Fisheries Standard Review

Multispecies Mixed Stock Fisheries Management – Review of Current & Best Practices

Consultant Report

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Katrina Nakamura

Sustainability Incubator

Marine Stewardship Council

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The views and opinions expressed in this report do not necessarily reflect the official policy or position of the Marine Stewardship Council. This is a working paper, it represents work in progress and is part of ongoing policy development. The language used in draft scoring requirements is intended to be illustrative only, and may undergo considerable refinement in later stages.

How to refence this report: Nakamura, K. 2015.Mutispecies mixed stock fisheries management – review of current & best practices. Fisheries Standard Review Consultant Report. Published by the Marine Stewardship Council [www.msc.org], (http://www.msc.org/docs/default-source/default-document-library/stakeholders/fsr-consultant-reports/msc-fisheries-standard-review---consultancy-report---mixed-multispecies-fishery-review.pdf) 22 pages.

1. Executive Summary

Yesterday's bycatch may be today's target species. Due to the overlapping nature of targets in many fisheries, some resources at risk of depletion are harvested together with others that can still sustain an economic activity, whereas when overfishing depletes a target stock minor stocks may become new targets. A significant proportion of fisheries worldwide are multispecies or mixed in character. In multispecies fisheries, a multitude of species contributes to the output of the fishery and reference points should consider trophic interactions. In mixed fisheries, where technical interactions occur between different gears, reference points should consider the effects of different levels of effort on the sustainable yields of all the species caught. The purpose of this report is to gather together the defining characteristics of a mixed stock or multispecies fishery as distinguished from a single-species fishery with retained and bycatch species. The intention is to inform future reviews of the current MSC Default Assessment Tree, which is based on single-species, single-stock fisheries. Case studies and current best practice for science and management are presented. Major findings are that (1) European fisheries are multi-gear and multi-species and this highly complex nature has been a major contributing factor to the limited success of certain management strategies, (2) simple considerations of MSY, species by species, are insufficient for enunciating management principles in multiple species situations and may induce discarding at sea due to low market value of some species compared to others or high grading the large sizes or prohibition to land undersized fish, (3) a discard ban and new requirements for reporting at landing in Europe have made a priority of new assessment and management tools for multispecies and mixed fisheries, (4) in some fisheries in Europe, stakeholders have favored a "Pretty Good Yield" (PGY) over trying to reach the absolute sustainable maximum in yield or profit (4) in Australia multispecies objectives are built into target reference points for sustaining biomass at a Maximum Economic Yield B MEY, (5) overfishing has been reduced successfully with optimum yield strategies for mixed fisheries in the USA, (6) in developing countries, stocks perceived as the 'targets' in multispecies and mixed fisheries may be significantly different than predicted, requiring adaptive management with dynamic biological reference points for a range of target species, and (7) multispecies models are being used to predict the effects of exploitation on species composition, size structure, biomass, and other ecosystem properties, for example in the Baltic Sea, but fisheries are still managed largely by combining single species MSYs rather than a "Multispecies Maximum Sustainable Yield".

2. Purpose

The purpose of this report is to gather together the defining characteristics of a mixed stock or multispecies fishery as distinguished from a single-species fishery with retained and bycatch species. Current best practice for science and management are presented.

3. Background

The current MSC Default Assessment Tree is based on single-species, single-stock fisheries. However, several fisheries target many species simultaneously, and these species may be managed as 'stock complexes' rather than on an individual stock by stock or species by species basis. MSC stakeholders have expressed an interest in MSC developing Principle 1 (P1) requirements to assess these mixed fisheries. The current approach does not account for multiple species harvested together in which the maximising the yield of one species will have an impact on the others[1].

4. Defining Characteristics for Mixed and Multispecies Fisheries

In broad terms, mixed fisheries are those in which technical interactions between different gears occur whereas in multispecies fisheries a multitude of species contributes to the output of the fishery[2]. Due to the overlapping nature of targets in these fisheries some resources at risk of depletion are harvested together with others that can still sustain an economic activity[2].

4.1. Fishery Types

Distinction should be made between different categories of mixed and multispecies fisheries:

- Mixed fisheries are based on the technical interactions of different gears used in the fishery, thus aspects of mixed catches of several species and several gears are usually referred to as mixed fisheries advice[2].
- Multispecies management advice addresses the effects of predator-prey interactions[2].
- Multispecies fisheries may involve mainly joint production, by the same fleet, of a single set of species that are captured in fixed proportions determined by the effort of the fleet. These are "single-fleet mixed fisheries"[3].
- Multispecies fisheries may involve multiple fleets with different harvesting technologies and objectives, spatial and seasonal patterns of effort allocation, and target sets of species. These are "multi-fleet mixed fisheries"[3].
- Multispecies fisheries may involve some fleets having the ability to alternate their activity between harvesting sets of multiple species, and focusing on the harvest of single target species. These are "multi-fishery systems"[3].

Fisheries interact with multiple species at the same time due to a number of different fishery characteristics:

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[1] Terms of Reference – Mixed Fisheries Management in legislation and practice, file 20150806 ToR mixed management.docx
[2] EU 2013: Characteristics of Multispecies Fisheries in the European Union. Director General for Internal Policies, European Parliament. See http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/529053/IPOL-PECH_ET%282014%29529053_EN.pdf
[3] Australia Department of Agriculture, Fisheries and Forestry 2013: Final report on the review of the Commonwealth Fisheries Harvest Strategy Policy and Guidelines. See http://www.agriculture.gov.au/SiteCollectionDocuments/fisheries/environment/bycatch/report-harvest-strategy.pdf

- Technical interactions: within a single fishery, the same fishing gear may catch several species simultaneously. Such technical interactions occur in fisheries where the species are caught together as either "target" or "byproduct" species, or as a mixed set of species with no single target; This may be more complicated in cases in which different sub-fisheries (in terms of gear types) are spatially overlaid, catching different combinations of the same sets of species[4].
- Biological interactions: a fishery may affect multiple species indirectly, through the biological interactions between the species directly impacted from fishing, and their predators, prey or competitors[4].

The sustainability of a fishery is determined by the balance between the amount of fishing impact and populations capacity to respond to harvesting, meaning that sustainability can be achieved at almost any exploitation rate[2]. The United Nations Fish Stocks Agreement indicates that limit reference points for fishing represent the level beyond which the reproductive capacity of stocks becomes impaired. For **mixed stock fisheries** with technical considerations, reference points should consider the effects of different levels of effort on the sustainable yields of all the species caught[5]. For **multispecies fisheries** with biological interactions, reference points should consider trophic interactions[5].

