Nordic Council of Ministers

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PROJECT: ECOSYSTEM BASED FMSY VALUES IN FISHERIES MANAGEMENT

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Nordic Council of Ministers/Publication Unit
Ved Stranden 18
DK-1061 Copenhagen
Denmark
pub@norden.org

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The Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen
pub@norden.org

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Affiliations

Nordic Marine Think Tank (NMTT), Ved Lunden 19, 4300 Holbæk, Denmark	Henrik Sparholt
Institute of Marine Research (IMR), P.O box 1870 Nordnes, NO-5817 Bergen, Norway.	Bjarte Bogstad Daniel Howell
Institute for the Oceans and Fisheries, The University of British Columbia, 2202 Main Mall, Canada V6T 1Z4.	Villy Christensen Michael C. Melnychuk
Graduate School of Oceanography, University of Rhode Island, Narragansett, RI, 02882, USA.	Jeremy Collie
DTU AQUA, Kemitorvet, Bygning 202, 2800 Kgs. Lyngby, Denmark.	Rob van Gemert
School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle WA 98195 USA.	Ray Hilborn Michael C. Melnychuk
National Marine Fisheries Research Institute (NMFRI), Kołłątaja 1, 81-332 Gdynia. Poland.	Jan Horbowy
EUFISHMEAL, Denmark. Axelborg, Axeltorv 3, 6th floor, 1609 Copenhagen V, Denmark.	Søren Anker Pedersen
Danmarks Pelagiske Producentorganisation (DPPO) - Axeltorv 3, 6, 1609 København V, Denmark.	Claus Reedtz Sparrevohn
Science Institute, Taeknigardur, University of Iceland, Dunhaga 5,107, Reykjavik, Iceland.	Gunnar Stefansson
Faroe Marine Research Institute, P. O. Box 3051, Nóatún 1, FO-110 Tórshavn, Faroe Islands..	Petur Steingrund

Correspondance to:henrik.sparholt@gmail.com

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Summary

The fish stock assessment models used around the globe to inform fisheries management generally do not account for ecosystem interactions. This result in an underestimation of the fishing pressure (FMSY) that leads to maximum sustainable yield (MSY), a central reference points in fisheries management. Ecosystem and multispecies research indicate that the bias in the FMSY estimates could be substantial. This is expected to result in foregone sustainable yield. This is unfortunate because an increasing global population is demanding more food, and because fish products are healthy and have a low carbon footprint compared to most meat produced on land. Well-managed fisheries are relevant for as many as 10 of the 17 United Nations Sustainable Development Goals for 2030.

We propose an approach that is simple and scientifically sound, which removes the known biases in current methodology. We exemplify the approach through an analysis of the fish populations in the Northeast Atlantic Ocean.

The proposed approach includes density dependent growth, reproduction and cannibalism, and is still based on single-species stock assessments. Thus, managers need not consider the balance between stocks for using the proposed set of F_{MSY} values, thereby avoiding the challenge of prioritizing among fish stocks, which invariably favors some fishing fleets or countries at the expense of others.

We have evaluated the impact of considering these issues for the Northeast Atlantic fisheries (FAO area 27). Fisheries and fish stocks in this area are, globally, among the most well-monitored. We focused on the 53 most important fish stocks in the area. We did not include short-lived, forage fish in these analyses, as F_{MSY} is not used in their management. We applied five approaches to estimate F_{MSY} for each of the 53 fish stocks: A) the well-established "Surplus Production Models", using time-series of catch and stock biomass from routine stock assessments, B) extraction of F_{MSY} from the literature on ecosystem and multispecies research, C) direct calculations based on sub-models for density dependence of growth, reproduction and cannibalism, D) the "great experiment" where fishing pressure on the demersal stocks in the Northeast Atlantic slowly increased, and catches initially increased, but then decreased as fishing pressure crossed the boundary to overfishing, and E) generalized linear regression linking F_{MSY} from A)–C) to life history parameters. "Surplus Production Models" are often used in data poor situations, but we here use them with stock assessment data and find them especially useful because they implicitly include all density dependent effects.

