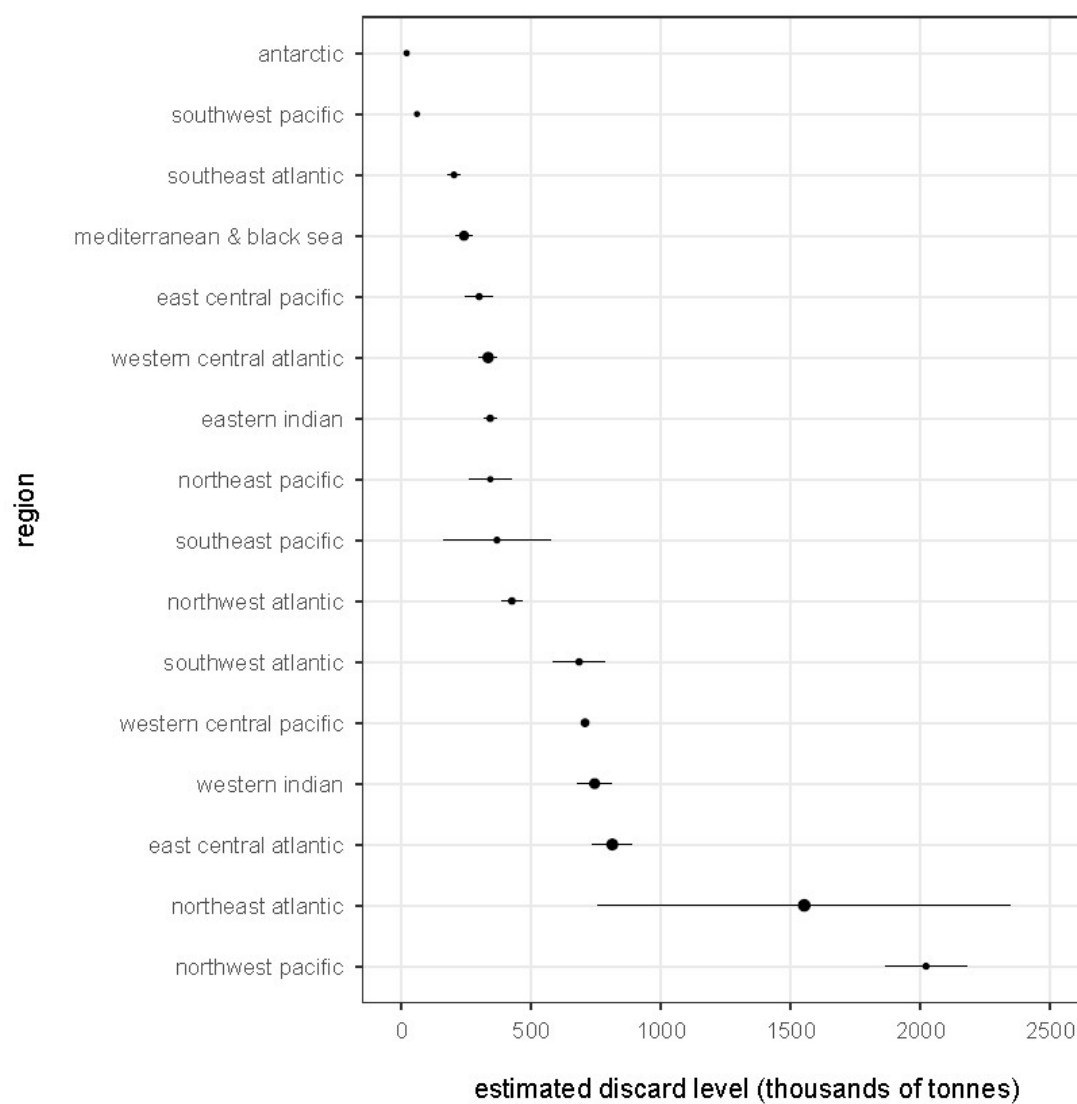
FIGURE 5
Distribution of global fisheries discard rates (top) and total discards (bottom) by FAO Major Fishing Area. Discard rates are metric tonnes of discards per metric tonnes of catch. Discards are metric kilotonnes (kt)

A
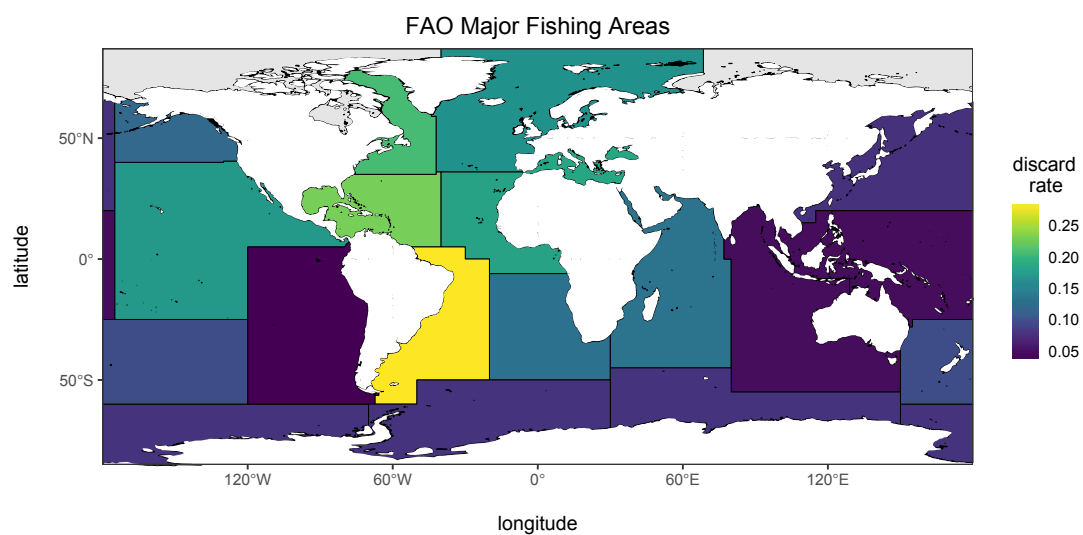
B
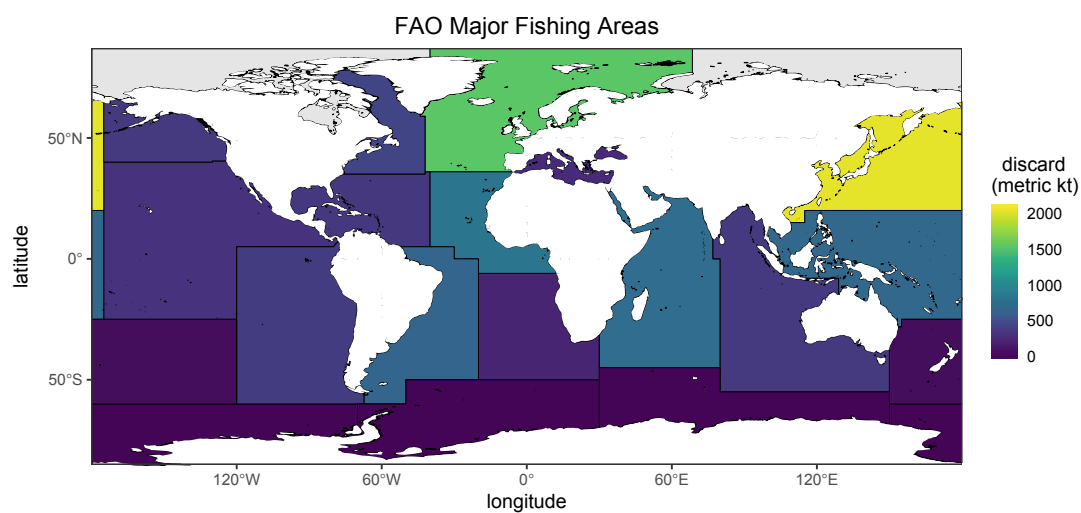
TABLE 2
Estimated discard level (t) and discard rates (t discards / t catch) by target species.
CI=confidence interval, HDI=highest posterior density interval

Target species category	Discard Level (t)			Discard Rate (t discards / t catch)			N
	Mean	*Lower 95% CI*	*Upper 95% CI*	*Expected*	*Lower 95% HDI*	*Upper 95% HDI*	
molluscs except cephalopods	207 196	179 228	235 163	0.132	0.118	0.144	57
tunas	485 652	391 020	580 284	0.054	0.044	0.062	429
cephalopods	497 205	275 508	718 903	0.156	0.092	0.176	58
mixed*	1 258 684	1 159 450	1 357 918	0.098	0.093	0.103	149
crustaceans	1 411 578	1 339 332	1 483 825	0.324	0.325	0.314	229
pelagic fishes	2 205 060	1 996 577	2 413 543	0.062	0.057	0.065	418
demersal fishes	3 074 432	2 291 129	3 857 735	0.167	0.131	0.180	514

* Mixed category includes pelagic and demersal organisms

4. Discussion

4.1   GLOBAL QUANTITY OF DISCARDS

An overall discard rate of 10.8% and an annual average discard quantity of 9.1 million t for marine capture commercial fisheries during the period of 2010-2014 are the key overarching results of this third decadal report on global fisheries discards. The annual quantity of discard is about the same as the recent estimate of global discards derived by Zeller *et al.* (2018) using data from the *Sea Around Us Project* (SAUP). The latter analysis suggests that annual global discards peaked at around 18.8 million t in 1989 and gradually declined to less than 10 million t by 2014. The Zeller *et al.* (2018) assessment relied on a wide variety of data and information sources, and unlike this study, tried to account for unreported landings.

Comparison of our latest estimate with the previous estimates by FAO in 1994 and 2005 suggest that significant changes have occurred in global discards during the last twenty years, from Alverson *et al.* (1994) initial estimate of 27 million t, down to Kelleher's (2005) estimate of 7.3 million t, to the slightly elevated estimate of 9.1 million t by this study. The dramatic decline in the estimates from the 1990s may be explained by significant differences in the methods used to derive estimates, improvements in the data availability and a host of gear-specific differences in assumptions made among the studies which will be discussed in detail below. In addition, during the past few decades, we have also seen the implementation of more selective fishing gears in many fisheries throughout the world and great expansions in the utilization of catches that were previously discarded, which may also have contributed to the declines in discards.

4.1.1   Estimates by gear type

The estimate of global discards from bottom trawls (4.2 million t, which made up 45.5% of the estimated total annual discards), which includes otter trawls, shrimp trawls, pair bottom trawls, twin otter trawls, and beam trawls, was consistent with that of the SAUP global catch reconstruction database (Zeller *et al.,* 2016) for the same period (41.9%).

Gillnet fisheries contributed 0.8 million t to global discards with an average discard rate of about 10.1%. The main part of gillnet discards came from bottom gillnets. Bottom set gillnets are widely used throughout the world, and improved materials and operational techniques have allowed the expansion of their use on rougher grounds and in deeper waters, resulting in the capture of a wider range of non-target species which are often discarded (Suuronen *et al.,* 2012).

Boat seines, primarily Danish seines, had high discard rate (Figure 2). Although the gear is lighter in construction and the area swept is much smaller than bottom trawls, bottom seines have many common features with bottom trawls (Suuronen *et al.,* 2012). Bycatch of undersized individuals of target species and non-target species can be high, leading to relatively high discard rates (Walsh and Winger, 2011).

Longline fisheries produced 3.8% (0.4 million t) of the global discards. Pelagic longline fisheries had an average discard rate of 6.7% and global annual discards of less than 0.1 million t. These estimates were similar to those of Gilman *et al.,* (2017) who reported an annual discards of 0.1 million t. However, Kelleher (2005) had much higher estimates for this gear, a 28.5% discard rate and 0.5 million t of global discards for pelagic longline fisheries. These high estimates came mostly by applying a discard rate of 40% for distant-water longline fisheries, and 15% for smaller, locally-based longline fisheries that lacked available estimates of discard rates. Kelleher (2005) also used advices from regional experts in deriving these estimates, including the discarded catch that had been damaged via depredation by sharks and whales. Such catch might have not been usually recorded as discards (Kieran Kelleher, personal communication,

1 Oct. 2016). Discards of damaged catch is currently recorded as discards by some longline observer programs (e.g., SPC and FFA, 2014). Furthermore, unlike the present study, Kelleher's discard estimates included shark carcass after finning which he reported to be 0.2 million t.