4.2. Management for Maximum Sustained Yield (MSY) in Mixed and Multispecies Fisheries

MSY can be defined as the maximum annual catch which on average can be removed yearly from a fish stock without deteriorating the productivity of the fish stock (Beverton and Holt, 1957 and Guillen et al., 2013)[6]. At equilibrium, the MSY should correspond to the catch of an optimally managed fishery aimed at maximizing production. MSY in principle has the twin virtues of focusing discussion on long-term management for sustainable yields (not discounting the future) and of indicating a level of exploitation that cannot be exceeded without depleting the stock to low levels incapable of high biological productivity. Achieving the MSY implies that fishermen shall not exceed the amount of catch recommended by scientists in order to guarantee the sustainability of the stocks[2]. So long as a harvested stock can be regarded as a single, isolated population, the notion of maximum sustainable yield (MSY) is a useful basis for discussing management principles, but simple considerations of MSY, species by species, are insufficient for enunciating management principles in multiple species situations (May, Beddington, Clark, Holt & Laws, 1979)[7]. MSY applied to each species individually cannot serve as a guiding principle when the harvested species have strong interactions. Overfishing may occur when some species in the catch find a place in the market and

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[4] Pascoe S, Hutton T, Thebaud O, Deng R, Klaer N and S Viera 2015: Setting economic target reference points for multiple species in mixed fisheries. CSIRO Oceans and Atmospheric Flagship. See http://frdc.com.au/research/Final_reports/2011-200-DLD.pdf

[5] Rindorf A, Schmidt J, Bogstad B, Reeves S and Y Walther 2013: A Framework for Multispecies Assessment and Management. An ICES/NCM Background Document. See http://www.ices.dk/publications/Documents/Miscellaneous%20pubs/A%20framework%20for%20multispecies%20assessment%20and%20management.pdf

[6] Beverton R and S Holt 1957: On the dynamics of exploited fish populations. UK Ministry of agriculture and fisheries. Fishery investigations. Series II, vol. XIX., London. Guillen J, Macher C, Merzéréaud M, Bertignac M, Fifas S and O Guyader 2013: Estimating MSY and MEY in multispecies and multi fleet fisheries, consequences and limits: an application to the Bay of Biscay mixed fishery, Marine Policy, 40, 64-74.

[7] May RM, Beddington JR, Clark CW, Holt SJ and RM Laws1979: Management of Multispecies Fisheries. Science 205;4403: 267-277

others have a low or no economic market value and may be discarded[2]. One of the serious problems in mixed and multispecies fisheries is the waste of fishing resources because of discarding at sea due to low market value of some species compared to others or high grading the large sizes or prohibition to land undersized fish[2].

There is a gap between single and multispecies approaches to MSY that MSY variants are starting to fill. MSY variants range from the original goal of maximizing the yield in weight per recruit on an annual basis to the combined goal of maximizing the economic yield per recruit (Maximum Economic Yield) and to long-term national goals for optimum yield. Ensuring precautionary is an important aspect in all definitions but, what is to maximized, what sustained, and how can mixed fisheries be managed aiming for MSY—with B or F?[5,8] The efficacy of MSY for single species management is being explored currently in the EU, Australia and the USA and includes consideration of "MMSY" or a multispecies MSY concept. Australia goes for B MEY2 to build multispecies objectives into target reference points, ICES for F MSY with flat curves to allow more flexibility and the USA combines the two in an overfishing limit (OFL). To achieve different goals of yield/MSY and rent/MEY in commercial fisheries, different fishery types require a different balance of objectives:

- maintaining a high yield, maximizing gross value-added (GVA) and profit for vessel types (small or large) in the single stock case[9];
- maximizing the most valuable part of the fishery with additional constraints to not overfish the other species, considering trade-offs in the mixed stock case[10]; and
- looking for stability in the multispecies case[10].

Balancing different objectives with trade-offs in MSYs across species in mixed and multispecies fisheries management was a major topic at a recent ICES symposium in Greece (October 2015). For some fisheries in Europe, stakeholders have favored a "Pretty Good Yield" (PGY) over trying to reach the absolute sustainable maximum in yield or profit[10]. It has been argued in the literature that PGYs around 80% of MSY are obtainable over a broad range of stock sizes and are precautionary[10].

5. Regional Approaches to MSY in Mixed and Multispecies Fisheries

In 1979, May et al asked what specific principles should be espoused to manage a mixed or multispecies fishery in such a way as to "maintain the health and stability of the marine ecosystem?"[7]. In 2015, MSY remains the dominant target but with regional twists from Australian (Pascoe et al 2015)[4], European[2,5] and American perspectives[11].

5.1. 1. Australia

The Commonwealth Fisheries Harvest Strategy Policy (HSP) and Guidelines state that "fisheries harvest strategies for key commercial stocks should be designed to pursue maximising the economic

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[8] For a discussion on variants of MSY see the MyFish project at http://www.myfishproject.eu/component/content/article/108-myfish/1152-international-workshop-on-definitions-of-msy-variants?highlight=WyJkZWZpbml0aW9ucyJd

[9] See the MyFish project for a discussion of the factors that affect the profitability of fisheries under a maximum yield regime at http://www.myfishproject.eu/images/MYFISH/Deliverables/D_1_1MYFISH.pdf

[10] ICES & MyFish 2015: Targets and Limits for Long-term Fisheries Management, Athens Greece, October 13-15 2015. See http://www.myfishproject.eu/images/MYFISH/symposium/Sessions/Myfish_ICES_Symposium_Session_3.pdf

[11] NOAA 2015: Question and Answers Related To Annual Catch Limits and National Standard 1 Guidance. See http://www.nmfs.noaa.gov/msa2007/docs/acl_faq_may27_2011.pdf

yield from the fishery, and ensure stocks remain above the levels at which the risk to the stock is unacceptably high". With these objectives in mind, the target biomass is that which produces MEY, or B MEY. In fisheries where B MEY is unknown, a proxy of 1.2B MSY is to be used instead, where B MSY is the biomass at maximum sustainable yield. In fisheries that target or catch multiple species, the guidelines propose to apply MEY "across all species in the fishery", implying that secondary (lower valued) species may be fished at levels that result in biomass levels lower than their individual B MEY but above their limit reference point, beyond which the government considers the risk to the stock as the basis of a commercial fishery to be too high to ensure that the fishery maximises net economic returns.

BOX 1—AUSTRALIA[4]:

TARGET REFERENCE POINTS IN MULTISPECIES MIXED FISHERIES

There is currently no standard framework to determine target reference points for individual stocks within a multispecies fishery to generate MEY for the fishery as a whole. Simple single species indicators such as the 1.2 B MSY proxy for B MEY is unlikely to be appropriate, especially for species that make up a small proportion of the catch.

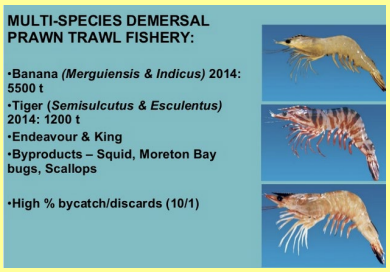
A "generic" multispecies bioeconomic model of a mixed fishery was developed. The model was run stochastically, varying the number of species and their individual biological and economic characteristics. The model was an optimisation model with the objective of maximising total fishery profits across all species, and the resultant optimal biomass of each species (B MEY) was compared with the biomass that would produce its maximum sustainable yield (B MSY) to produce a target reference point consistent with the current management framework. From this, a wide range of biological and economic conditions was considered. The output from the model was used to develop the generic decision support framework. Two approaches were used to develop this framework: (1) the use of a regression tree to provide a simple set of "rules of thumb" for determining an appropriate target reference point; and (2) a Bayesian network to provide an estimate of the likely probability of a target reference point given the information known about the fishery and species. The models were also used to assess the impact on profits of imposing the estimated proxy reference point on the dominant species only and also the impact of imposing the default target reference point of B MEY=1.2B MSY.