The F_{MSY} estimates have been developed so that they can be used directly in the annual assessment and advisory process to guide managers. The new F_{MSY} values are substantially higher (average equal to 0.38 yr-1) than the current FMSY values (average equal to 0.26 yr-1) used by management. This corresponds to an almost 50% increase in fishing pressure. The average fishing pressure corresponding to the new

F_{MSY} is equal to that of the 1950s and early 1960s, and about 30% lower than in the overfished 1980s–2000s.

We conclude that managing the Northeast Atlantic fisheries using the new F_{MSY} values will increase the sustainable catches by several million t per year compared with a management based on the current F_{MSY} values.

1. Global fisheries catches can be increased after rebuilding of fish populations

1.1 Abstract

Global fisheries catches can be increased in a sustainable way after rebuilding of fish populations, if a few basic ecosystem functions are considered.

1.2 Main text

Overfishing is a major and recognized problem, but management interventions have in many areas lead to an end to overfishing (*1*), with some fish stocks rebuilding and others already rebuilt (*2*). Where this is the case – notably in temperate parts of the world ocean where effective management is in place – it raises a new twist to the central question for fisheries management (*3*): how should fisheries be managed to obtain maximum sustainable yield (MSY)?

During the decades of overexploitation where fisheries managers were under strong pressure to reduce effort, it became clear that management approaches had to be precautionary to promote rebuilding and limit the risk of collapses under sustained fishing pressure. This in turn has led to adoption of reference points for management that may be downward biased – and thus implicitly represent a precautionary approach. While populations were rebuilding such a bias was understandable, but in the areas where populations *have* rebuilt the implicit incorporation of a precautionary approach leads to lack of transparency in the management process.

An issue here is that the standard approaches for estimating the fishing pressure (F_{MSY}) that will give MSY do not consider a range of ecosystem factors that all point toward higher reference levels. As populations rebuild across trophic levels, interactions such as predation and food competition strengthen, leading to higher mortality and slower growth (*4*), two basic elements of ecosystem dynamics that determine ecosystem carrying capacity and density dependent mechanisms. As is the case for agricultural produce, higher density decreases per-capita productivity.

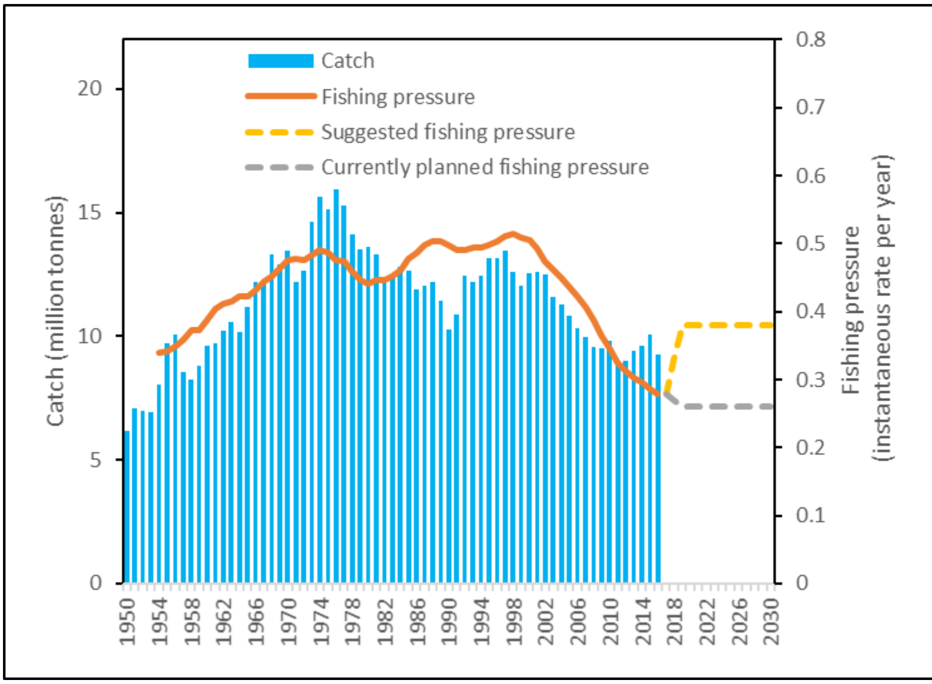
The fish stock assessment models used around the globe to inform fisheries management generally do not account for most of these interactions, leading to a downward bias of F_{MSY} (*4*). Ecosystem and multispecies modeling indicate that the bias in F_{MSY} estimates could be substantial (*5*), which is expected to result in foregone sustainable yield at a time when the global population is demanding more food. Fish products are healthy and have a low carbon footprint compared to most meat produced on land (*1*), and well-managed fisheries are relevant for as many as 10 of the 17 United Nations Sustainable Development Goals for 2030 (*1*).