In the current assessment, relatively high discard levels were associated with purse seining (1.0 million t) and midwater trawling (0.9 million t). However, discard rates in these fisheries, in particular in purse seining (discard rate 3.9%), are often relatively low. On the one hand, the high overall quantity of discard is largely a result of large catch volumes in pelagic fisheries. On the other hand, current discard rate data suggest that there are some pelagic fisheries where discard rates are high, for example the herring purse seine fishery in Sea of Okhotsk (discard rate 26.5%, see Discard Rates data table). Similarly, the SAUP estimate of discards in midwater trawling (ca 1.0 million t) is similar to our estimate. This observation is inconsistent with that of Kelleher (2005) who noted that midwater trawl and purse seine fishing for small pelagic fish generated little discards. Kelleher (2005) estimated the global discards in midwater trawling as 0.15 million t, 0.75 million t lower than the current estimate. This considerable difference might have been caused, in part, by some pelagic fisheries (e.g. midwater trawl fisheries in Celtic-Biscay shelf grounds) with relatively high discard rates included in the current estimates.

In many purse seine fisheries it is a common practice to release the catch when the size or species composition of catch is not desirable, or when the crew safety is under threat. The practice of releasing unwanted catches from purse seines while the catch is still in the water is known as "slipping" (Box 1). Slipped catches have not been included in the current study, and there is little data available on quantities of such "discards" in the global scale. Nonetheless, it is known that quantities slipped can be high and the mortality of fish that are slipped from a purse seine may be variable depending on factors such as crowding density and exposure time (Tenningen *et al.*, 2012, Marçalo *et al.*, 2018).

4.1.2   Discards by fishing area

From a regional perspective, we observed the lowest discard levels in southern regions such as Antarctic and southwest Pacific. These results are consistent with previous studies (Kelleher, 2005). In the Antarctic region, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) has been implementing Conservation Measures dealing with discards and collecting data on this practice for more than ten years. However, inconsistencies between the different terms used in Conservation Measures makes it impossible to derive an appropriate quantification of discards (Marschoff & Serra, 2017). In southwest Pacific, New Zealand, the major fishing nation of the region, has a policy of a discard ban associated with an individual transferable quota (ITQ) system since 1986 (Borges *et al.*, 2016).

In terms of discard rates, the lowest are in southeast Pacific, eastern Indian, and western central Pacific Ocean. These results are also consistent with Kelleher (2005). In the southeast Pacific purse seine fishery targeting small pelagic fish (mainly *Engraulis ringens* and *Sardinops sagax*) discard rates appear to be very low (Torrejón-Magallanes *et al.*, 2016) or even negligible in the case of Chile (Vega Muñoz *et al.*, 2016). Chilean Fisheries Law introduced a general discard ban in 2001, which was amended in 2012 to allow for some exemptions (Borges *et al.*, 2016). Such exemptions are subject to the implementation and development of monitoring programs and mitigation plans. In this study, discard data from Chilean purse seine, bottom trawl and shrimp trawl fleets were obtained from an observer program and logbooks. Unfortunately, robustness of such data is low due to the low coverage of the observer program (1.8%) and low availability of logbook data (23.8%) in 2016, and consequently discard estimates are not conclusive.

BOX 1
Slipping of fish from a purse seine

In purse seine fisheries it is a common practice to deliberately release fish from the net over the float line of the purse seine after it has been partially hauled or "dried-up" towards the end of a fishing operation while the catch is still in water. The release is generally known as "slipping". Slipping is done when the size or species composition of fish is found not desirable, or the amount of the catch in the net is excessive. Release may also be a response to regulatory restrictions or market demands. Usually, only a part of the catch is slipped, but in some cases, the entire catch is slipped. There is little data available on the quantities of catches that are slipped in the global scale, but it can be substantial. Whilst slipped fish is not usually considered as discards because the fish had not yet been brought on to the deck, it can lead to mortality in the released fish if the slipping is not done properly. Mortality of slipped fish of small pelagic species such as sardines, herring and mackerel may result in unacceptably high rates of unaccounted collateral fishing mortality (Huse and Vold, 2010; Tenningen *et al.*, 2012; Marçalo *et al.*, 2018). The mortality of slipped fish is directly related to the conditions and interactions that occur within the net, with higher mortality in conditions of higher crowding densities and longer holding time before slipping, both of which can cause hypoxia and scale loss. These operational stressors are elevated at later stages of the operation. Therefore, slipping at earlier stages of operation, when fish are less crowded, would likely lead to lower mortality. However, it is a challenge to fishers to accurately characterize the fish in the net in terms of species and sizes for which the decision on slipping is often based. New methods and technologies to address this challenge are being developed so that operational improvements can be made to significantly reduce stress and mortality in released fish (Breen *et al.*, 2012).

In contrast, in eastern Indian and western central Pacific oceans, there are no discard bans nor observer programs that record discard data. In the countries of these areas almost all catch is utilized. Even when the catch has a low commercial value by virtue of their low quality, small size or low consumer preference, it is either used for human consumption (often processed or preserved) or as feed for livestock animal or aquaculture species, either directly, or in the form of fish meal or fish oil. "Trash fish" is a term often used to describe mixed, unsorted and unidentified assemblages of small fish that are caught in fisheries (APFIC, 2005), in particular in Southeast Asia, but also in other tropical regions. These fish were often discarded decades ago but have gradually grown in importance as a landed bycatch.

The highest discard levels during 2010-2014 occurred, as reported by Zeller *et al.* (2018), in the northwest Pacific and the northeast Atlantic, which together account for 39% of the total discards. However, in the northwest Pacific the discard rate appears to be relatively low (9.12%) due to low to negligible discard rates of Chinese fisheries (Kelleher, 2005) which make up 62% of total catch in that region. In contrast, discard rates are relatively high in the northeast Atlantic as 33% of the total catch come from bottom trawl fisheries, which have the highest discard rates among all gear types.

4.2   STRENGTHS AND LIMITS OF THE CURRENT STUDY

Several factors have contributed to a more comprehensive assessment of fisheries discards in the current study than in the previous two FAO reports on discards. In many countries, the capacity for monitoring and reporting in fisheries has improved during the last 10-15 years. More programs and methods are in place throughout the world to monitor and report catches and discards, including (i) dockside and at

sea observer programs, (ii) electronic monitoring (including onboard video camera monitoring schemes) and electronic logbooks, (iii) smartphone reporting, (iv) fisheries surveys, and (v) fisher interviews and collaborative sampling schemes (Gilman *et al.,* 2012; Mangi *et al.,* 2015). Many countries have developed sophisticated systems for collecting such data that were not available a decade ago. As a result, there are more bycatch and discard data available during the period covered by this study than those covered by Alverson *et al.,* (1994) and Kelleher (2005).

The most reliable and accurate means to collect data on bycatch and discards is through onboard observer programs, including conventional human observers and electronic monitoring (EM) systems. Bycatch and discards data collected and reported by independent onboard human observers and EM systems contain more accurate and detailed information than those reported in logbooks by fishers. Fishers may lack time and training to record data according to prescribed data collection methods and may have an economic or regulatory disincentive to accurately record data, e.g., to avoid catch or size limits (Brown, 2001; FAO, 2003; Walsh *et al.,* 2002, 2005; Gilman *et al.,* 2018). Observer programs have become a mainstream source of fisheries information for the collection of data on bycatch and discards and other information (e.g. Gilman *et al.* 2012). In fact, more than 78% of the discard rate records in this study have come from observer programs (see Discard Rates data table). However, onboard observer programs are expensive, leading to low coverage rates, and consequently less certainty in estimates. Low-cost complementary methods such as the Length Frequency Distributions (LFD) method to explore commercial landings may complement and extend information from observer trips for those fisheries where main driving factors of discarding are known (Depestele *et al.,* 2011). Recent developments in the use of EM systems can augment coverage by human onboard observers. Studies comparing the precision and accuracy of data collected by EM and onboard observers found that EM data had relatively high precision than those collected by onboard observers. However, EM systems are in need of improvement in some areas, such as detection of some discarded species (Gilman *et al.,* 2018).

Research vessels are increasingly used to quantify bycatch and discards but it relies on whether these vessels are able to mimic conventional commercial fishing operations. A considerable part of the data in the current assessment has been based on fisheries survey data (see the Discard Rates data table).

Post-trip interviews of captains and crews are also used to collect data on bycatch and discards. However, as mentioned above, discarding is a bad practice (in some cases illegal) and fishermen could tend to underestimate the amount or volume of discarded organisms or they may simply lack training to record data according to prescribed data collection methods. As a consequence, the data collected on discards are considered to be less reliable than other methods. The advantage is that such techniques can be quite inexpensive.

The new fisheries-based discard dataset developed in this study can be easily updated and modified. The Fishery Table can be refined and then updated against the latest FishStat J landings data, and the Discard Rates data table can be updated with new information as is becomes available. The data protocol used is highly transparent, with all data tables being open source, and further development and refinement is encouraged. The Fishery Table is the first of its kind and may be of significant value for a variety of uses by fisheries scientists and managers. The results obtained in this study can be fine-tuned over time as fisheries allocations and discard rates are added to the data tables. Notwithstanding these advantages, this first attempt at using this dataset to estimate discards has methodological and data allocation weaknesses that will need to be addressed in future applications (see Subsection *Next steps* for more details).

Although more and better data on discards are available now, many shortcomings and challenges encountered by Kelleher (2005) are still relevant in the current study (see

Specific challenges in the current assessment Subsection for more details). Furthermore, bycatch and discards have never been assessed in many fisheries, particularly in many small-scale fisheries (e.g. Zimmerhackel *et al.*, 2015). Significant efforts were made in this study to obtain data from as many countries, regions and agencies as possible. Where data had been traditionally difficult to obtain, regional experts were contacted to provide their estimates (regarding both fisheries landings allocations and discard rates). Nonetheless, many data gaps remained with a number of countries not included in the current assessment (see Annex A.1).

As a global study, it was not possible to evaluate all factors affecting discards. We focused primarily on differences between gear types, but we may have lost some resolution regarding discards in different areas and by different target species. Nonetheless, the lack of focus on target species may have been compensated by the fact that the gear type often infers a specific target species. For other fisheries, some of our lower resolution gear-categories with a small sample of observed discard rate records may not have provided accurate estimates of discard rates. For example, we included a single gear category of handline, which includes fisheries targeting both demersal and pelagic species. The discard rate estimate for this gear type was based on only two records, one from a demersal handline fishery and the other from a fishery with a mix of demersal and pelagic target species. The extremely small sample size of records used to estimate the discard rate for handline has resulted low certainty in the discard level and rate estimates for this gear type.

We did not address the issue of species and size composition of discards in this study. These are important issues for food security and stock assessments, but it was not possible to include this information in this study, although there was an extensive literature regarding species and size composition of discards in various fisheries and regions.

Specific challenges in the current assessment

The current assessment was based on several assumptions which are sources of uncertainty but had not been completely reflected in the estimates of precision. For example, a linear relationship between discards and total landings was assumed although this may not be realistic for some species, e.g. in a particular fishery the discard rate for a non-commercial species can be 100% and then landings would be 0 (all individuals are discarded). The total quantity of discards was derived by extrapolating the discard rates from limited studies to the total catch of these fisheries. No estimation at a fisheries level was made for domestic fisheries in specific countries where there is few or no data on discards. Instead, in such countries the same discard rate (country-level discard rate) was applied to all domestic fisheries. These countries either have had a discard ban policy (e.g. Norway and Iceland) or were believed to have extremely low discard rates because (almost) all landed catch is used either for human consumption, and/or aquaculture and livestock feeds, including Bangladesh, Cambodia, China, Democratic People's Republic of Korea, India, Indonesia, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand and Viet Nam. However, it should be noted that in the case of East and Southeast Asian countries, no empirical discard data exists and assumptions used in other studies were also used in the present study (see CountrySpecificDR data table). In the case of Norway and Iceland, their country-level discard rates are based on a few discard data on commercial species reported to the European Commission (Data Collection Framework programme). Together, all these countries produced more than 45% of annual landings included in this study (see Subsection Methods of estimating discard rates). Therefore, when interpreting the results of this study, due consideration should be given to the fact that the uncertainty generated by this group of countries might not be well captured.