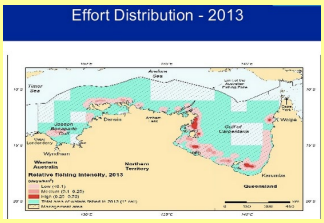
The results from the generic models suggest the key determinants of the target reference point of individual species in multispecies mixed fisheries are catchability, growth rates and share of total fishery revenue. Other variables, such as costs of fishing, prices and number of species in the fishery are also influential but to a lesser degree.

In such cases, the biomass of some species at the fishery-wide MEY may be lower than the biomass at which MEY would be reached if each species was caught independently of the others, while for other species it may be higher. This implies that some species will be utilised at relatively low levels, while other species will be fished at levels where the stock will be at higher risk of becoming overfished[12]. Identifying an appropriate target reference point for species within a multispecies fishery is complex and remains experimental in Australia (see Box 1 for Australia's experience setting target reference points in mixed multispecies fisheries). At a fishery level, targeting maximum economic yield at a fishery level involves optimising biomass targets for individual stocks so that they are consistent with achieving the maximum economic return across the suite of species taken in the fishery.

Australia's Northern Prawn (Multispecies) Fishery was certified by the MSC in 2012. See Box 2 for an overview.

BOX 2—MSC CERTIFIED AUSTRALIA'S NORTHERN PRAWN FISHERY[13]





Harvest strategies include TRP: Maximum Economic Yield (2004) and LRP: Maximum Sustainable Yield

Escapement: Inseason trigger limits for banana and tiger prawn fisheries

Bioeconomic stock assessment model: Tiger prawns & Indicus

MPAs, spatial & temporal closures—permanent & seasonal

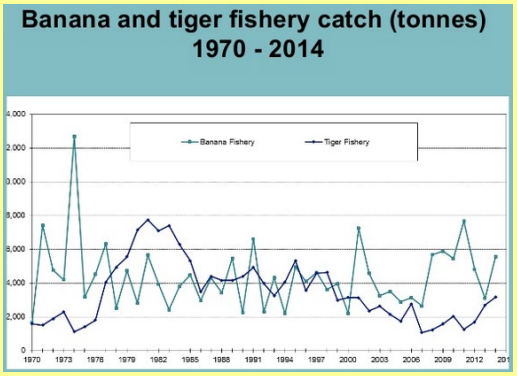
Fishing seasons: 1 April – 15 June is banana prawn season; 1 August – 30 November is tiger prawn season

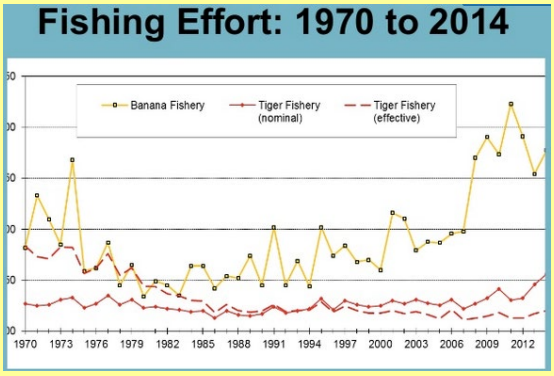
Limited entry: 52 prawn trawlers with 19 owners

Fishing rights: Input controls (effort units), legislated as Gear Statutory Fishing Rights (SFRs): Boat SFRs (1 per boat); Gear SFRs (based on headrope length ie. 1cm headrope = 1 Gear SFR); Quad (4), Twin (2), Triple (3), or tongue net. Mandatory VMS, TEDs, BRDs, logbook-95% using electronic logs)

The banana prawn fishery has highly variable recruitment that is rainfall dependent (5500t in 2014).

The tiger prawn fishery is at or above MEY (1200t in 2014). GVP $65-95 million. User pay management ($2.5 million/year).





[13] 2015: User rights in Australia's Northern Prawn Fishery: a Southern hemisphere developed country experience; See http://www.slideshare.net/FAOoftheUN/userrights-in-australias-northern-prawn-fishery-npf-a-southern-hemisphere-developed-country-experience-by-annie-jarrett

5.2. European Union

BOX 3—EUROPEAN UNION
MULTISPECIES BENCHMARKING—BALTIC SEA[14]

The goal of a benchmark is consensus agreement on an assessment methodology that is to be used in future update assessments. The result will be the 'best available' method that ICES advice will be based on which will be documented in a "stock annex"[13]. Typically, a stock will be benchmarked every 3–5 years to keep pace with changing situations.

A Benchmark Workshop on Baltic Multispecies assessment (WKBALT) met at ICES Headquarters in November 2012 and February 2013 to suggest a format for multispecies advice for the Baltic Sea and to review the methods used to assess and estimate biological reference points for Eastern and Western Baltic cod, Baltic sprat, and herring in Subdivisions (SDs) 25–19 and 32 in the Baltic.

WKBALT suggested a format for multispecies advice for the eastern Baltic, which included a description of the most important species interactions, advice on natural mortality, biomass by guild, and the proportion of large fish. Advice was provided on the combination of target fishing mortalities (F) that produce precautionary, close-to-MSY yields in a multispecies environment and on the important trade-offs between the yield of cod and clupeids.

The group evaluated the appropriateness of data and methods used to determine stock status and investigated methods for short-term outlook in a single and, when possible, multispecies context for Western Baltic cod, Eastern Baltic cod, Central Baltic herring and Baltic sprat. The evaluation included consideration of fishery-dependent (including recreational fishery), fishery-independent, environmental and life-history data. Stock annexes of all stocks were updated as part of the process. A multispecies annex describes overall data, methods used to estimate

[14] ICES 2013: Benchmark Workshop on Baltic Multispecies Assessment. See http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2013/WKBALT%202013/wkbalt_2013.pdf; See page 345 for the Stock Annex and Multispecies Annex.

community, food web and stock productivity indicators[13].

European fisheries are in general defined as mixed and multispecies fisheries[2]. In the European Union, marine resources are shared by many Member States' fleets. 75% of EU fish stocks are overfished compared to 25% of world fishing resources[2]. With 80% of Mediterranean fish stocks and 47% of Atlantic fish stocks overfished, strict rules are needed to restore fish stocks in the coming years[2]. The new Common fisheries Policy (CFP) entered into force January 1, 2014 and it grants special attention to multispecies and mixed stock issues. Multispecies benchmarking in assessment is a priority (See Box 2 for the new approach to assessment for the Baltic Sea area). For the North Sea area, mixed fisheries advice has been provided by ICES since 2012 based on a single stock assessment for the main species (cod, haddock, whiting, saithe, plaice, sole and nephrops) but combined with knowledge on the species composition in catches. The group uses the Fcube approach to present different scenarios for advice. It is often not possible to achieve all management objectives simultaneously with this approach. Instead, different mixed-fisheries catch scenarios take specific management priorities into account. For instance, if rebuilding of the cod stock is the major objective, this could mean that the TAC for other species in the mixed fisheries cannot be fully utilized. There is therefore no single recommendation but a range of plausible options, in contrast to single-stock advice [15].

[15] ICES 2013: Report of the Working Group on Mixed Fisheries Methods (WGMIXFISH-METH), 26-30 August 2013.

New priorities for multispecies mixed fisheries in Europe are to implement the discard ban and to adopt Maximum Sustainable Yield (MSY) as the cornerstone of management[2]. Box 3 describes multispecies mixed cod fisheries with discard bans in Iceland and Scotland. Box 4 shows efforts on discards and MSY in representative multispecies mixed fisheries in Europe.