Already in the 1970s, the "North Sea model" (*6*) demonstrated the importance of both predation and competition, but it has proven difficult to use this knowledge and most of the subsequent research on marine ecosystems in fisheries management. There have been challenges due to lack of clear management objectives, lack of capacity to address trade-offs between competing fisheries, and structural problems on the scientific side, with a gap between the science on ecosystem functioning and that of management advice. We propose an approach that is simple, scientifically sound, builds on the existing stock assessment framework, and which removes known bias in current methodology. We exemplify the approach through an analysis of the fish populations in the Northeast Atlantic Ocean.

The proposed approach does not include all multispecies interactions, but includes density dependent growth, reproduction and cannibalism, and is still based on single-species stock assessments. Thus, managers need not consider the balance between stocks for using the proposed set of F_{MSY} values, thereby avoiding the challenge of prioritizing among fish stocks, which invariably favors some fishing fleets or countries at the expense of others.

We have evaluated the impact of considering these issues for Northeast Atlantic fisheries (FAO area 27 (*1*), which account for about 9 million t of catch annually, i.e. 11% of global capture fisheries in landed weight. The annual catch increased in the 1950s and 1960s to reach a maximum of 15 million t in the mid-1970s. decreasing to 12 million t in the 1990s, and later to 9 million t as fishing pressure was reduced (Figure 1). Fisheries and fish stocks in this area are, globally, among the most well-monitored. We focused on the 53 most data-rich and important fish stocks in the area (representing an annual catch of around 6 million t over the past 25 years). We did not include short lived, forage fish in these analyses, as F_{MSY} is not used in their management in the Northeast Atlantic. We applied five approaches to estimate F_{MSY} for each of the 53 fish stocks, building on estimates of F_{MSY} from ICES stock assessments: A) the well-established surplus production models (*7*), using time-series of catch and stock biomass from stock assessments (*2*), B) extraction of F_{MSY} from the literature on ecosystem and multispecies analysis, C) direct calculations based on sub-models for density dependence of growth, reproduction and cannibalism, D) the "great experiment" where fishing pressure on the demersal stocks in the Northeast Atlantic slowly increased, and catches initially increased but then decreased as fishing pressure crossed the boundary to overfishing (*8*), and E) generalized linear regression linking F_{MSY} from A)–C) to life history parameters (see supplementary information). Surplus production models are often used in data poor situations, but we here use them with abundant stock assessment data and find them especially useful because they implicitly include all density dependent effects.

Figure 1: Catch and fishing pressure in the Northeast Atlantic



Note: Average fishing (5 years running means) for 53 data rich Northeast Atlantic fish stocks (see supplementary information). Until 2017 the values are historic values based on actual catches (2). From 2018 and onwards it is forecasts. The "Currently planned fishing pressure¬" curve is the development forecasted if the current FMSY¬ values are used in management, and the "Suggested fishing pressure" curve is the forecasted fishing pressure if the new F_{MSY} values suggested in the present study, are used.

Source: FAO area 27. From ICES database (http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx) except unreported catch (discards and IUU catch) which is from the "Sea Around Us"- database (http://www.seaaroundus.org/).

The F_{MSY} estimates have been developed so that they can be used directly in the annual assessment and advisory process to guide managers (see supplementary information). The new F_{MSY} (9) values are substantially higher (average equal to 0.38 yr-1) than the current F_{MSY} values (average equal to 0.26 yr-1) used by management (2). This corresponds to an almost 50% increase in fishing pressure. The average fishing pressure corresponding to the new F_{MSY} is equal to that of the 1950s and early 1960s, and about 30% lower than in the overfished 1980s–2000s (Figure 1).