FishStat landings records seldom exactly match with national statistics, which made it difficult on allocation of landings to specific fisheries. As a consequence, almost all countries have a fishery named "other fisheries in X area" which include either the multi-gear inshore fisheries that are common in many parts of the world and/or species that are recorded in FishStat but not in national statistics. Another similar issue is the category "Marine fishes nei" in the FishStat data table. This category includes marine fish "not elsewhere included" (nei), which are fish that have not been identified by species or family, including hundreds of fish species and 10.84 million t of landings in total (14.35% of total landings included in this assessment).

National fisheries statistics are not always readily available by fleet, gear or by fishery. In these cases, we have assumed that certain fisheries exist, based on similar countries elsewhere in the region, the composition of landed species where possible, or discussions with national fisheries authorities. The source of data for these fisheries is flagged as Expert Opinion in the Fishery Table (see RefNotes field).

The structures of some key commercial fisheries (in terms of gear and vessel types, target species, and location) are not well known. For example, many of the distant water activities of some flag states are not well characterized. In such cases, we based our assumptions on similar fisheries in countries elsewhere in the region. Furthermore, some fishing countries, which only contribute 0.13% (772 117 t) of the total landings worldwide, were not included in the assessment, because no information was found about the characteristics of the commercial fisheries in these countries.

The Discard Rate data table was compiled with records from a wide range of published scientific and industry studies. Many of these analyses were based on large sample sizes, often as a part of long-term discard monitoring, especially in Europe and North America. However, many other areas lacked robust discard monitoring, e.g. North and Southeast Asia, sub-Saharan Africa. In terms of types of fishery, the focus of discard monitoring are bottom trawls and boat seines (mainly Danish seines). In fact, mobile bottom gears are the best represented within our discard records. By contrast, trolling, handlines, pole-lines and in general artisanal gears (e.g. beach seines) are the least represented.

4.3   OTHER ISSUES

Economic and social impacts of discards

Discarding, from a societal perspective, can have economic impacts (Pascoe, 1997) which can be classified into four categories (FAO, unpublished): (i) discarding of juvenile and adult target species with an associated impact on future stock growth, resulting in forgone income; (ii) discarding juvenile bycatch species can reduce target species catch and revenue in other fisheries; (iii) costs associated with discarding of non-commercial species (time spent removing the individuals from the fishing gear or sorting on deck); and (iv) cost associated with measuring/estimating the levels of discards (observer programs are known to be costly).

However, discarding is also an economically rational decision by fishers to maximize benefits. The benefits of discarding to individual fishers can be considered in terms of: (i) the increased value of the commercial catch (quality, size, species mix) as a result of discarding unwanted catch; (ii) reduced costs of handling and storing non-commercial catch and onshore disposal; and (iii) avoiding sanctions if vessels are catching illegal fish (and are not able to sell it undetected on black market).

Management regimes (such as quota, size and sex restrictions, and effort controls) can incentivize discarding (see Section 3 of Pascoe 1997 for more details). However, independent of management systems, discarding is influenced by specific characteristics of fishery and status of stocks being harvested. Moreover, social spheres (fishing community and market) have been identified as factors influencing discarding and selective fishing behaviors (Eliasen *et al.*, 2014). Therefore, solving the discard problem

requires a suite of measures tailored to a fishery, taking into account all factors that incentivize or discourage discard behavior as well as interactions between different fisheries in terms of target species and species caught (both target and bycatch species). In all cases, achieving a common perception on the problem of discarding among fishers, fishery managers and other relevant stakeholders is essential to foster cooperation and trust to reduce discards (Eliasen *et al.*, 2014; Johnsen and Eliasen, 2011).

4.4   FUTURE GLOBAL DISCARD ASSESSMENTS – LESSONS LEARNED

Reliable information on fisheries bycatch and discards is an important step towards more effective management and improved utilization of fisheries resources. Failure to effectively manage bycatch and reduce discards jeopardizes long-term sustainability of fisheries, threatens biodiversity and impact on food security, thus affecting the livelihoods of those dependent on fisheries resources. It is thus important to monitor the performance of fishing sector in reducing discards and seafood wastes over time.

Accurate information on discards is also critical for improving quality and reliability of stock assessments. The lack of reliable data on the level of discards in fisheries represents a significant uncertainty in the assessment of total fishing mortality, thereby decreasing the quality of scientific advice. However, assessment of fisheries discards is a daunting task because discards have not been properly estimated for many fisheries. Although there have been increases in the number and diversity of observer programs, logbook programs and EM systems, there are still many fisheries, regions and fishing methods for which no such data exist. Therefore, our estimates incorporate many assumptions and extrapolations as we assign estimates from other fisheries to fisheries with few or no data, and as we aggregate data across regions, fisheries and fishing methods.

New solutions for improved data acquisition and processing are an increasingly important global topic, especially in Europe with the new reform of the European Union Common Fisheries Policy which established a discard ban (or Landing Obligation). New approaches are being developed by the scientific community and the fishing sector in order to get better data on catch quantities and composition, for example, optical technologies used for the identification and quantification of the catch on board (iObserver system). This information has been used to develop better models that more reliably predict discards hot-spot areas (Vilela and Bellido, 2015; Pennino *et al.*, 2017), which can be used by the fishing sector to avoid high levels of discards.

Considering public ownership of natural resources in the sea, the general public in any society are the key fisheries stakeholders. Therefore, governments are responsible for undertaking all appropriate activities, including discard monitoring, for the management of these public resources. In recent years, the importance of bycatch and discards monitoring has also been recognized in many formal international agreements, guidelines and policies, such as FAO's International Guidelines on Bycatch Management and the Reduction of Discards (FAO, 2011). Finally, it is widely recognized that all key stakeholders, in particular the fishing sector, should participate in the process of the management of fisheries bycatch and discards. The status of the global implementation of the relevant paragraphs of the Code of Conduct for Responsible Fisheries (FAO, 1995) is a useful index of this progress (see Annex C).

The discard assessment described in this report can be improved in many ways. Reporting on fisheries landings by species and by gear types would be the first step. In order to do so, enhanced national buy-ins and engagement would be needed. The scope could further be extended by adding or completing the data fields regarding the state of the fishery, value, total 'wastage', discard composition and food security dimensions. Moreover, best practices in protocols for inclusion of discards in stock assessments, pathways for discard reduction or elimination, and elements of environmental accounting are some areas for consideration and development.

It is important to have a clear goal for future assessments. The ultimate goals should be informing fishery management and policy initiatives (e.g., the reduction of wastage in capture fisheries) and reporting to the public owners of these resources. A direct engagement with Regional Fisheries Management Organizations (RFMOs) and UN member states is fundamental to generate discard estimates. Furthermore, engagement with Regional Fisheries Bodies (RFBs) to capture small country and developing country information is important, and if necessary, regional experts should be engaged to work closely with these countries.

Next steps
An important objective of this update of global discards estimates was to develop an open and repeatable methodology linking FAO's FishStat J landings data with discard records. This has largely been achieved, but it is also recognized that considerable work is needed to update and refine various datasets and their linkages.

In particular, two tables need further development:

1. **Fishery table:** this table allocates species data from FishStat J with individual, gear-related fisheries conducted by each flag state. This list of fisheries is well defined in countries where fishing fleet *métiers* are well documented, and catches are reported against these. However, this is not the case for many other countries, so further work needs to be done to better identify specific fisheries and their characteristics (e.g. gear type, location, water depth, vessels sizes, selectivity, etc.)

2. **Discard rates table:** this second table was compiled with records of discard rates from around the world. It was the result of an extensive literature review but needs further attention to ensure it contains all recent discard rate records and is updated as new data become available. For instance, on the latter it would be useful if there were an easy way to import new data from the European Union's Data Collection Framework (DCF) when it is released, as well as other data sources such as Marine Stewardship Council reports which contain these types of data.

A second area for development is the joining between the various data tables. This was found to be more complicated than first thought, especially when joining the Fishery Table with the Discard Rates table. Information on discard rates was often insufficient to identify which fishery observations were taken and it was not always clear to which species the discard rates might apply. A more rigorous evaluation of fishing operations might yield better discard rate estimates so that they may be used to infer discard rates in other similar fisheries using a model-based approach.

The third area for development is to further refine the fisheries-specific nature of discarding. For instance, whilst some fisheries may generate large volumes of fish not desirable for human consumption (e.g. some bottom tropical shrimp fisheries), the natural assumption, which is also often supported by official observer trip reports, is that they are discarded. However, in reality it is often retained and sold in the fish reduction market, thus discarding levels would be overestimated. Another scenario is that fisheries which have discard ban policy instated may have a number of derogations, or indeed unreported discarding, which may mean that discard levels are underestimated. The challenge for further development of this approach will be capturing these particular anomalies.

4.5   CONCLUSIONS
The current study established a method for assessing discards at the global level by creating a fishery-by-fishery dataset of landings and discards (landdisc.csv file). The estimate can be checked and updated through changes to individual records in the data tables which are the source from which the dataset is built. The majority of the Fishery

Table and Discard Rates data tables contain fields with standardized codes. Thus, the dataset can be easily updated as new discard and/or fishery data become available.

The estimate of annual discards in global marine capture fisheries for 2010-2014 was around 9.1 million t (95% CI: 6.7 – 16.1), with a wide range of discard rates among fisheries, regions and gear types. Fisheries using bottom towed gears – trawls and boat seines - accounted for almost 51% of the estimated global discards. Hence, it is well justified that the focus in bycatch management and discard reduction is still focused on mobile bottom fishing gears.

The assessment still excludes a number of fisheries, and no allowances were made for illegal, unreported and unregulated (IUU) catch, recreational catch or freshwater fisheries. Small-scale fisheries from many countries were poorly represented in the data. The assessment was built on the FAO landings data table (FishStat J) which is not totally coherent with other landing databases (national or regional databases) in terms of species composition and area allocation.

Unfortunately, no coherent time series of discard rates at the global level can be constructed on the basis of the series of FAO assessments. Therefore it is not possible to estimate temporal trends in discard levels. However, it is worth noting that new countries and regions start including in their legislation the words "bycatch" and "discards" as a sign of an emerging political will to mitigate the wasteful practice of discarding. Some examples are the European Union (reform of the Common Fisheries Policy of 2013), Chile (Borges *et al.* 2016) and Australia. Moreover, efforts are being made by RFMOs and RFBs in addressing bycatch and discard issues, but generally they only include commercial species (FAO, 2015).

The range of policy options to reduce discards is determined both by the biological characteristics of the fishery and its social and economic environment. Best practice in discard reduction is illustrated by a number of countries in the Organization for Economic Cooperation and Development (OECD), while many other countries, especially in Asia, provide valuable experiences in the utilization of bycatch. Increased bycatch utilization is now widespread in Asia, Africa and America leading to reduced discards (e.g. Funge-Smith *et al.*, 2005; Hutchinson *et al*, 2007; Lobo *et al.*, 2010; Bage, 2013).

PART II - RELATED ISSUES

5. Bycatch and discards of endangered, threatened and protected species

This chapter provides a global synthesis of the available data concerning one of the most controversial components of bycatch associated with the capture and discarding of endangered, threatened and protected (ETP) species in commercial and artisanal marine capture fisheries. The chapter contains information in a report commissioned by FAO for this project, which has recently been published in peer-reviewed journal *Reviews in Fisheries Biology and Fisheries* (Gray and Kennelly, 2018). That review examined the available data for key taxa in this category of bycatch (seabirds, turtles, sea snakes, marine mammals, sharks, rays and teleosts) and provided a preliminary estimate of discards in a global scale.

ETP species are generally defined by national legislations and international agreements and assessments (e.g. the IUCN Red List, the MSC fishery standard, etc.). The previous FAO report on global discards (Kelleher, 2005) contained a section "*Incidental catch and discards of charismatic and endangered species*" (Section 4.2.3), which briefly described the discarding of ETP and charismatic species. However, that report did not provide an estimate of discards of ETP species.