BOX 3—DISCARD BANS IN ICELAND & SCOTLAND MULTISPECIES MIXED FISHERIES[5]

Iceland[5]: In the 1980s, Iceland introduced a quota management program and a total ban on discarding has been in place since 1996. Under the Icelandic system, if a vessel catches a species for which it does not have sufficient quota, this catch is automatically deducted from its cod quota using 'a cod-equivalent' index. This can be done for up to two per cent of the total cod quota held by that operator and does not work in reverse. Operators can reverse the cod-equivalent transaction by purchasing quota for the over caught species.

Other measures in place include the mandatory retention of all undersize catch (not to exceed 10 per cent of the quota) counting against the operator's quota at a 50 per cent rate. At the end of the season, when operators run out of quota, as an extra incentive to report and land all their catch, operators are allowed to sum all their catch (all species) and land an extra percentage (from two to 10 per cent according to gear type) of any species regardless of whether they have quota for that species. This extra catch is auctioned off with 80 per cent of the sale value being kept by the Ministry of Fisheries to be used in a fisheries development fund. Any catch beyond that incurs a post-season cost and the operator is invoiced for it with the government keeping one hundred percent of the auctioned value of the catch. Any quota left at the end of the year can be carried over up to 15 percent.

Iceland's discard ban may have led to increased prices for certain species due to better selectivity of the catch and reduction of small fish. This increase in selectivity may have occurred by avoiding high risk areas for juvenile fish or improved gear selectivity. An important factor in this scheme is the emphasis on at-sea inspections and port observers. Even though not all trips carry observers or are monitored, being able to compare catches of monitored and non-monitored trips carried out at the same place and time has proven to be a useful tool in identifying high-risk vessels for inspection.

Scotland[5]: Scotland has implemented a system of incentives to reduce discarding of cod. Cod was estimated to be subject to discarding at a rate of 35 per cent of the retained catch previously. The scheme provides increased quota and allowable effort for vessels that commit to landing all cod caught regardless of the size (that is, no discarding), cease fishing once the quota for cod or any other species was reached and allow the installation of electronic monitoring devices such as cameras and winch sensors. An increasing number of vessels are joining the scheme. The results have included an increase in cod landing, more vessels being able to fulfill their quotas for other species in the fishery and a change in fisher behaviour. Fishers have also used their participation in the scheme as a marketing tool, selling their fish as 'discard-free'.

BOX 4—EU:
ACHIEVING MSY IN MULTISPECIES, MIXED FISHERIES[2,5]

Four fisheries with large-scale discarding that are also representative of Europe's mixed, multispecies fisheries, were reviewed in 2014 by the EU Director General for Internal Policies to support decision-making and legislative proposals[2]. The results showed that MSY targets are not achievable for all species simultaneously and the efforts needed to reach MSY for each of the stocks are very different[2,5]:

1. Cod mixed fisheries in the North Sea
Large-scale discarding is known to occur in the mixed demersal trawl fisheries in the North Sea. Discards are mainly composed of small and juvenile fish below or close to the minimum landing size and of larger individuals of species without a reliable market. Single stock management is one of the reasons for discarding in mixed fisheries in the North Sea. Cod interacts with a range of species in the ecosystem. It is obvious that all MSY targets cannot be achieved simultaneously. A new management system based on a multispecies approach has been proved for the North Sea, suggesting changes in single-species MSY values in order to maintain all stock within precautionary limits.

2. Mixed demersal fisheries in the Celtic Sea
Large-scale discarding is known to occur in the demersal fisheries in the Celtic Sea. While juvenile hake is discarded in otter trawler fisheries, a variety of finfish species are discarded in the nephrops fishery. Discards are mainly composed of undersized fish. Improved selectivity is needed to counteract high levels of discarding. Current effort restrictions might induce highgrading. There is a need for reconciliation of TAC for choke species. Only cod, whiting, sole and herring are being exploited at individual MSY levels.

3. Demersal multispecies and mixed fisheries in Iberian waters
The Iberian stocks are managed by applying single-species management measures. This is recognized as one of the main causes of discarding because individual management objectives are not consistent with each other. Otter and Pair trawls targeting hake, horse mackerel, monkfish and megrim are reported to have discards. Discards reach 30-60% in weight of the total catch. Significant inconsistencies in TAC of different species being caught by the same fleets are identified in the Iberian waters. In the mixed fisheries context, the conclusion is that all MSY targets cannot be achieved simultaneously. Multispecies/ecosystem considerations have not being taken into account when estimating MSY values.

4. Trawl demersal multispecies fisheries in the Mediterranean Sea
Mediterranean demersal fisheries are not regulated through quotas but through restrictions on the number and horsepower of vessels, gears, size of landed fish and time of activity. Size restrictions exist but are poorly enforced. The main causes of discarding in Mediterranean fisheries are the lack of commercial interest of a significant fraction of catches, and price control in high landing periods (recruitment season). The overall state of Mediterranean demersal resources is "overexploited" according the most recent stock assessments (100% of the 18 demersal stocks assessed by the

STECF are overexploited). Effort reductions should be accompanied with technical measures to increase the size of first capture and this would increase the productivity of Mediterranean demersal fisheries.

Overall Findings[2]:

- The ICES mixed-fisheries advice is currently implemented only in the North Sea stocks.
- This work is taken into account to give the first catch advice.
- Important inconsistencies in TAC of different species being caught by the same fleets are identified in the Iberian waters.
- The conclusion is that all MSY targets cannot be achieved simultaneously.
- Multispecies considerations have only been deeply analysed and included for advice for some North Sea stocks.
- It is recommended that other ICES ecoregions (Celtic Sea & Bay of Biscay and Iberian waters) continue and/or start working on assessment of multispecies in mixed fisheries.
- MSY references ranges of the main European commercial species should be defined in a multispecific context.
- On average, fishing mortality used under the precautionary approach (Fpa) is 1.6 times that fishing mortality used under the maximum sustainable yield approach (Fmsy). Meaning that, the Fmsy is, in general much more conservative. So when establishing multispecies MSY reference ranges, it is recommended to overview the total catch profile by fleet, and to avoid simplifying the complex ecosystem to single catch advice.

5.3. United States

In the US, overfishing limits (OFLs) are calculated for stocks as an amount of catch calculated from the estimate of biomass for a year and the maximum rate of fishing mortality that does not result in overfishing. The premise is that a catch equal to OFL results in equal probability that overfishing is or is not occurring. A number of fisheries are managed regionally as multispecies and mixed stock complexes, for example New England Groundfish, Pacific cod and flatfish, and Alaska salmon. If a stock is caught in more than one fishery, one Fishery Management Plan (FMP) should be designated as the primary FMP in which the stock's overall annual catch limit (ACL) is established[11]. Conservation and management measures in other FMPs should be consistent with the primary FMP's management objectives for that stock, however an exception allows overfishing to occur on stocks within a complex, if certain criteria are met and approved.

When the exception was established in the guidelines to the National Standard 1 (NS1) in 1998, overfishing could occur so long as the target species did not become listed under the Endangered Species Act. Recent amendments to the overfishing and rebuilding provisions of the Magnuson Stevens Act further strengthened the Act's conservation goals and the ESA listing was deemed an inappropriate threshold. Today, all stocks should be managed so they retain their potential to achieve MSY. The NS1 guidelines (2009) have a higher threshold, limiting fishing mortality to a level

that will not lead to the stock becoming overfished more than 50-percent of the time in the long term. In addition, the 2009 guidelines made clear that the mixed-stock exception cannot be used if the stock is in an overfished condition[11].