The scientific evidence is accumulating that aiming for multispecies MSY in a marine ecosystem involves fishing higher trophic levels at higher rates than F_{MSY}, because the foregone catch from higher trophic levels will be more than compensated by increases in catches from lower trophic levels (10–12). Overfishing the predators, however, results in predator biomass declines below the lower biomass limits for management (Blim), and is rarely acceptable to management and the public, or in line with biodiversity goals (13). The suggested increases in fishing pressure will increase the risk of stocks falling below Blim. However, the application of the suggested increases in

F_{MSY} should be based on a case-by-case evaluation of the risk to remain below acceptable levels – in the Northeast Atlantic this is typically considered to be a 5% chance of falling below Blim (2). It may be added that the risk of forage fish stocks falling below Blim will decrease because of the reductions in predation mortality and food competition with other stocks.

The proposed approach does not include the interaction between predators and forage fish. The ecosystem-wide average F_{MSY} is therefore likely to be higher than our suggested values because higher F_{MSY} on the predators result in lower stock sizes and predation intensity, and thus higher survival of forage fish. We conclude that managing the Northeast Atlantic fisheries using the new F_{MSY} values will increase the sustainable catches by several million t per year compared with a management based on the current F_{MSY} values.

We suggest that in order to make an improvement here and now, instead of waiting maybe decades for managers to set priorities between the various objectives, a pragmatic method like the proposed one, presents a simple solution based on available science.

2. Supplementary Materials

2.1 Materials and Methods

The aim of the current study is to come up with unbiased estimates of the fisheries management reference point F_{MSY}. The stocks included in the present study are the so-called data rich stocks named by ICES as "category 1" stocks (2). The list of analysed stocks is given in Table 1.

Some of the ICES category 1 stocks were found unfit for the methodology and analysis used in the present study and they were excluded. The excluded stocks are: a) short lived, forage fish like sandeel, capelin and Norway pout, because they have a management control rule where F_{MSY} is not relevant, b) ill-defined stock units where separation between neighboring stocks are very uncertain, c) stocks with relative and not absolute fishing mortality (F) estimates, d) all shellfish and elasmobranch stocks as they have very different population dynamics from ordinary teleost fish species, e) stocks where most of the catch data are estimated rather than sampled by e.g. sales slips, and f) stocks which historically have had fishing mortality much lower than natural mortality in most years and therefore have a stock size development over time that is more based on natural variability than on fishing pressure. The excluded ICES category 1 stocks are given in Table 2 along with reasons for their exclusion.

2.1.1 *Froese et al. (14) estimation of F/F_{MSY} in combination with ICES F time series*

Froese *et al.* (*14*) calculated the ratio F/F_{MSY} by year for all stocks in the Northeast Atlantic. F_{MSY} was fixed over the years for each stock. For the stocks in Table 1 they used the catch and spawning stock biomass (SSB) time series (corrected to exploitable biomass by a so-called catchability factor estimated as part of the modelling process) from ICES routine assessments and an ordinary Surplus Production Model (SPM) of the Schaefer (*15*) type:

$$B_{t+1} = B_t + r\left(1 - \frac{B_t}{k}\right)B_t - C_t$$

where B_{t+1} is the exploited biomass in the subsequent year t+1, B_t is the current biomass, r is the maximum intrinsic rate of population increase, k carrying capacity and C_t is the catch in year t. To account for depensation or reduced recruitment at severely depleted stock sizes, such as predicted by all common stock–recruitment functions, a linear decline of surplus production was incorporated if biomass fell below ¼ k:

$$B_t = B_t + 4\frac{B_t}{k}r\left(1-\frac{B_t}{k}\right)B_t - C_t|\frac{B_t}{k} < 0.25$$

The term 4 B_t/k assumes a linear decline of recruitment below half of the biomass that on average produce MSY, as MSY is equal to ½ k in the Schaefer type SPMs.

For a year where $F/F_{MSY} = 1$, the fishing pressure that year obviously is equal to F_{MSY}. From the ICES time series of F we know the value of F that year, and this F value must then be F_{MSY} in the ICES "currency" of F, which is a mean over some age groups and based on numbers rather than biomass. Of course for all the other years where F/F_{MSY} is not equal to 1, we can still obtain an estimate of F_{MSY} in the a similar way, say if F/F_{MSY} in a given year is 1/1.3, F_{MSY} in the ICES F-"currency" must then be 1.3 times the F value from the ICES time series for that year. Thus, for all years we get an F_{MSY} estimate in the ICES F-"currency" and these should ideally give the same F_{MSY} value. They often differ slightly due to different basic model structures between ICES models and the SPMs. We use the mean of the estimates of F_{MSY} for 2000–2012 as the final F_{MSY} estimate from this method.