5.1 ESTIMATES OF ETP SPECIES BYCATCH

Assessing the impact of fishing on ETP species poses several problems. In particular, there is a lack of data because: (i) the species involved are almost always in low abundances so their interactions with fishing gears are often sporadic; and (ii) fisheries interactions with ETP species are usually viewed negatively and therefore are often not reported by fishers. This means that the main source of reliable data on the discarding of ETP species comes from observer programs using human observers and/or more recently EM system. When Kelleher (2005) prepared his report, the number and extent of observer programs was far less than the time frame covered by this report. There have been substantial advances in identifying, quantifying and ameliorating incidental catches and discarding of ETP species in marine fisheries throughout the world in the past 10-15 years. This, for the first time, allowed FAO to make global estimates (albeit imprecise) of the bycatch and discarding of ETP species in the world marine capture fisheries.

It was estimated that one million seabirds, 8.5 million sea turtles, 225 000 sea snakes, 650 000 marine mammals and 10 million sharks, amounting to a total of around 20 million individuals, were captured and discarded annually in global fisheries (Gray and Kennelly, 2018). However, the study highlighted gaps and constraints in datasets (across taxa, fisheries and regions) to produce such estimates with certainty and precision. The inherently rare nature of ETP interactions with fisheries usually preclude the conventional estimation of variances around extrapolated estimates.

The above estimates of the bycatch of ETP species are skewed to particular fisheries and regions, with the most notable gap being small-scale (multi-method) coastal and artisanal fisheries – both in developed and developing countries. Small-scale fisheries could collectively have very large quantities of bycatch of ETP species, which might

even exceed larger scale fisheries (Lewison *et al.,* 2014; Pott and Wiedenfeld, 2017; Temple *et al.*, 2018). The major concern is that it is not only logistically difficult to obtain reliable and robust estimates of bycatch, but it is also challenging to develop and implement measures to reduce bycatch in these fisheries.

Much of the available data on ETP bycatch (particularly for marine megafauna) has come from observer programs in high-value large industrial fleets (mostly longline and trawl gear) that fish in the high seas. Whilst bycatch data from such direct observations are most reliable, many observer-based programs have relatively small (< 10%) coverage and restricted spatial and temporal resolutions that compromise the utility of the data (for more discussion, see Babcock *et al.,* 2003). Different levels of protection are also afforded to different ETP species across countries and fisheries, complicating the need and objectives of region-wide conservation efforts.

It is logistically difficult and expensive, and in most cases not viable, to implement widespread observer surveys across all fisheries, particularly in the small-scale, multi-method artisanal fisheries in developing countries to quantify ETP species bycatch. Consequently, alternative data collection methodologies are used, including self-reported (e.g. logbook) data, and fisher and community-based surveys that rely on recall and trust. Although such methodologies can provide valuable information, there is often a reluctance by fishing industries and communities to report ETP species interactions (and especially mortalities) in logbooks and other self-reporting schemes because of perceived negative connotations and other socio-economic reasons. Validation and auditing systems are therefore required to meet data quality standards (Kraan *et al.,* 2013). It is noteworthy that electronic monitoring using cameras can be quite useful in collecting bycatch data on ETP species in such cases, especially megafauna species which can easily be identified by video cameras. There is an urgent need to develop novel methods to quantify and report ETP interactions in small-scale fisheries, which may include educational outreach and collaboration with local communities.

Despite these data uncertainties, over the past decade there have been substantial advances in the estimate of bycatch and associated mortality of ETP species (as well as ameliorating these interactions) in marine fisheries (e.g. Anderson *et al.*, 2011; Lewison *et al.*, 2014). But such advances have been far from uniform among groups of organisms, fisheries and regions. For example, assessments of bycatch of sharks and rays are still hampered by broad-scale species identification and amalgamation issues, as well as basic non-reporting across fisheries and regions, despite worldwide concerns of their overexploitation (Oliver *et al.*, 2015).

Large knowledge gaps remain concerning fishery interactions with ETP species throughout the world. Importantly, prioritizing the quantification and amelioration of ETP bycatch both within and across fisheries also requires concomitant assessments of discard mortality. In addition, sublethal effects on the fitness (in terms of growth and reproductive success) of discarded individuals also requires consideration (Wilson *et al.,* 2014).

5.2   MITIGATION OF ETP BYCATCH MORTALITY

The development and implementation of various bycatch mitigation measures have reduced fishing-induced mortalities for certain ETP species in several fisheries. Although further developments and refinements are required, the lack of implementation and enforcement of existing best-practice mitigation techniques in many fisheries has compromised reduction of mortality of ETP species (Gilman *et al.*, 2008; Boyd, 2014). A significant challenge to mortality reduction will be the uptake of existing and new measures in many small-scale artisanal fisheries in developing countries. It is important to note that when gear modifications are not viable or practicable, small changes in fishing behavior and handling practice can have a positive impact on the survival of discarded or released ETP species, notably sea turtles. Nevertheless, before we have improved management policies and greater adoption of available mitigation measures across all fisheries globally, bycatch remains a significant threat to many ETP species.

5.3   CONCLUSIONS

Improvements in future reporting of fishery interactions with ETP species will require the implementation of internationally-agreed standardized data collection, analysis and report criteria, with a particular focus on regions and fisheries that currently lack any such reporting (i.e. the world's many small-scale fisheries). Greater precision in estimates of bycatch and associated mortality will require greater observer coverage in spatial and temporal scales, augmented with novel analytical and modelling techniques. Costs and benefits need to be weighed when determining optimal levels of coverage across different types of fisheries. Risk-based analyses should be used to help identify priority areas and appropriate types of data collection, particularly for data-poor fisheries. Whilst not addressed here, given the scale and importance of marine recreational fisheries worldwide and their possible interactions with ETP species, ETP bycatch and mortality in recreational fisheries should also be included in such data collection regimes.

6. Measures to manage bycatch and reduce discards

There are various types of measures to manage bycatch and to reduce discards, including modifications to fishing gear or fishing practices, spatial and temporal measures (time and area restrictions), bycatch limits, effort restrictions and discard bans (landing obligations). In addition, discards can be reduced through fleet communication, awareness raising, training, and economic incentives. Many of these measures are aimed at protecting juveniles and reducing discards of unwanted or prohibited species, but they also often have other management objectives (Kelleher, 2005; Suuronen and Sardà, 2007; FAO, 2011).

6.1   SPATIAL AND TEMPORAL MEASURES (AREA AND TIME RESTRICTIONS)

Spatial management measures are widely used to manage bycatch and reduce discards (Dunn *et al.*, 2011; Little *et al.*, 2015). These measures are usually established for multiple purposes, for instance, to protect juveniles, spawning and foraging grounds, migratory pathways, and areas of special biological interest. Spatial measures include the creation of areas reserved for traditional fishing activities and areas where certain gears are prohibited (e.g. no-trawl areas). Protected areas can be useful in ensuring that, for example, portions of the spawning stock are protected.

Spatial measures are likely to be of particular use in regions and fisheries where more sophisticated measures are not feasible, such as in multispecies fisheries in tropical areas. With the increased use of vessel monitoring systems on smaller vessels, such spatial measures are gradually less expensive to implement over large archipelagic sea areas than, say, output-based measures. However, when impacts of establishing closed areas are not assessed both before and during their implementation, it may unintentionally increase discarding and cause other unexpected effects because of the reallocation of fishing areas (e.g. Pastoors *et al.*, 2000; Suuronen *et al.*, 2010).

Real-time dynamic area closure schemes have emerged across Europe and North America to protect juvenile fish and reduce discards (Little *et al.*, 2015). Areas to be closed are often related to distribution of juveniles, with information from real-time monitoring on fishing activities. High catch of unwanted fish can trigger an area closure. Real-time fleet communication can be an efficient tool to enable vessels to avoid fishing grounds with high bycatch (Little *et al.*, 2015; Gilman *et al.*, 2006a). In Australia, this type of dynamic spatial management is successfully used to avoid Bluefin tuna bycatch and concomitant discards (Hobday *et al.*, 2010). Real-time closures have the advantage of responding to current conditions on the fishing grounds. They provide benefit to fishers to develop, use and share information and technology to avoid undesired catch. The disadvantage may be the high costs of administering such regimes.

Temporal measures such as seasonal closures are commonly used to reduce mortality and discards of juveniles. For instance, a fishery may be open only when the majority of fish in the area have reached a certain size. Time restrictions are often applied in varying levels of detail, and seldom achieve full protection. For example, often a particular season of the year is banned for a particular type of fishing.

6.2   BYCATCH QUOTAS (AND LIMITS)

Bycatch quotas are implemented in many fisheries, especially in the United States and New Zealand. Because exceeding bycatch quota would trigger an early closure of the

fishery, which would have serious economic consequences for fishers, they would more likely to adapt or change their fishing gear and/or fishing strategy to reduce bycatch (e.g. Holland, 2007). Fishers in general are concerned that bycatch quotas result in loss in fishing opportunity and profit from their fishing. Furthermore, feasibility and cost of establishing an observer program capable of providing the required level of coverage to accurately estimate catch composition is a major concern in bycatch quota management. Combining bycatch quotas with other measures, such as bycatch avoidance through fleet communication, may help better achieve bycatch objectives than a single management tool (O'Keefe *et al.*, 2014).

6.3 EFFORT REGULATION

Overfishing contributes to discarding through declining average sizes of fish captured which make the catch less marketable and hence more likely to be discarded (Cook, 2003). Alverson *et al.* (1994) noted that no other actions would likely contribute more to reduction of bycatch and discards than the reduction of fishing effort, especially if fisheries resources are overexploited. Reduction of fishing effort for instance through a fleet capacity reduction or days-at-sea program, if properly applied, can make a significant impact on discard quantities.

6.4 NO-DISCARD REGIMES (DISCARD BANS OR LANDING OBLIGATIONS)

Several countries pursue a no-discard (discard ban) policy and prohibit discards at sea. The ultimate goal is to reduce or eliminate catch of unwanted fish through incentives that promote selective fishing. No-discard legislation is often enforced only partially in recognition of the unpredictable nature of fishing operations and various concerns of the fishing industry. Some allowance is made to ensure that fisheries remain economically viable with such a measure. A ban may stimulate opposition from the fishing sector as has taken place in many regions in Europe as the EU started enforcing its landing obligation measures (e.g. Damalas, 2015; Sarda *et al.*, 2005 and Box 2). Discard bans require broad industry support, flexibility in output controls, incentives, and extensive surveillance and enforcement (Hall *et al.*, 2000; Poos *et al.*, 2010; Batsleer *et al.*, 2013; Guillen *et al.*, 2018).

Guillen *et al.* (2018) noted that banning discards will inevitably induce diverse short- and long-term ecological, economic and social impacts, which may determine whether the objectives of the ban will be achieved. Thus, to ensure compliance but also to mitigate fishers' costs to meet the obligation, it is essential to further involve fishers in the design of tailored and flexible policies at a *métier* level (Deporte *et al.*, 2012).

On a positive note, as a consequence of the new EU Common Fisheries Policy (CFP), a significant joint effort is being made in Europe by governments, the scientific community, and the fishing industry to mitigate discarding practices by following an Ecosystem Approach to Fisheries Management (see Annex D for more details).

Developing a financially viable mechanism for the disposal of landings of unwanted catch may also be a challenge in many fisheries. Nonetheless, promoting the development of new products from unwanted bycatch, and innovative trade and marketing channels are required, but can be especially challenging in fisheries that land their catch in remote locations with small human population sizes (e.g. for non-tuna catch of some tuna purse seine fisheries; Lewis, 2016).

There are also measures banning the retention of some ETP species, encouraging their non-capture. These measures may lead to fishing practices with enhanced selectivity.

BOX 2

The Landing Obligation in European Union fisheries

In the early 2000s, discarding in European Union (EU) fisheries received significant attention and substantial political focus. Consequently, a ban on discarding (the landing obligation) in EU fisheries was introduced as a core element of the Common Fisheries Policy (CFP) reform in 2013. The landing obligation (LO), as defined in the basic regulation of the CFP, required gradual phasing-in of the obligation to land all catches across areas, fisheries and species (Article 15 of REGULATION (EU) No 1380/2013). Under the landing obligation, which contains numerous exemptions, all catches must be kept on board, landed, and deducted from established quotas. The LO applies only to species or stock with established total allowable catch (TAC) and species covered by minimum landing size regulations, the latter has since referred to as Minimum Conservation Reference Size (MCRS). All fish that are below MCRS size must be landed and deducted from the quota, but they cannot be sold for human consumption. This is intended to discourage fishermen to catch small fish that cannot be sold. Overall, introducing the LO has represented a fundamental shift in the management of EU fisheries, switching from the regulation of landing to catch.