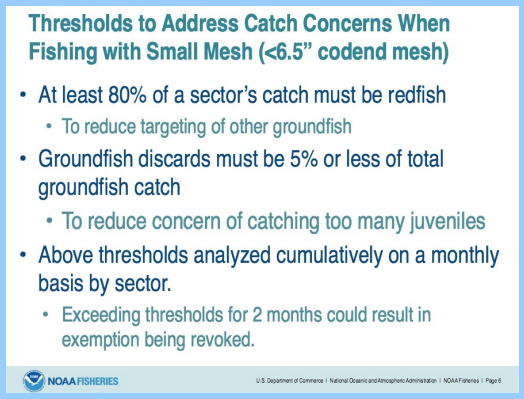
For all US fisheries, including multispecies fisheries, catch limits are set against an Optimum Yield (OY), being the long-term average amount of desired yield from a stock, stock complex, or fishery. Because the population size of a fish stock fluctuates every year, the amount of fish that is available to the fishery in any given year may be above or below the OY but cannot exceed MSY and must be achieved to prevent overfishing[11]. US multispecies mixed stock fisheries score fairly well against MSC Principle 1 as a result. Box 5 presents the defining characteristics of the Northeast (New England) multispecies fisheries for groundfish and the standing of silver hake, formerly a bycatch species in the cod fishery and now a minor target stock in the groundfish complex, against MSC's Principle 1 indicators. Groundfish management in the Northeast made a dramatic shift in May of 2010 from primary input-based controls to primary output based controls[16]. Amendment 16 to the Northeast Multispecies Fishery Management Plan (FMP) established the rules for sector management, as well as catch limits and accountability measures mandated by the reauthorization of the Magnuson-Stevens Act. If multispecies sector management is to be successful, the fleet must be able to catch and land stocks of high abundance like redfish while exercising their ability to avoid limiting species (e.g. most recently, Gulf of Maine cod)[16]. Fishery conservation and management goals now: (1) redirect fishing effort in the multispecies fishery away from stocks that are overfished to stocks that are considered rebuilt, (2) achieve optimum yield by increasing commercial landings of redfish through development of a directed fishery under the adaptive management ability of groundfish sectors, and (3) increase the economic viability of groundfish sectors by providing access to the ACL of a recovered species and thus generating much-needed revenue for the industry.

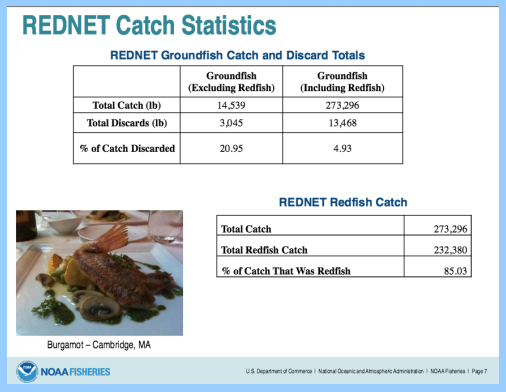
Box 5—USA: NORTHEAST GROUNDFISH STANDING OF MINOR STOCKS ON MSC PRINCIPLE 1:[17]

The Northeast multispecies fishery is managed by the New England Fishery Management Council using a variety of management tools including days-at-sea, special management programs, and sectors. The fishery is managed as a complex of numerous species of groundfish found throughout the Greater Atlantic region and formerly dominated by Atlantic cod. The fishery is executed using primarily trawl, gillnet, and hook gear. The regulations are found at 50 CFR Part 648 Subpart F. Groundfish catches declined in the mid 2000s but some formerly-minor stocks in the complex, for example redfish and silver hake, have recovered from overfishing and currently have a low probability of overfishing. Uncertainties and challenges facing the stock assessment of multispecies and multi-gear fisheries targeting redfish and silver hake have been considered (Helser and Alavade 2012)[18] and corrective management measures have been initiated through annual quota limitations in U.S. waters to allow *fishing these stocks among other overfished species*. Overfishing is avoided for the stock complex by efforts to maintain fishing effort and Total Allowable Landings. The current harvest strategy is expected to achieve stock management objectives. The fishery has incorporated overfishing limits, acceptable biological catches, and Annual catch limits to improve compliance with the Fishery Management Plan[17].

[16] Kanwit K, Pol M and P He 2012: Rednet: a network to redevelop a sustainable redfish fishery. See: http://archive.nefmc.org/research/cte_mtg_docs/120625/Rednet%20Report/FInalComponent2.pdf
[17] Ganapathiraju 2014: (1) Pre-assessments to the Marine Stewardship Council standard for New England Ocean Perch / Acadian Redfish and (2) 2015: Silver Hake. Contact info@sustainability-incubator.com for a reprint.
[18] Helser T and L Alade 2012: A retrospective of the hake stocks off the Atlantic and Pacific coasts of the United States: uncertainties and challenges facing assessment and management in a complex environment. Fisheries Research 114, 2-18.

For all target stocks in the groundfish complex, biological reference points and target reference points have been set at a level below which there is less risk of impairing Spawning Stock Biomass (SSB). Multispecies interactions between abundant and overfished species are considered in Total Catch allocations for groundfish, executed through sector-based management. For example for redfish:





Target reference points have been set such that stocks are maintained at a level consistent with the biological maximum sustained yield or above, or some measure or surrogate with similar intent or outcome. NEFSC uses relative exploitation index (i.e. total landings divided by NEFSC autumn survey biomass index) as a proxy for estimating fishing mortality. Overfishing is reported when the 3-year average exploitation index is below the F_{MSY} proxy (the average exploitation index during 1973-1982), and is used as both target and threshold value for estimating fishing mortality for the northern stock (NEFSC 2006)[19]. Current stock assessments use research vessel survey indices, port sampling, and landings of commercial fishing vessels, recreational catches as well as discards. Exploitation indices have been below the F_{MSY} proxy since 1978 (Col and Traver 2006)[20].

The abundance of small mesh multispecies has been increasing over the past three decades with both the northern and southern stocks of whiting currently considered rebuilt, or above their biomass (B_{MSY}) target values. The southern stock of whiting is above its biomass threshold value and stock is rebuilding to target biomass (B_{MSY})[21]. Small-mesh multi-species fisheries are managed effectively through lower possession limits and mesh size restrictions (Kulka *et al.*, 2012)[22] and sector-management.