2.1.2 SPM based on the approach in RAM Legacy Stock Assessment Data Base

The RAM Legacy Stock Assessment Database is a compilation of stock assessment time series for commercially exploited marine populations from around the Globe (*16*). They use SPMs in an approach to estimate F_{MSY}/F like in (*14*), but differ in the way they look at the annual surplus production (SPt_obs) observed in a given year, t. They take annual surplus production as the sum of the change in stock biomass (B) and the catch (C):

$$SP_{t\_obs} = B_t - B_{t-1} + C_t$$

They also calculate the predicted annual surplus production SP_{t_pred} based on (*16*):

$$SP_{t\_pred} = \left[\left(\frac{\varphi}{\varphi-1}\right)\cdot B_t \cdot ER_{MSY}\right] - \left[\frac{ER_{MSY}\cdot {B_t}^{\varphi}}{(\varphi-1)\cdot {B_{MSY}}^{(\varphi-1)}}\right]$$

where φ is the shape parameter for the production curve. When $\varphi = 2$, it is the Schaefer curve, $\varphi = 1$ is the Fox curve, and $\varphi = 1.763$ it is the mean in a meta-analysis by (*17*) of 141 stocks. ER_{MSY} is exploitation rate, i.e. catch biomass divided by stock biomass.

In the analysis it is important that the stock biomass metric is the relevant one for SPMs, i.e. exploitable biomass. Often in fish stock assessment data the biomass metric is different from exploitable biomass, being e.g. SSB. A conversion from SSB to exploitable biomass was performed by a GLM analysis linking the ratio of exploitable biomass to SSB to life history parameters (*16*).

A robustness analysis was performed regarding which of several alternative SPM that performed best and the Schaeffer model (φ =2), the "general Thorson et al 2012" model (φ = 1.736) and the "taxa based Thorson et al 2012" model (Pleuronectiformes φ = 1.406, Gadiformes φ = 2.027, Perciformes φ = 0.799, Clupeiformes φ = 1.427, Scorpaeniformes φ =3.377, Other φ = 1.026) came out as the three best models and were used in the present study. See www.fmsyproject.net for details.

A filtering of stocks was performed before the analysis was conducted. The criteria used for inclusion were: a) more positive than negative SPs in the middle quartiles of B; b) sum of SPs in the middle quartiles of B > 0; c) $ER_{MSY} > 0.005$; d) $ER_{MSY} < 0.9$; e) $B_{MSY} > 0.05 * B_{max\ observed}$; f) $2 * B_{max\ observed} > B_{MSY}$; g) timeseries longer than 25 years, and h) SP model fit is better (lower AIC value) than a linear fit SP = m*B +b. Of the stocks in Table 1 five stocks failed due to the time series length and two stocks failed due to the other criteria. The observed annual production against exploitable biomass for the stocks (normalized to MSY and k respectively, from the "general Thorson et al 2012 model") that passed the filter are shown in Figure 2. Here the variation of the individual year's production is obvious, but it is also obvious that there is a clear pattern consistent with the classic surplus production model curves.

The outcome of this analysis was the ratio F/F_{MSY} for each stock and year in the timeseries and this ratio was linked to ICES time series of F to obtain F_{MSY} in the ICES F-"currency", as described above. We used the mean of the estimates of F_{MSY} for 2000–2012 as the final F_{MSY} estimate from this method.

2.1.3 Literature F_{MSY} estimates from Multispecies and ecosystem models

We extract F_{MSY} estimates from peer reviewed publications of well-established multispecies and ecosystem modelling. We focused on models that many scientists have worked on for several years and where the results have stood the test of time. From these models we selected the analysis where the balance in terms of stock biomass composition across species have been like what they are at present and scenarios where fishing pressure have been varied up or down simultaneously across stocks. This was done in order to mimic the current management approach with harvest control rules (HCR) that secures that all stocks are kept at healthy stocks sizes defined as capable to produce un-impaired recruitment (*2*). We did not consider the Barents Sea ecosystem, because the main part of the multispecies interaction is covered already in the way the current F_{MSY} used in management are calculated (*2*). The references to which publications are used, can be found in Table 4 for individual stocks.