The reform aims at gradually eliminating the practice of discarding. It also aims to provide more accurate data on catch by changing from a system that records the landed fraction to the entire catch. The implementation of the landing obligation has taken place gradually from 2015 and will continue through 2019 to cover all commercial fisheries in European waters and European vessels fishing in high seas.

Exemptions to the landing obligation were established in order to lessen economic impact to fishers and create a gradual transition to the new system. These exempt catches must be documented in the logbook, but are not deducted from the quota. Species Exemption means that species where discard survival is shown to be "high" may be exempt from the LO based on scientific evidence. Differing, and contentious opinions exist on the definition of this "high" survival. The exemptions also include a concept of Minimum Allowable Discards. A small percentage (de Minimis) of continued discarding is permitted annually. This is defined as a percentage of total annual catches subject to the landing obligation and is based on two conditions: (i) improvements in selectivity are difficult to achieve and (ii) handling and sorting present disproportionally high costs. Defining the volume of these discarded fish is ambiguous. Other key issues include quota flexibility (inter-annual vs. established) and species with minimum allowable discards. Overall, the volume and justification for a minimum allowed discard system presents significant challenges.

There are indications that "choke species" issues in mixed species fisheries managed by single species TACs may present a strong driver to continue underreporting unwanted catches of such species. Additionally, documentation of unwanted catches is difficult to quantify in practice (e.g. slipped catches from purse seine). Overall, the adoption of the landing obligation presents a fundamental shift in the management of European Union fisheries. Numerous issues in the execution of the LO system must be continually re-evaluated in order to ensure continued success and health of EU fisheries under the new system.

6.5   SELECTIVE FISHING

Promoting more selective fishing is often the principal approach to reduce discards, which has worked in many fisheries (e.g. Kennelly and Broadhurst, 2002; Hall and Mainprize, 2005; Enever *et al.*, 2009).

Changes in fishing gear design and operation have long been employed by fishers to achieve desired selective properties of fishing gear toward preferred catch compositions, often to minimize the capture of certain age groups or unwanted species (Lokkeborg and Bjordal, 1992; Kennelly and Broadhurst, 2002; Valdemarsen and Suuronen, 2003; Broadhurst *et al.*, 2007; Graham *et al.*, 2007; Madhu, 2018). Gear modifications include, for example, changes in the size and shape of mesh and hook, longlines leader material, escape panels in traps, acoustic alarms, biodegradable panels, square mesh panels, underwater lights, sorting grids, and other bycatch reduction devices (BRDs). Depending on the type of problem, solutions may also involve adjustments to operational procedures and rigging of the gear.

Typically, active gears such as trawls and boat seines are less selective compare to passive gears (e.g. Broadhurst *et al.*, 2007). As in almost all fishing gear types, the selectivity of trawl gears includes species selectivity and size selectivity. In size selectivity research, the starting point for modifications has often been the trawl codend, since this is where most size selection occurs (e.g. Wileman *et al.*, 1996). Selection in conventional diamond-mesh codends is highly variable and influenced by numerous factors including size of mesh, as discussed above, but also hanging ratio, twine thickness, diameter of codend, towing speed, towing depth, gear hauling practice and weight of the catch (Lowry and Robertson, 1996; Broadhurst and Kennelly, 1996; Dahm *et al.*, 2002). The shape of mesh (e.g., square mesh) and knot orientation (e.g., T-90 mesh) of the codend also have great impacts on selectivity (He, 2007; Wienbeck *et al.*, 2011).

Developing species selective designs for trawls is particularly difficult when the species to be separated are of the same size. To be effective, the selectivity system has to utilize potential behavioral differences of these species (e.g. He, 2010). More recently, innovative gear modifications that attempt to separate unwanted fish species before they enter into trawls have been tested. Melli *et al.* (2018) demonstrated that a simple counter-herding rope system (FLEXSELECT) installed in the front of the trawl mouth significantly reduced finfish bycatch in crustacean trawls, but the rate of reduction varied considerably among species and sizes of bycatch fish species. Furthermore, studies that use LED lights in the headline or fishing line of a trawl have shown promising results in reducing bycatch (Hannah *et al.* 2015).

In some cases, a shift away from demersal trawl toward more selective gear may be the best option. Broadhurst *et al.* (2007) illustrated the potential of trap to harvest penaeid shrimp, which may be considerably more selective than towed gears. Use of alternative methods to capture fish may provide a completely different selectivity pattern and in some cases could profitably substitute the problematic gear (Suuronen *et al.*, 2012). The switch to an alternative gear may also take place through regulations that make the use of certain gear types illegal, like a trawl ban in Indonesia (Endryono, 2017), and the high seas driftnet ban enforced globally.

A necessary condition for any successful new regulation is the industry support. The successful use of gear-related technical measures to reduce bycatch and discards appears to depend largely on acceptance by industry (e.g. Suuronen and Sardà, 2007). Effective management should create incentives for fishers to change their behavior, so that in the long run the entire industry can benefit economically from the use of fishing methods that reduce bycatch. This emphasizes the need for a close partnership with industry in the introduction of more selective gears in a gradual and adaptive manner. To ensure industry acceptance and adoption of modified designs, the implementation process has to address the fact that the fishing sector has a limited capacity to accept loss of catch of target species. The issue frequently becomes on what is the acceptable loss of the targeted catch in order to improve selectivity and reduce bycatch (Kennelly, 2007). The loss of targeted catch could be offset via some compensatory increases in

the value of catch or other measures such as additional days at sea or quota allocated (Broadhurst *et al.*, 2007; Suuronen and Sardà, 2007).

6.6   CONCLUSIONS

A wide range of measures to manage bycatch and reduce discards is presented. However, such measures have to be employed as a package, often in conjunction with other management measures in order to achieve desired goals.

Because discard practices are resulted from a wide range of factors and conditions, the piecemeal approach used in many bycatch management measures can result in unintended cross-taxa conflicts (Gilman *et al.*, 2018). Hence, fisheries managers may face a dilemma where regulations designed to reduce bycatch and discards of one species, or species group, may increase bycatch or discards of another. It is therefore essential, first, to have a good understanding of both environmental and socio-economic dynamics of the fishery or fisheries concerned by the discard problem. Second, the implication of relevant stakeholders should be identified in the decision-making process in order to create a common vision to ensure acceptance and adoption of the management measure. Finally, data collection of both fishery dependent (including socio-economic data) and independent data has to be consistent with management objectives in order to measure the effectiveness of the management plan and revise or modify where needed.

7. Mortality due to pre-catch, discards and ghost fishing

Gear-related measures to reduce discards are considered important tools for conservation on the assumption that fish escaping from a fishing gear or released following capture survive and are subsequently recruited to the exploited population. But escapees may not always survive (Main and Sangster, 1990; Suuronen, 2005; Broadhurst *et al.*, 2006; Gilman *et al.*, 2013). In general, a fish has better chances to survive when it is released or escaped from a fishing gear at early stages of capture and at the fishing depth than those escaped during hauling or those released or discarded from the vessel deck after capture (He, 2015). For many species and fishing gears, there are currently no reliable estimates of escapee survival and failing to quantify the biological impact of this mortality can result in biased evaluations on the benefit of bycatch reduction devices and designs.

The main sources of such mortality include pre-catch losses and discards mortality. However, losses may also occur from ghost fishing mortality and other combined effects of interacting sources of stress and injury from fishing operations (Chopin and Arimoto, 1995; Gilman *et al.*, 2013). All these components of mortality have one thing in common: they are generally not easily quantifiable during fishing operations, but instead must be estimated through elaborative research. The relative proportions of these components vary by fishing gear, method, fishery and vessel, as well as spatially and temporally (Gilman *et al.*, 2007, 2013).

7.1 PRE-CATCH MORTALITY

Pre-catch losses occur when organisms are caught, or collide with the vessel or gear, and die but are not brought on board when the gear is retrieved (Chopin and Arimoto, 1995; Broadhurst *et al.*, 2006; Gilman *et al.*, 2013). For example, fish may die and fall from the gear before retrieval, or crew may intentionally release a portion of or the entire catch prior to landing on board, often referred to as 'slipped' catch (Box 1). Pre-catch losses may also occur when organisms are excluded or escape from the gear but die later.

Most experiments that have examined pre-catch losses have focused on mortality of fish escaping from trawl codends, and documented, in general, relatively high pre-catch survival rates for those finfish species investigated (Broadhurst *et al.*, 2006). However, survival is highly species- and size-dependent (Soldal *et al.*, 1993; Misund and Beltestad, 2000; Ingolfsson *et al.*, 2007). Demersal species generally have a higher likelihood of survival compared to small pelagic species that are sensitive to process of capture by and escape from a trawl (Suuronen *et al.*, 1996a; 1996b).

Fish size is an important factor affecting pre-catch mortality in some gear types, with smaller size classes in general having higher vulnerability (Breen *et al.*, 2007; Tenningen *et al.*, 2012). There can also be great variations in pre-catch mortality by season, time of day, gear soak time, haul duration, and gear design, including the location and design of BRDs in trawl nets (Breen *et al.*, 2007; Suuronen and Erickson, 2010).

Stresses and injuries that contribute to the probability of pre-catch mortality happen during the process of interacting with the gear. Stresses include enduring swimming that may lead to exhaustion and suffocating due to a lack of oxygen when density of fish is high in the catch. Injuries are resulted from crushing and wounding when in contact with the trawl netting, colliding with other organisms, scale loss when escaping

through a mesh or a BRD (Davis, 2002; Broadhurst *et al*., 2006). High catch densities amplify the effects of these stressors. Other stressors are related to environmental factors that the organism encounters after escape from the gear, such as water temperature, light conditions, currents, water pressure and sea state.

Fish may also escape from a gear near the surface while the gear is being hauled on board (e.g. Madsen *et al*., 2008) and little is known about the mortality of these fish. Preliminary experiments, however, has showed that a much smaller proportion of haddock escaping at the surface survived compared to those escaping at fishing depth (Breen *et al*., 2007). The higher mortality rate of surface escapees was most likely due to barotrauma, aerial predation and higher or lower water temperatures.

Methods to avoid, minimize and offset pre-catch fishing mortality are similar to those for mitigating capture and discard fishing mortality. For example, the use of small gillnet mesh sizes to reduce catches of sea turtles, marine mammals, large species of seabirds and other large organisms (Price and Van Salisbury, 2007; Murray, 2009) will likely reduce pre-catch mortality of these larger organisms. However, some methods that reduce catch may have unintended consequences of increasing pre-catch mortality. For example, using monofilament leaders instead of wire leaders can reduce shark bycatch in pelagic tuna longlines, but it might increase shark pre-catch mortality because these sharks swim away with a hook in their mouth (Ward *et al.*, 2008; Gilman *et al.*, 2016b). Some methods that reduce discards such as using circle hooks instead of J-hooks, may reduce pre-catch mortality due to less injury to escaped organisms (e.g., Gilman and Huang, 2017).

7.2   DISCARD MORTALITY

Discard mortality occurs when fish die after they are brought on board and subsequently discarded; it may be alive when they are discarded but stressed and injury they suffered during capture, handling and discarding process may cause them to die later. Some species, such as flatfishes, crustaceans, and elasmobranchs, are more "hardy" and may survive better (Hill and Wassenberg, 1990; Van Beek *et al.,* 1990). For example, 90% of blue sharks released alive from pelagic longline vessels were believed to have survived the capture and release process (Moyes *et al.,* 2006; Campana *et al.,* 2009; Musyl *et al.,* 2011).

Studies on the survival of finfish discarded from trawler decks have generally documented high discard mortality rates, although types and severity of injuries which generally impact mortality are highly specific to the fishing gear used, operational modes, environmental conditions, species and size, and handling and release practices (Broadhurst *et al.,* 2006; Parker *et al.,* 2006; Benoît *et al.,* 2010). Discard mortality may occur due to fatal wounds or increased probability of fatal diseases resulting from injuries incurred during interactions with the gear (Swimmer *et al.,* 2006; Snoddy and Southwood Williard, 2010; Gilman, 2011). In many multi-species bottom trawl fisheries discard mortality may represent a large source of uncertainty for estimates of total fishing mortality (Suuronen, 2005).