Could minor stocks in the groundfish complex be MSC certified? Using the example of silver hake:
MSY- based reference points for northern and southern silver hake stock (Col and Traver 2006)
FMSY Threshold Proxy = 2.57; FMSY Threshold Proxy = 34.39
FMSY Target Proxy = 2.57; FMSY Target Proxy = 20.63
BMSY Proxy = 6.63 kg/tow; BMSY Proxy = 1.78 kg/tow
1/2 BMSY = 3.31 kg/tow; 1/2 BMSY = 0.89 kg/tow

Well-defined harvest control rules are in place that are consistent with the harvest strategy and ensure that the exploitation rate is reduced as limit reference points are approached. Relevant information is

[19] Northeast Fisheries Science Center 2006: The 42nd Northeast Regional Stock Assessment Workshop (42nd SAW). Northeast Fish. Sci. Cent. Ref. Doc. 06-09. http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0609/
[20] Col L and M Traver 2006: Silver hake - Status of fishery resources off the Northeastern US, NEFSC - Resource Evaluation and Assessment Division, December 2006, 19 pages.
[21] New England Fishery Management Council (2014a) Stock Assessment and Fishery Evaluation (SAFE) Report for Fishing Year 2013 - Small-Mesh Multispecies, and (2014b) Small-Mesh Multispecies Fishing Year 2015-2017.
[22] Kulka D, Rivard D and I Scott 2012: The United States Atlantic Fishery for Spiny Dogfish (*Squalus acanthias*), Marine Stewardship Council, Version 4, Final Report, July 2012, 381 pages.

available related to stock structure, stock productivity, fleet composition and other data is available to support the harvest strategy. Stock abundance and fishery removals are regularly monitored at a level of accuracy and coverage consistent with the harvest control rule. There is good information on fishery removals from the stock but not from other commercial, recreational and ecological uses (cannibalism, species mis-ID). Current stock assessment is appropriate for the stock and for the harvest control rule. The assessment evaluates stock status relative to reference points. A minor target stock in the multispecies groundfish fishery can reach the 80 score for MSC indicator with efforts to: improve quantification of discards and incidental catches in groundfish fisheries along the east coast of America, 1.1.1; if current catch quota allocations are maintained and rebuilding efforts continue through lower possession limits and mesh size, 1.1.2; scientific monitoring shows that the harvest strategy is working and the stock is being rebuilt, 1.2.1; with increasing evidence of stock rebuilding, 1.2.2; if fishery removals are better quantified from benthic trawl, shrimp and squid fisheries and observer coverage for monitoring discards at sea increases in the Small Mesh multi-species fisheries, 1.2.3; and if fishery removals are quanitified for commercial, recreational and fishery survey uses and cannibalism, 1.2.4.

6. Food Web Considerations

The relationship between the yield and the relative depletion of species in ecosystem is considered in multispecies fisheries management in the form of trade-offs between the overall yield and the status of individual species in the ecosystem (Worm et al 2009)[23]. Disruption to marine food webs occurs when the trophic structure of the fishing environment is steadily altered beyond the capacity of the food web to compensate and maintain its necessary structure and function. 'Fishing through the food web' is the most common mechanism underlying declines in mean trophic levels in marine ecosystems by the serial addition of low trophic-level fisheries (Essington et al. 2006)[24]. Fishing low trophic species at conventional maximum sustainable yield (MSY) levels can have large impacts on other parts of the ecosystem, particularly when they constitute a high proportion of the biomass in the ecosystem or are highly connected in the food web (Smith et al. 2011)[25]. Multispecies models can be used to predict the effects of exploitation on species composition, size structure, biomass, and other ecosystem properties[23]. Worm et al (2009) prepared ecosystem models across 31 ecosystems with a range of different fishing scenarios with remarkably similar predictions. With increasing exploitation rate, total fish catch increased toward the "multispecies maximum sustainable yield" (MMSY) and decreased thereafter. The corresponding exploitation rate for maximum yield uMMSY was ~0.45 and total community biomass BMMSY equilibrated at ~35% of unfished biomass. Overfishing occurs when u exceeds uMMSY. To rebuild, catches must fall below uMMSY[23].

Advances in multispecies fisheries analyses focus on reducing discards (Europe)[5,8-10,13,14] and increasing overall profits (Australia)[3,4]. Predator-prey relationships are not commonly factored into harvest scenarios, even though mortality rates are predator-, prey- and fishery-dependent (Overholtz and Link 2007)[26]. In multispecies fisheries there is a need to make explicit and well informed decisions on the balance of species in a marine ecosystem subject to heavy commercial fishing, and not to deplete any species to the point where irreversible or slowly reversible change happens (for example by recruitment overfishing, extinction or near extinction or loss of key ecological processes). The outputs of multispecies analyses should focus on 'what if' questions such as 'what will happen if

[23] Worm B, Meyers R et al. 2009: Rebuilding Global Fisheries. Science 325, 578–585 (2009).
[24] Essington T, Beaudreau A and J Wiedenmann 2006: Fishing Through Marine Food Webs. PNAS 103:9:3171-5
[25] Smith et al 2011: Impacts of fishing low trophic species on marine ecosystems. Science 333:1147
[26] Overholz W and J Link 2007: Consumption impacts by marine mammals, fish, and seabirds on the Gulf of Maine-Georges Bank Atlantic Herring (*Clupea harengus*) complex during 1977-2002. ICES J. Mar. Sci. 64:83-96.

predatory fish are fished at F MSY?[5] What will happen if the biomass of prey species is serially fished down below B MSY, or if B MSY for prey species is unknown? Multispecies models are needed to generate better estimates of natural mortality and recruitment in order to better understand spawner–recruit relationships, variability in growth rates, to incorporate alternative views on biological reference points, and to develop a framework for evaluating ecosystem properties[27].

Modified fisheries management plans can align catch levels with environmental targets to conserve trophic structure, including sensitive species and habitat, although assessment of fishing mortality for rare and sensitive species remains a significant challenge[25].

7. MSC for Multispecies, Mixed Fisheries in Developing Countries

Fisheries in developing countries can include artisanal and industrial fleets, multiple species and stocks fished on the same grounds. Targets may change over the calendar year. Although regarded often as 'data-poor' for MSC certification, in some cases the evidence needed to complete a preliminary assessment can be drawn from pertinent regional science studies framed outside of the single species concept. For example, fishers along the Yucatan peninsula of Mexico fish year-round and sequentially for snapper, grouper, sea cucumber, octopus, lobster, and crab, depending on price and availability. Changes in ecosystem structure over time are well documented for Yucatan fisheries. A pre-assessment for Yucatan snapper by Francisco Arreguin-Sanchez in 2014 enumerated 41 species caught alongside snapper, noting that snapper was a relatively small component but all of the catch is sold or consumed locally. Snapper is fished by two domestic fleets of artisanal boats and 'bicicleta' gear alongside medium sized hook and line boats and shrimp trawlers; formerly it was fished also by US and Cuban fleets as well. The record shows that the role of red snapper in the fishery is dynamic and significantly different than predicted for a 'target species', making clear the need for adaptive management including the need for dynamic biological reference points for target species[28]. Arreguin-Sanchez recommended that management must be developed separately[29].

8. Model Components for Mixed and Multispecies Fisheries

Empirical models have addressed the spatial component of **mixed fisheries** through modelling the fishery at the "metier" level[3,4]. Métiers correspond to a fishing activity that is defined spatially (i.e. a given location), using a given gear and catching a given combination of species. The models estimate catches, costs and profits based on effort allocation across these different métiers, capturing both multi-gear interactions as well as mixed species catch (technical interactions)[4]. Pascoe et al developed a framework for estimating appropriate economic target reference points for species within mixed fisheries[4].

The development of bioeconomic models for **multispecies fisheries** requires considerable biological information on each individual species that is often unavailable (biological interactions). In some data poor fisheries where only catch and effort data are available (plus some indicative economic

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[27] ASDA 2015: Minimizing and managing the impact of fisheries on marine food webs. See https://www.undercurrentnews.com/2014/06/05/asda-sponsored-report-exposes-wider-impact-of-fishing-on-marine-ecosystems/ and https://www.sustainablefish.org/publications/2014/06/03/sfp-best-practices-report. The report was prepared by this author, Katrina Nakamura, in 2013.

[28] Arreguin Sanchez F 2012: The Dynamics Linking Biological Hierarchies, Fish Stocks and Ecosystems: Implications for Fisheries Management. Developments in Environmental Modeling 25:501-516

[29] Arreguin Sanchez F: Red snapper fishery pre-certification report. CICIMAR-IPN. Contact info@sustainability-incubator.com for a reprint.

variables), yield functions that aggregate across stocks have been used. That is, total catch of all species is modeled as a function of total effort. These have been deployed largely in developing countries but have also been used in more developed countries where fisheries are based on a large number of species, each contributing a relatively small proportion to revenue[3]. Within multispecies fisheries, identifying the level of biomass that is associated with maximum economic yield (MEY) requires detailed bioeconomic models of the fisheries[4]. For many fisheries, such models are unavailable, so some form of cost effective proxy measure is required to estimate approximate target reference points based on, in some cases, limited information[3].

A model suitable for the analysis of multispecies resources shared between artisanal and industrial fisheries is the BioEconomic Analytical Model (BEAM4)[30]. The model behind BEAM4 is an age-structured cohort-based fish stock assessment model combined with an economic model of both harvesting and processing sectors. Its objective is to predict yield, value and a series of measures of economic performance as a function of fishery management measures such as fishing effort control, closed season, closed areas and minimum mesh size regulation. BEAM4 is primarily designed for the analysis of tropical mixed fisheries with penaeid shrimps as the target and finfish as the by catch. It is, however, general, and in principle may be used to analyze any fishery. It can deal with a fishery system of several stocks, several fleets, several areas (fishing grounds) and several processing plants and can account for migration of the animals as well as seasonality of recruitment.[30]

9. Cost considerations beget a risk-based approach

There are fisheries or species within multispecies fisheries that are sufficiently complex that the costs of moving beyond very little data make the move almost impossible[3]. Having little information regarding the biological and economic characteristics of a stock does not necessarily justify that additional information be collected[3,4]. The benefit of collecting further information needs to be set against the cost of collecting the additional information. To ensure fisheries are managed at an acceptable level of risk to the Australian Government irrespective of the level of knowledge, the Australia Harvest Policy advocates a risk management approach whereby exploitation levels reduce as uncertainty around stock status increases. Both sustainability and profitability depend on the long-term productivity of the stock being maintained. This balance is placed at risk when stocks are reduced to a level where the recruitment of young fish is substantially reduced as a result of the reduction of the breeding adult population (referred to as 'recruitment failure')[4]. Where information to quantify risk levels is unavailable, a precautionary approach will be taken to fishery management leading to more conservative outcomes to account for the uncertainty[3].

10. Current best practice

In 2014 and 2015 formal reviews were completed of mixed and multispecies harvest strategies and management approaches in Australia and the European Union. In Europe the reviews suggest that MSY is nearly as challenging a fit to multispecies mixed fisheries as total allowable catch (TAC). The findings indicate more experimentation is needed to balance priorities across species. 'Pretty Good Yields' are a generally reliable target but this relatively new concept has not been tested enough empirically to represent 'best practice'[2,5]. Ray Hilborn has defined "Pretty Good Yield" as a

[30] FAO 2015: BEAM4 - Analytical Bioeconomic Simulation of Space structured Multispecies and Multifleets Fisheries. See http://www.fao.org/fishery/topic/16069/en

sustainable yield that is at least 80% of the maximum sustainable yield[31]. In Australia, three reviews found that strategic averaging of biomass limits across multiple species and stocks is an effective way to sustain yields[3,4,15]. Overfishing is being reduced successfully with optimum yield strategies in the USA[11],[32].

[31] Hilborn R 2010: Pretty Good Yield and exploited fishes. Marine Policy 34:1:193-6. Such yields are generally obtained over a broad range of stock sizes (20–50% of unfished stock abundance), and this range is not sensitive to the population's basic life history parameters such as natural mortality rate, somatic growth rate, or age at maturity; rather, the most important biological parameter determining this range is the intensity of recruitment compensation.
[32]NOAA 2015: Status of Stocks 2014-Overfishing and overfished numbers hit all time lows. See http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/archive/2014/2014_status_of_stocks_final_web.pdf

11. Takeaways

11.1. European approaches to multispecies mixed fisheries are evolving via CFP reform:

- European fisheries are characterised by a great diversity of exploited species (fish, crustaceans and molluscs) and by a variety of fishing gears. European fisheries are multi-gear and multi-species. This highly complex nature has been a major contributing factor to the limited success of certain management strategies (e.g. TAC).
- Different catch limits for the various stocks may lead to imperfect implementation of the single-species TAC through incentives for misreporting or discarding.
- The main issue for MSY should be to look at the relationship between population growth and mortality and specifically, how much more mortality is caused by fishing than by nature and not just for target species but for the whole fish community and taking into account the heterogeneity in the fleets that harvest the species.
- In relation to the ecosystem objectives of the CFP: fishing for MSY also ignores fundamental aspects of the ecosystem such as the need to leave enough fish in the sea for other parts of the food chain including mammals and seabirds.
- Maximum sustainable yield is a weak statement in the context of other CFP objectives: the economic and the environmental.
- The reality is that the actual European scientific advice in the framework of MSY (as defined by ICES) for European stocks is now aiming to establish fishing rates targets rather than stock biomass targets. In the last four years of this ICES MSY framework approach application, fishing rates are now falling in the most critical fisheries, and are closer to MSY.
- In a multispecies fishery with more than one species caught at the same time, fish stocks' MSYs targets are calculated separately. However, in multispecies fisheries it is not possible to apply different levels of fishing effort to the species inhabiting a single habitat and that are vulnerable to the same fishing gear. In other words, what may be "safe" for one stock may be "dangerous" for another stock caught together with it.
- If MSY has to be used as the policy accepted by the EU for multispecies mixed fisheries, then it should be made as a limit and not a target.
- Managing at or above BMSY seems to be possible.
- In multispecies and mixed fisheries, the idea will be to define fishing mortality or biomass ranges, which assure sustainability that can be used when advising on catch options ("pretty good yield concept"). The concept will be to move from the traditional MSY towards a "pretty good multiyield" concept applicable to multispecies and mixed fisheries.
- In multispecies and mixed fisheries, MSY simple concept is weak in relation to its own definition and implementation. MSY is not able to cope with real world complexities, i.e. i) variability in population productivity; ii) species other than the target species, iii) food chain interactions and/or changing ocean environments and iv) considering just only the income and not the costs of harvest.

- In multispecies and mixed fisheries, if the overall level of exploitation is fixed at the lowest level required by the species with the lowest resilience, this will reduce drastically the utility of the resource.

The suggested format for multispecies advice for European fisheries is (ICES 2013)[5]:

- A description of the ecosystem including a sketch of species interactions,
- Identification of the most important interactions which affect management of fisheries, and
- Advice on the important trade-offs that should be considered in fisheries management.