Lower discard mortality probability is often associated with shorter air exposure time and lower air temperature (above freezing) on deck (Broadhurst *et al.,* 2006; Suuronen and Erickson, 2010). Impacts of air temperature on fish deck may be compounded by direct sunlight and many other stressors. Extreme thermoclines with high surface water temperature may adversely affect survival of discarded fish (Erickson *et al.,* 1997). Soak time in passive gears or tow duration in active gears, fishing depth, catch amount and composition in towed nets, and the temperature of sea water are other factors that may significantly affect discard mortality (Gilman *et al.,* 2012, 2013).

The size and species of pelagic sharks has been observed to have a significant effect on the probability of discard mortality (Diaz and Serafy, 2005; Hight *et al.,* 2007; Mandelman *et al.,* 2008). Smaller fish are generally weaker and more sensitive to

capture and handling stress (Broadhurst *et al.,* 2006). Fish species with gas bladders and other organs that enable positive buoyancy are vulnerable to barotrauma, and as a result, are more likely to suffer internal injuries compared to species lacking gas bladders. They are less capable of returning to the depth after release, and more likely predated by pelagic and aerial predators (Davis, 2002; Benoît *et al.,* 2013).

Differences in discard mortality between and within taxonomic groups are also related to fragility and other physical characteristics of the animal. For instance, invertebrates with protective shells or exoskeletons are less likely fatally damaged from gear contact and handling than animal without such protection (e.g. Hill and Wassenberg, 1990; Lancaster and Frid, 2002; Bremec *et al.,* 2015). Likewise, leatherback sea turtles (*Dermochelys coriacea*) may be more delicate and experience higher risk of injury from fishery interactions than hard-shelled turtles (Ryder *et al.,* 2006). Other reasons for differential probabilities of cryptic mortality between species and between taxonomic groupings include differences in their propensity for scale loss and skin damage, and differences in sensitivity to changes in temperature, both in the water during haul back and air temperature on deck (Davis and Olla, 2001, 2002; Suuronen and Erickson, 2010).

7.3   GHOST FISHING MORTALITY

Ghost fishing occurs when lost, abandoned or otherwise discarded fishing gear (ALDFG) continues to catch and kill organisms (Fowler, 1987; Matsuoka *et al.,* 2005; Macfadyen *et al.,* 2009). Various factors affect the ability, efficiency and duration of ALDFG to ghost fish. Organisms caught in derelict nets, traps and other gear types can attract scavengers, which subsequently are caught, causing long-term ghost fishing due to this self-baiting mechanism (Kaiser *et al.,* 1996; Matsuoka *et al.,* 2005).

Methods to reduce ghost fishing mortality include preventative approaches that reduce gear loss and abandonment such as gear marking (He and Suuronen, 2018). Properly marked gear can help identify the owner, which may create a disincentive for intentional abandonment or discarding of gear, increase visibility of passive gear, which could reduce gear conflicts and damage by passing vessels to reduce accidental gear loss (Huntington, 2017 a & b). Remedial methods to mitigate ghost fishing include, for example, programs to detect and remove ALDFG and the use of less durable and biodegradable gear to reduce their ghost fishing duration (Gilman *et al.,* 2016a). The newly-adopted FAO Voluntary Guidelines on the Marking of Fishing Gear will greatly contribute to the prevention of ALDFG and reduction of its harmful impact on marine environment, ghost fishing and entanglements of ETP species (FAO, 2018).

7.4   OTHER COMPONENTS OF INDIRECT MORTALITY

Collateral sources of fishing mortality are those that are indirectly caused by various ecological effects of fishing (ICES, 2005). Examples in this category are diverse, complex and difficult to quantify, in part, because there is great uncertainty in inferring main factors that cause mortalities (Jones, 1992; Gilman *et al.,* 2013). For example, animals escaped from fishing gear or discarded from vessels are often displaced from suitable habitat for shelter and may experience predation near the sea surface and in the water column, increasing the risk of predation as they sink or swim back to their preferred habitat (Broadhurst *et al.,* 2006).

Injuries and stress sustained by organisms interacting with fishing operations can be caused by many factors, where cumulative and interacting effects of these factors, both individually and repeated sub-lethal interactions, result in mortality (Davis, 2002). For example, Caddy and Seijo (2011) estimated that high proportions of juveniles may be subject to mortality from repeated interactions when trawling occurs in nursery areas. Jorgensen *et al.* (2005) and Ingolfsson *et al.* (2007), however, did not observe any marked additional mortality in Atlantic cod as a result of repeated escape from

trawls. It is worth noting, however, that the latter is a species that has proven to have a relatively low probability of escapee mortality (Breen *et al.,* 2007).

Cumulative and interacting effects of multiple factors that an organism encounters during the capture process may result in higher mortality than the sum of mortality resulting from individual factors (Gilman *et al.,* 2013). For example, while moderate damage to finfish skin alone is unlikely to induce mortality, when combined with exhaustive swimming in a trawl, plus extreme temperature changes, this may cause fish to die, for instance, through metabolic acidosis or osmoregulatory failure.

7.5   CONCLUSIONS

The International Guidelines on Bycatch Management and Reduction of Discards (FAO, 2011) included recommendations for member States to identify, quantify and reduce impacts of mortality from pre-catch losses and ghost fishing and to maximize discard survival. A good understanding of factors causing such indirect fishing mortality is necessary to estimate levels and rates of removals, and to devise measure for mitigation. As a result of the complexity that causes such removals during various aspects of fishing operations, few studies have estimated such fishing-related mortality accounting for the full suite of ways an organism can interact with the gear and stresses and injuries caused by fishing operations (Suuronen, 2005; Broadhurst *et al.* 2006). This creates uncertainty in estimates of the probability of mortality. This is especially relevant to collateral, cumulative and interactive sources of mortalities, due to indirect and relatively highly complex nexus between stressors and removals for these components.

There remains limited understanding of collateral mortality rates or broader community-level changes caused by fishing. For example, there is limited knowledge of the relative importance of collateral removal resulting from artificial drifting floating objects, including FADs and masses of derelict gear and other marine debris, or from enduring or permanent shifts in benthic community structure and functions resulting from direct physical contact with fishing gear and discards (Hall *et al.,* 2000; Kaiser *et al.,* 2006; Dagorn *et al.,* 2010; FAO, 2010).

For some gear types and species groups, significant progresses have been made to identify best handling and release practices to maximize probability of survival of discarded animals. For example, best practices handling and release methods for seabirds and sea turtles captured in longline fisheries, and to release dolphins from purse seines, have been developed (Hall, 1996; AIDCP, 2009; FAO, 2010). Certain factors that significantly affect finfish discard mortality can be controlled, such as controlling crowding and aerating the net prior to landing, minimizing the time exposed to air, avoiding adverse environmental conditions on deck (e.g. high air temperatures), reducing the risk of barotrauma, employing best practices to remove tackle prior to release, and reducing stress and injury from the release process (Davis, 2002; Broadhurst *et al.,* 2006).

PART III – CONCLUSIONS

8. General Conclusions

This report is the third decadal report concerning a major part of fisheries resources –unwanted and discarded fish, and endangered, threatened and/or protected species.

The report contains two major new outcomes concerning marine fisheries: (i) an annual discard quantity of around 9.1 million t, and (ii) at least 20 million individuals of endangered, threatened and/or protected species interacted with capture fisheries annually.

The first outcome indicate that world fisheries are still discarding some organisms, despite of a general improvement in fisheries management, the implementation of bycatch reduction devices in many problematic fisheries and greater utilization of the fish. While there is still long way to go to achieve optimum selectivity and utilization, it is encouraging that new countries and regions (including RFMOs and RFBs) start including in their legislation the words "bycatch" and "discards" as a sign of an emerging political will to mitigate the wasteful practice of discarding.

It is difficult to quantify the progress in reducing discards but this report indicates that in the last 10 years there is a greater scrutiny of such issues via the public reporting of discards. This may include country-specific reports such as the USA's National Bycatch Reports, reporting and minimizing discards required by third-party certifying entities such as the Marine Stewardship Council, and the consequential increase in the number and scale of onboard observer and electronic monitoring programs.

Regarding fisheries interactions with endangered, threatened and/or protected species (ETP), it was estimated that twenty million individuals interacted with fishing operations worldwide, some of which lead to mortality of the animals. While overall impact is difficult to assess for all species, for some species that are in very low population levels, mortality associated with fishing is a major concern. However, such an estimate was noted in this report to be very tenuous due to the lack of solid data for many fisheries and for many parts of the world. Therefore, more effort is needed to better quantify fisheries interactions with such species, and to implement measures to reduce such interaction, especially those leading to mortality, with a collaborative approach that involves all relevant stakeholders.

This report also summarized the status of other issues concerning bycatch and discarding, including (i) measures to manage bycatch and to reduce discards and (ii) challenges associated with estimating cryptic sources of fishing mortality such as pre-catch, discard and ghost fishing mortality.

Annexes

A. Method

A.1– THE ESTIMATE OF AVERAGE GLOBAL QUANTITY OF DISCARD HAS EXCLUDED:

FAO areas	Countries[1]	Taxa	Fisheries[2]
Europe - Inland waters	American Samoa	Algae	MIS gear type
Africa - Inland waters	Bermuda	Aquatic plants	under the gear
America, North - Inland waters	Bonaire/S.Eustatius/Saba	Rhodophyceae	type estimate GE
America, South - Inland waters	Bosnia and Herzegovina	*Gracilaria* spp	
Asia - Inland waters	British Indian Ocean Ter	*Porphyra* spp	
Oceania - Inland waters	China, Hong Kong SAR	*Gelidium* spp	
	China, Macao SAR	Phaeophyceae	
	French Southern Terr	**Macrocystis** spp	
	Greenland	*Lessonia* spp	
	Guam	Chlorophyceae	
	Iraq	*Ulva* spp	
	Mayotte	Invertebrates (except sea urchins)	
	Netherlands Antilles	Ascidiacea	
	Niue	Asteroidea	
	Northern Mariana Is.	**Echinodermata**	
	Palau	*Polychaeta*	
	Réunion	Gorgoniidae	
	Saint Barthélemy	*Actiniaria*	
	Saint Helena	*Scleractinia*	
	Saint-Martin	*Antipatharia*	
	Sint Maarten	*Rhopilema* spp	
	St. Pierre and Miquelon	*Cnidaria*	
	Sudan (former)	Spongiidae	
	United Arab Emirates	*Spongilla* spp	
	Wallis and Futuna Is.	Reptiles	
	Zanzibar	Amphibian	
		Marine mammals	
		Freshwater fish	

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[1] The total sum of landings from these countries is 772 117 tonnes.
[2] The total sum of landings from these fisheries is 4 460 179 tonnes. See Subsection 2.2.2 in Methods.

A.2– CODES USED IN THE DATA TABLES AND DATASET: (GEAR, AREA AND TARGET)

Gear code	Gear name	FAO Area Code	Ocean code	Area name
DRB	Boat dredges	Area 21	nwA	northwest Atlantic
FPO	Pots	Area 27	neA	northeast Atlantic
FSN	Stow nets	Area 31	wcA	western central Atlantic
FWR	Barriers, fences, traps, etc.	Area 34	ecA	eastern central Atlantic
GNB	Gillnet, bottom	Area 37	mbs	Mediterranean and Black sea
GNP	Gillnet, pelagic	Area 41	swA	southwest Atlantic
GNS	Gillnet Surface & Bottom	Area 47	seA	southeast Atlantic
GTR	Trammel nets	Area 51	wIO	western Indian ocean
HL_	Handlines	Area 57	eIO	eastern Indian ocean
LL_	Longlines, Surface & Bottom	Area 61	nwP	northwest Pacific
LLB	Longlines, bottom	Area 67	neP	northeast Pacific
LLP	Longlines, pelagic	Area 71	wcP	western central Pacific
LNB	Boat-operated lift nets	Area 77	ecP	eastern central Pacific
LTL	Trolling lines	Area 81	swP	southwest Pacific
MIS	Miscellaneous/not known	Area 87	seP	southeast Pacific
OTB	Otter trawls, bottom	Area 48	AO	Antarctic ocean
OTM	Otter trawls, midwater	Area 58	AO	Antarctic ocean
OTS	Shrimp trawl	Area 88	AO	Antarctic ocean
OTT	Otter twin trawls			
PL_	Pole-and-line			
PS_	Purse seine			
PTB	Pair trawls, bottom			
PTM	Pair trawls, midwater			
SB_	Beach seines			
SV_	Boat seines			
TBB	Beam trawls			

Target Species Group	Definition
demersal fish	all demersal fish including reef associated fish and the majority of coastal fish
pelagic fish	all pelagic fish but tunas, bonitos and billfish
tuna	tunas, bonitos and billfish (ISSCAAP group 35)
crustaceans	all crustaceans (ISSCAAP groups from 41 to 47)
cephalopods	all cephalopods (ISSCAAP group 54)
molluscs (excluding cephalopods)	all molluscs (excluding cephalopods) (ISSCAAP groups 51, 52, 53, 55 and 56)
mixed	can include a mix of 2 (or more) different categories

B. Results

Supplementary tables

TABLE B.1.