11.2. USA approaches for multispecies mixed stock fisheries optimize fishing yields:[8]

- For all US fisheries including multispecies fisheries, catch limits are set against an Optimum Yield (OY), being the long-term average amount of desired yield from a stock, stock complex, or fishery.
- Because the population size of fish stock fluctuates every year, the amount of fish that is available to the fishery in any given year may be above or below the OY but cannot exceed MSY and must be achieved to prevent overfishing[8].
- In the Northeast Groundfish fisheries where only some cod stocks are recovering, the Overfishing may occur on stocks within a complex, if certain criteria are met and approved. Uncertainties and challenges facing the stock assessment of multispecies and multi-gear fisheries targeting redfish and silver hake have been considered (Helser and Alavade 2012)[18]. Corrective management measures have been initiated through annual quota limitations in U.S. waters to allow fishing these stocks among other overfished species. Overfishing is avoided for the stock complex by efforts to maintain fishing effort and Total Allowable Landings.

11.3. Australia's approaches for multispecies mixed fisheries maximize profits:[3,4]

Smith et al (2013)[33] and other reviews of Commonwealth mixed multispecies fisheries [3,4] offer findings that:

- Australia's Commonwealth Harvest Strategy Policy's Maximum Economic Yield (MEY) target reference point and proxy exceed international best practice for targets. The policy's limit reference point and proxy are consistent with international best practice.
- The harvest strategy policy proxy for the biomass limit reference point is half the biomass that supports maximum sustainable yield (or 20 per cent of the unfished biomass for a target proxy of 40 percent of unfished biomass).
- As a 'rule of thumb' the risks of recruitment overfishing increase at biomass levels lower than half of those that support maximum sustainable yield.

[33] Smith ADM, Smith DC, Haddon M, Knuckey I, Sainsbury K and Sloan S 2014: Implementing harvest strategies in Australia: 5 years on. – ICES Journal of Marine Science, 71: 195–203.

- A biomass level of 20 percent of unfished biomass is an acceptable proxy for that figure.
- For highly productive species, the biomass that supports maximum sustainable yield may be less than 40 percent of unfished biomass levels, in which case limit reference points could potentially be set lower than 20 percent of the unfished biomass using the above guidelines.
- Estimates of maximum sustainable yield are inherently uncertain, rebuilding overfished stocks has proven difficult (both in Australia and elsewhere) and possible ecosystem effects of low stock levels are often poorly understood.
- The precautionary approach requires good evidence that 0.5BMSY [the biomass level equivalent to half of that which supports maximum sustainable yield] is indeed below B20% [20 percent of unfished levels].
- In the face of these various doubts and uncertainties it would be difficult to argue that there would be no increase in the risk of depletion affecting consequent recruitment levels if the limit biomass reference point was permitted to vary below the current B20%. Accordingly, it is probably appropriate to retain 20 per cent of the unfished biomass as the lowest proxy value for the biomass limit reference point, even in cases where a half the biomass level that supports maximum sustainable yield is less than 20 per cent of the unfished biomass, except where there is a strong scientific basis to do otherwise.

12. Conclusion

Most fisheries around the world utilize single species approaches to set catch limits[23]. Where different gears and even fleets target multiple species, the species mix in catches may not necessarily match the mix in combined TACs [total allowable catches] or in quota holdings[4]. Overfishing has not been reduced in Europe by combining multiple single species catch targets (calculated Fpa's or F MSYs)[2]. Overfishing has been reduced in the US[8] and Australia[2,3] by optimizing yields across a range of species in fisheries to sustain the profitability of fishing within mixed fisheries. Fishing risks to long-term productivity for multiple species in a complex are considered in harvest planning in the USA and Australia.

A significant proportion of fisheries worldwide have a multispecies mixed character[5]. The results of this review indicate that managing these fisheries with single target methods can over time diminish sustainability rather than improve it. Fishers can usually 'target' to some degree through fishing different areas and depths, seasons, times of day and by modifying gear—but it is the degree to which fishers can target that is the issue[3]. This difficulty in balancing quotas for multiple species with actual catches may then lead to increased discarding and TAC over-runs leading to effort restrictions or fishery closures. Unwanted incidental catch of commercial species is generally discarded at the present time and contributes to the cycle of worldwide overfishing[5]. The statistics for European fisheries, where 100% of assessed Mediterranean demersal stocks are overfished[2], demonstrate that overexploited fish stocks cannot sustain a competitive fishing activity where single species fishing yields lead to more overfishing and overcapitalization[2,5]. It is for these reasons that the European Union is requiring fisheries scientists to start advising on the setting of targets for ecosystems rather than single species[9,10].

The findings in this review indicate that the interaction effects of fishing in multispecies and mixed fisheries regimes are deterministic to overfishing status, particularly through discards. The Terms of Reference for this review state "there is not sufficient science to enable MSC to arrive at an

acceptable mixed fisheries assessment solution". The results of this review indicate that a significant amount of published case study evidence is available and indicates that single species management induces highgrading, discards of juveniles and unwanted species, unreported fishing, and overfishing on non-target species in general. Fishing impacts on marine food webs are very well described in the scientific literature.

The Marine Stewardship Council standard for sustainable fisheries distinguishes target stocks from bycatch species and retained species in all fisheries. The current MSC Default Assessment Tree is based on single-species, single-stock fisheries[1] and, in general, provides a higher standard of care for target species in assessment over bycatch species[1]. Currently, single stocks within multispecies and mixed stock fisheries can be certified where the client chooses to identify the species of interest as individual single species targets, and whether or not it represents the actual management regime. Special consideration is warranted of the effects for multispecies mixed fisheries in developing countries where single species assessments to the MSC standard, for certification or a fishery improvement project, can create more demand and increase fishing pressure on a suite of species caught alongside the target, for example in grouper and snapper fisheries.

New questions arise from this review regarding the treatment of minor target stocks in future MSC assessments. Minor targets are more significant contributors than 'bycatch' to the overall sustainability of the fishery in multispecies mixed fishing complexes, even where the productivity of the primary target is the major concern.

Bycatch can be a critical component in the viability of business that is valuable for fisheries, whether it is assessed well or not[4,34]. The subject of wastage in fisheries has generated a whole host of words that have different meanings in different contexts and in different parts of the world. Bycatch is the word that is used extensively and causes most confusion[30]. At least three accepted definitions of the word refer to (1) catch which is retained and sold but which is not the target species for the fishery, (2) species/sizes/sexes of fish which are discarded, and (3) all non-target fish whether retained and sold or discarded. The MSC has long recognized sustainability in multispecies mixed fisheries in certifications for Alaska salmon, Pacific cod, Pacific flatfish, Australia's Northern Prawn Fishery and many others. It is recommended that the MSC look into recent advances in Europe, the USA and Australia and consider a decision tree that includes highgrading, discarding and overfishing of minor targets at the P1 level. It may be worthwhile to review the P1 outcomes for certified multispecies mixed fisheries for changes in overfishing status and discard trends in the certificate period. It is recommended that the MSC look at fisheries management models that are successfully reducing overfishing. For multispecies mixed fisheries these models include the MSY variants from the USA and Australia that balance biomass thresholds across a suite of species.

Fishing management frames are shifting toward a balance of biological with ecological and economic factors around the Maximum Sustainable Yield concept. The productivity emphasis in MSC's Principle 1 indicators does not need to change to better suit multispecies mixed fisheries. Rather the challenge for MSC is to encourage innovation in "sustainable fisheries" to evolve and embrace ecological and economic alongside biological considerations in the balance of factors behind the determination of a sustainable fishery.

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[34] FAO 1997: A Study of the Options for Utilization of Bycatch and Discards from marine resources. See http://www.fao.org/docrep/w6602e/w6602e03.htm