Posterior mean discard rates, 95% credible intervals and sample sizes (N, number of compiled discard rate records per gear type[3]), for 25 gear categories

Gear Category	Gear Code	Discard Rate			
		Mean	Lower 95% CI	Upper 95% CI	N
Barrier, fence, trap, etc.	FWR	0.039	0.002	0.568	2
Purse seine	PS	0.047	0.039	0.056	60
Longline, pelagic	LLP	0.074	0.058	0.094	42
Pole-and-line	PL	0.094	0.064	0.144	5
Handline	HL	0.095	0.019	0.442	2
Lift net, boat-operated	LNB	0.100	0.012	0.619	1
Gillnet, pelagic (driftnet)	GNP	0.117	0.074	0.190	13
Otter trawl, midwater	OTM	0.121	0.082	0.182	26
Longline, bottom and pelagic	LL_	0.134	0.110	0.164	66
Boat dredge	DRB	0.138	0.110	0.173	15
Seine, beach	SB	0.148	0.057	0.344	6
Pots	FPO	0.166	0.121	0.222	30
Stow net	FSN	0.172	0.080	0.361	2
Gillnet, surface and bottom	GNS	0.174	0.088	0.329	4
Trammel net	GTR	0.182	0.132	0.251	21
Trawl, pair, midwater	PTM	0.192	0.033	0.735	1
Trolling lines	LTL	0.199	0.068	0.498	5
Longline, bottom	LLB	0.239	0.180	0.311	24
Gillnet, bottom	GNB	0.261	0.198	0.338	28
Otter trawl, bottom	OTB	0.309	0.275	0.346	118
Trawl, otter twin	OTT	0.435	0.285	0.600	9
Trawl, beam	TBB	0.457	0.377	0.538	22
Trawl, pair, bottom	PTB	0.482	0.141	0.878	1
Seine, boat	SV	0.506	0.358	0.657	9
Trawl, shrimp	OTS	0.549	0.500	0.596	68

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[3] See Discard Rate table.

TABLE B.2.
Estimates of mean discards levels (t) and 95% credible intervals by gear type.
N=number of fishery records[4]

| Gear type | Gear Code | Annual discard level (t) | | | |
		Mean	Lower 95% CI	Upper 95% CI	N
Stow net	FSN	149	0	308	2
Longline, bottom and pelagic	LL_	6 530	5 312	7 747	6
Trammel net	GTR	10 565	9 052	12 077	30
Barrier, fence, trap, etc.	FWR	13 393	0	50 218	22
Lift net, boat-operated	LNB	27 836	8 470	47 202	8
Pole-and-line	PL_	33 487	30 052	36 923	44
Trolling lines	LTL	39 872	0	87 853	36
Seine, beach	SB_	40 754	21 592	59 917	27
Trawl, pair, midwater	PTM	58 791	0	188 622	14
Longline, pelagic	LLP	97 761	93 264	102 257	233
Gillnet, surface and bottom	GNS	100 152	83 307	116 997	28
Pots	FPO	177 720	169 280	186 161	141
Boat dredge	DRB	198 365	170 441	226 289	38
Trawl, pair, bottom	PTB	225 981	0	900 841	11
Longline, bottom	LLB	252 082	227 015	277 149	111
Trawl, otter twin	OTT	291 505	200 827	382 184	11
Gillnet, pelagic	GNP	299 451	278 840	320 062	132
Handline	HL_	323 116	90 692	555 539	124
Gillnet, bottom	GNB	393 499	369 233	417 764	78
Trawl, beam	TBB	423 905	356 222	491 588	16
Seine, boat	SV_	478 112	398 800	557 423	50
Miscellaneous	MIS	526 292	485 699	566 885	61
shrimp trawl	OTS	836 397	787 175	885 619	90
Otter trawl, midwater	OTM	881 240	770 777	991 703	102
Purse seine	PS_	1 019 002	916 306	1 121 699	203
Otter trawl, bottom	OTB	2 383 849	1 994 561	2 773 138	236

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[4] See Fishery Table.

TABLE B.3

Discard levels (t) and rates (t discards / t catch) by FAO Major Fishing Area. CI=confidence interval, HDI=highest posterior density interval, N=number of fishery records

FAO Area	Region name	Annual discard level (t)			Discard rate			N
		Mean	Lower 95% CI	Upper 95% CI	Expected	Lower 95% HDI	Upper 95% HDI	
48, 58, 88	Antarctic	18 773	15 630	21 916	0.075	0.064	0.085	37
81	Southwest Pacific	58 584	50 178	66 991	0.095	0.083	0.104	28
47	Southeast Atlantic	201 160	176 514	225 805	0.131	0.119	0.137	56
37	Mediterranean and Black sea	239 824	206 801	272 848	0.184	0.165	0.191	176
77	East central Pacific	298 277	245 501	351 052	0.170	0.146	0.183	69
31	Western central Atlantic	332 832	299 633	366 031	0.228	0.214	0.229	225
57	Eastern Indian	340 800	318 144	363 457	0.045	0.042	0.047	81
67	Northeast Pacific	341 336	259 005	423 667	0.123	0.096	0.140	34
87	Southeast Pacific	366 877	159 725	574 029	0.041	0.018	0.060	62
21	Northwest Atlantic	424 333	385 473	463 193	0.205	0.194	0.211	87
41	Southwest Atlantic	683 798	585 248	782 347	0.291	0.267	0.284	78
71	Western central Pacific	706 291	692 202	720 379	0.055	0.054	0.056	131
51	Western Indian	743 352	679 670	807 034	0.150	0.143	0.150	210
34	East central Atlantic	811 547	736 021	887 073	0.181	0.175	0.178	245
27	Northeast Atlantic	1 551 318	757 833	2 344 803	0.162	0.086	0.184	271
61	Northwest Pacific	2 020 705	1 864 773	2 176 636	0.091	0.086	0.095	64

C. Progress on compliance with the Code of Conduct for Responsible Fisheries regarding bycatch and discards

Article 4 of the Code of Conduct for Responsible Fisheries (hereafter, the Code) states, *inter alia*, that FAO will report regularly to the Committee on Fisheries (COFI) concerning the implementation of the Code, including issues related to bycatch and discards (FAO, 1995). Progress reports are produced based on the responses from Members, RFBs and NGOs to a web-based version of the questionnaire on the implementation of the Code (add citation for the website). This web-based reporting system has resulted in the possibility of analysing important information on the activities and applications of the Code at the various levels, hence making the key findings of the progress report more valuable. The following summary of the analyses on the implementation of the Code is focused on sections of FAO's web-based reporting system related to bycatch and discards for years 2011, 2013 and 2015.

There has been an increase in the number of responses per year in all sections of the questionnaire. These responses reflect that, on the one hand, an increased number of countries are monitoring bycatch and discards and implementing measures to minimize them, including protection of juveniles and ghost fishing prevention (Figure C.1). On the other hand, countries reporting that bycatch problems do exist in their fisheries has slightly decreased in 2013 and 2015 compared to 2011 (Figure C.2). Among those countries which were implementing measures to promote the improved use of bycatch in fish processing, awareness raising and training/dialogue with processors together with the implementation of a mandatory landing of bycatch in given fisheries appeared to be the most effective measures (Figure C.2).

Regarding the status of IPOA-Sharks implementation, an increasing number of countries were conducting assessments from 2011 to 2015 to determine whether a NPOA-Shark is needed (Figure C.3). At least 80% of respondents that haven't conducted the assessment were willing to do so. More than 70% of those which concluded that an NPOA-Shark was needed already had one in place and the rest were willing to develop it.

In relation to the status of national IPOA-Seabirds implementation, respondents in 2011 where longline, trawl and/or gillnet fisheries occurs in their national waters, conducted more assessments to determine the necessity of implementing a NPOA-Seabirds than those that responded in 2013 and 2015. In turn, there was a decline on assessments which concluded that an NPOA-seabirds was necessary respectively from 2011 to 2015. More than 60% of those which concluded that an NPOA-Seabirds was necessary already had one in place and 100% of the rest were willing to develop one only in 2011 and 2013.

FIGURE C.1

Percentage of responses from Member countries to questions of the section on "management of bycatch and discards" for 2011 (blue), 2013 (red) and 2015 (green). Numbers in parentheses represent total numbers of responses to each question per year. Responses come from Member countries from the following regions: Africa, Asia, Europe, Latin America and Caribbean, Near East, Northern America and southwest Pacific. *Number of positive responses only

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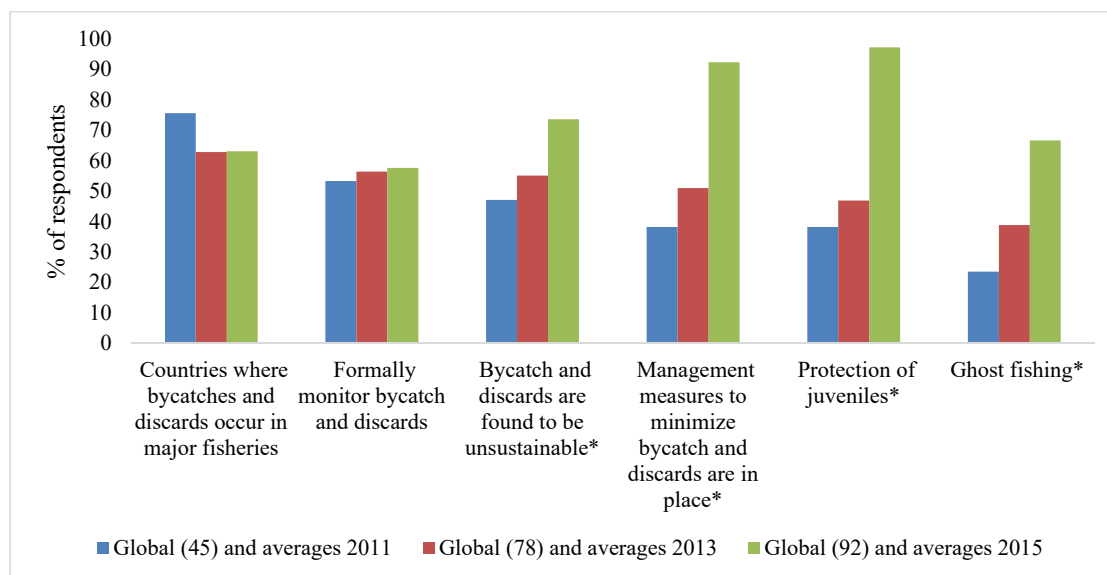
FIGURE C.2

Percentage of responses from Member countries to questions of the section on "Most effective measures taken by Government to promote the improved use of bycatch in fish processing" for 2011 (blue), 2013 (red) and 2015 (green). Numbers in brackets represent total numbers of responses to each question per year. Responses come from Member countries from the following regions: Africa, Asia, Europe, Latin America and Caribbean, Near East, Northern America and southwest Pacific

FIGURE C.3
Percentage of responses from Member countries to questions of the section on "Summary information relating to the status of national IPOA-Sharks implementation" for 2011 (blue), 2013 (red) and 2015 (green). Numbers in brackets represent total numbers of responses to each question per year. Responses come from Member countries from the following regions: Africa, Asia, Europe, Latin America and Caribbean, Near East, Northern America and southwest Pacific. * only refer to the group of countries that have conducted an assessment; ** only refer to the group of countries which have not yet conducted an assessment; * only refer to the group of countries that concluded that a plan was needed**

■ Global (44) and averages 2011   ■ Global (78) and averages 2013   ■ Global (90) and averages 2014
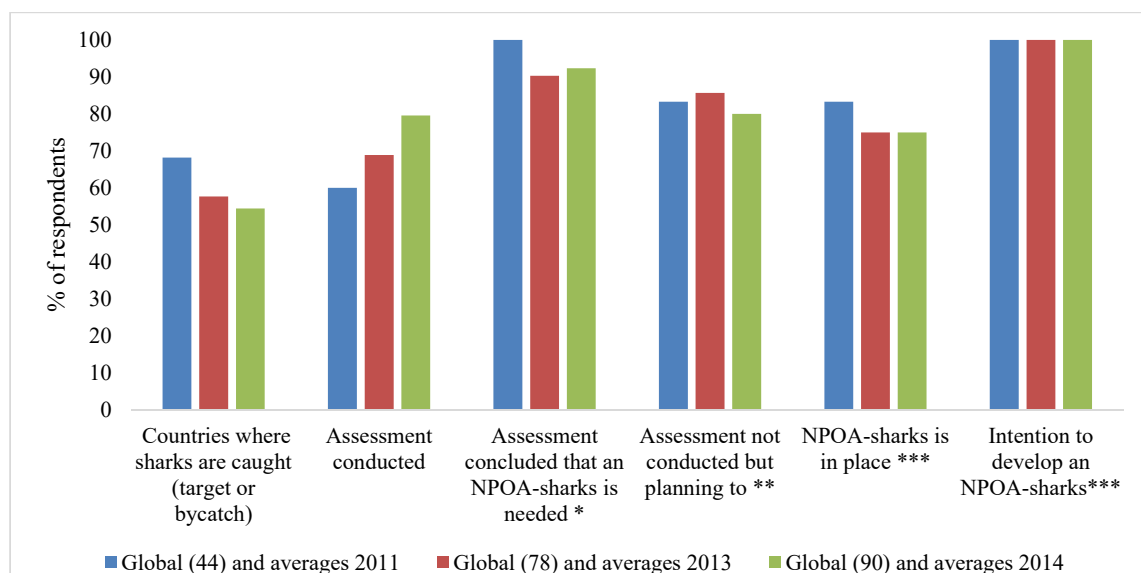
FIGURE C.4
Percentage of responses from Member countries to questions of the section on "IPOA Seabirds: Mitigation measures applied to longline fisheries" for 2011 (blue), 2013 (red) and 2015 (green). Numbers in brackets represent total numbers of responses to each question per year. Responses come from Member countries from the following regions: Africa, Asia, Europe, Latin America and Caribb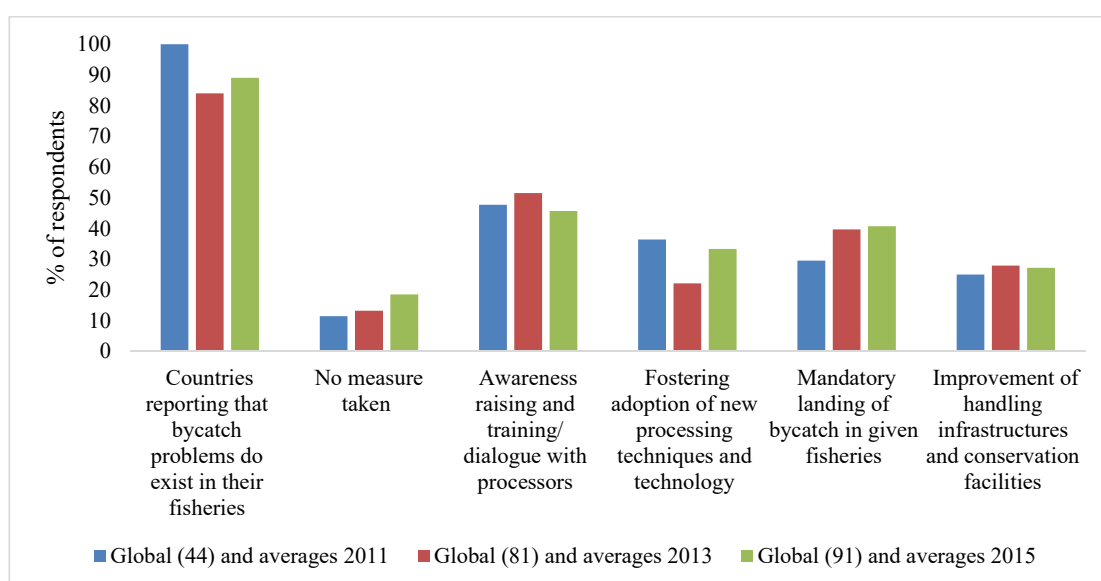ean, Near East, Northern America and southwest Pacific. * only refer to the group of countries that have conducted an assessment; ** only refer to the group of countries that has not yet conducted an assessment; * only refer to the group of countries that concluded that a plan was needed**
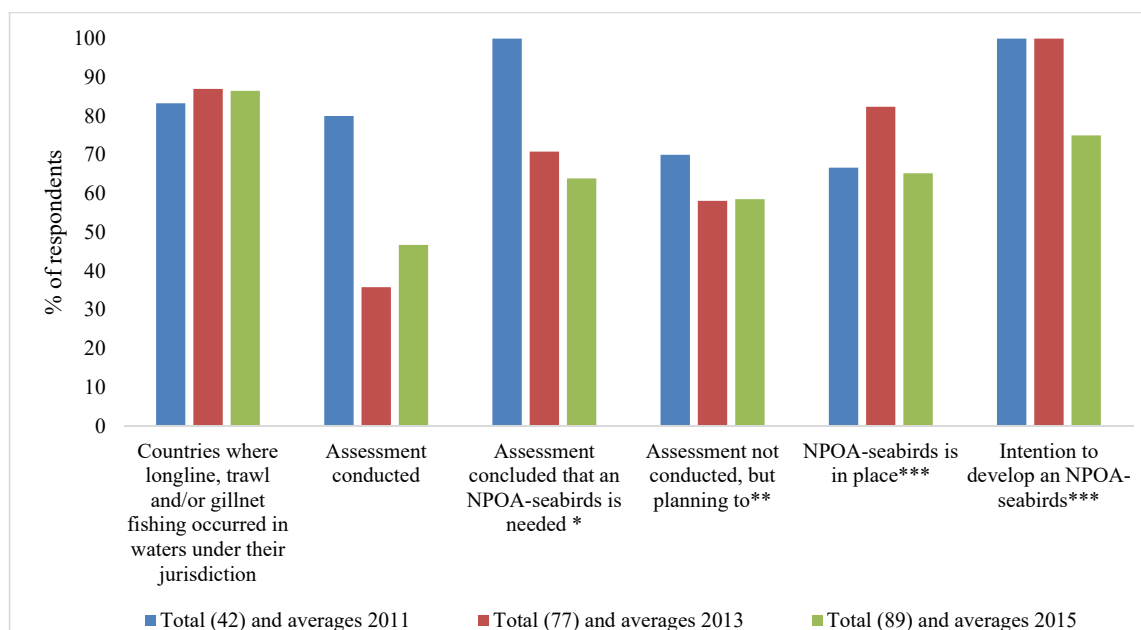

■ Total (42) and averages 2011   ■ Total (77) and averages 2013   ■ Total (89) and averages 2015

D. DiscardLess and other efforts in European Union to mitigate discards

The landing obligation in the new EU Common Fisheries Policy (CFP) aims for a gradual elimination of discards of commercially exploited stocks on a case-by-case basis (Regulation (EU) No 1380/2013 of the European parliament and of the council of 11 December 2013 on the Common Fisheries Policy).

As a consequence of the reform of the CFP, governments, scientific institutions, fishing industry, fishermen and other stakeholders in the European Union have worked together to find technologically feasible, environmentally sustainable and economically viable solutions for realization of the landing obligation. Large EU-wide projects such I-Seas (I-Seas project, n.d.), Minouw (Minouw, n.d.) and DiscardLess (DiscardLess, n.d.), funded by the EU (EU, n.d.), address this issue in a comprehensive manner. Each project has its own unique characteristics defined by their main focus, yet they share many common features such as: (i) avoid unwanted catches, or where this cannot be reasonably or practically achieved, to utilize them productively and sustainably; (ii) involve multi-stakeholder engagement in the design and implementation of actions; (iii) demonstrate the environmental and socio-economic impacts/benefits that the implementation of proposed innovative solutions and the new management model may have to the fishing sector; (iv) increasing awareness of the problem of unwanted catches and the solutions that are available; and (v) disseminate knowledge through open-access publications and scientific papers.

The objective of the *DiscardLess* project was to develop practical, achievable, acceptable and cost-effective Discard Mitigation Strategies to either avoid or utilise unwanted catch, in order to reduce discards while maintaining viable fisheries. *DiscardLess* were to integrate knowledge, tools and technologies at local, national, EU and international levels to provide and promote solutions needed to implement such strategies throughout the seafood supply chain. Further, the project were also to assess the effects of discard reduction policies on the ecosystem, economic and social sustainability, and provide feedback for improved fisheries management. *DiscardLess* results are thus essential in the achievement of policy goals of reducing waste and increasing the net economic value of fisheries for society.

The good intentions of reducing discards in EU fisheries must be followed by effective implementation using the right methods and processes on a fishery specific basis. In the 2015 North Sea demersal fishery alone, the introduction of a landing obligation without changes in behaviour of the fishery or marketing of currently discarded catches, would result in forgone landings worth 300 million euros (about 47% of total landed value), as the fishery being halted when the first TAC was exhausted (ICES, WGMIXFISH 2014 report). However, on longer time scales, landing discards has the potential to increase the return for the fishery while promoting human health.

DiscardLess addresses both the short-term challenges and the potential benefits to allow the practical implementation of the landing obligation while making it understandable and legitimate across the whole supply chain, from stakeholders to consumers. To specifically address these challenges, *DiscardLess* are working in close cooperation with stakeholders and policy makers to:

- Assess the impact of discards on the ecosystem, economy and society
- Investigate the drivers of discarding, and identify how those can be abated
- Develop user-based innovative tools and strategies to avoid unwanted catches
- Develop innovative methods and new value chains to handle and use unavoidable unwanted catches
- Enhance controllability of and compliance with the landing obligation policy via the development of operational and cost-effective tools for traceability and monitoring
- Formulate policy guidelines to reduce incentives to discard and promote the adoption of alternative mitigation strategies, and support other maritime policies
- Integrate the gathered knowledge on discard mitigation strategies and transfer it widely

The collaborative approach of *DiscardLess* ensures that the developed tools, information and strategies will provide relevant, acceptable and cost-effective means with a wide uptake by the fishing industry which would result in the achievement of the goals of the landing obligation. The *DiscardLess* project was to extend for 48 months (2015-2019). The project has been funded by EU and the partners, and is coordinated by DTU Aqua (Denmark). The project has 31 partners in 12 countries, including 9 universities, 9 small medium enterprises, 8 research institutes, 3 multinational companies and 2 organisations.

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Bycatch and discards threat sustainable fisheries by inflicting unnecessary mortalities. Sound management of bycatch and reduction of discards in capture fisheries will lead to healthy ecosystems and sustainable fisheries, contributing to long-term global food security, and alleviation of poverty, especially for coastal communities and Small Island Developing States which heavily depend on fish as food, fisheries as the main source of employment, and fishing as a way of life. Accurate and timely assessment of bycatch and discards provide necessary data for making sound management decisions and effective mitigation measures

This report includes three parts. Part I is an estimate of annual discards for the period 2010-2014 by marine commercial fisheries. Part II includes an evaluation and discussion of bycatch and discards of endangered, threatened and protected species, providing an updated overview of this specific dimension of the bycatch and discard issue. Part II also includes a review of current measures for managing bycatch and reduction of discards, as well as a discussion of other sources of fishing mortality, such as pre-catch loss, discard mortality and ghost fishing mortality. Part III is the conclusion of the whole report.