2.1.4 Dynamic Pool models

Dynamic pool models account for variable growth, sexual maturation, natural mortality, and recruitment in terms of density dependence and is based on number of individuals in the stock rather than biomass and where age groups are treated separately rather than lumped together (*18*). This is the most often used approach by ICES, except that density dependence in growth, maturation and mortality usually are missing. Here, we include density dependence in these factors.

Stochastic projections of an age structured dynamic pool population model were done using the software PROST (*19*) based on Java. PROST has been used by ICES for the Northeast Arctic cod stock (*20*) to obtain the currently used F_{MSY} values in the annual assessment and advice to management. PROST can be used for any stock to make single-species, single-fleet, single-area projections, incorporating density dependence in recruitment, growth, mortality, and maturity. This method was used in the present study for North Sea cod and Northeast Atlantic mackerel. Input data are provided in www.fmsyproject.org.

The model NE_PROST from (*21*) has the same basic functionalities as PROST but is based Excel and Visual Basic. This model was used for Northeast Arctic cod and cod at Icelandic grounds in the current study. Input data are from (*21*) for Northeast Arctic cod. For cod at Icelandic grounds, input data are from (*22*), and a) B_{lim} was set to 207,000t based on a segmented regression analysis ("Hockey stick" model), b) B_{pa} set to 330,000t, c) density dependent growth based on (*23*), d) cannibalism set as for the Barents Sea cod 1970–1985, based on (*21, 24, 25*). Input data are provided in www.fmsyproject.net (*26*) used a tailor-made code in VisualBasic to obtain dynamic pool model estimates of F_{MSY} by density dependent growth and predation mortality for Baltic sprat. Cod is by far the most important predator on sprat in the Baltic Sea and the cod stock biomass was assumed constant at various levels between 100 kt and 600 kt. The predation mortality is then only dependent on the biomass of sprat for each level of cod biomass and there is a small negative relationship between predation mortality (not cannibalism here but cod predation) and sprat biomass, when the cod biomass is kept constant. We used a cod biomass value of 200 kt to represent the present stock situation, unlikely to be much changed within the coming say 5 years. If the cod stock is rebuilding some time into the future, this choice of cod biomass will need to be revised. The cod stock biomass has previously been over 600 kt.

In all the above model runs ICES defaults HCR has been applied, with the biomass trigger points at the values from (*2*) or if these were missing, at B_{pa} which also can be found in (*2*).

2.1.5 F_{MSY} and life history parameters

F_{MSY} has often been linked to life history parameters such as natural mortality and growth rate. We used General Linear Models (GLM) coded in R, for the purpose. We tested a set of relevant life history parameters (age at 50% maturity - "a50mat", natural mortality of mature fish - "natM", L infinity times K from the von Bertalanffy growth models - "Linf_K", preferred temperature -"prefT", trophic level of adult fish - "troph") against the F_{MSY} values obtained from the methods mentioned above. The parameter values were based on ICES current input data to fish stocks assessments (*2*) supplemented with data from Fishbase (*28*). We tested a few relevant groupings of species and found that a 5-category grouping of species "taxg3" (cod and hake, other gadoids, flatfish, herring and sprat, and others) worked well with the model. Only a few parameters can be included in the model because we only have 53 F_{MSY} "observations". We tested several relevant GLM models (see www.fmsyproject.net for detailed information). Across most of the models, we found a) a positive influence on F_{MSY} of "natM" and to a lesser degree, of "Linf_K"; b) a negative influence on F_{MSY} of "a50mat" and to a lesser degree, of "prefT"; and c) "troph" was correlated with both "a50mat" and “Linf_K” and did not add much to the model when both of these were included. “Linf_K” was preferred to “natM” because it is easier to estimate with good precision for most stocks. The final GLM model used were:

$$\log(F_{MSY}) \sim \log(a50mat) + \log(Linf_K) + taxg3$$

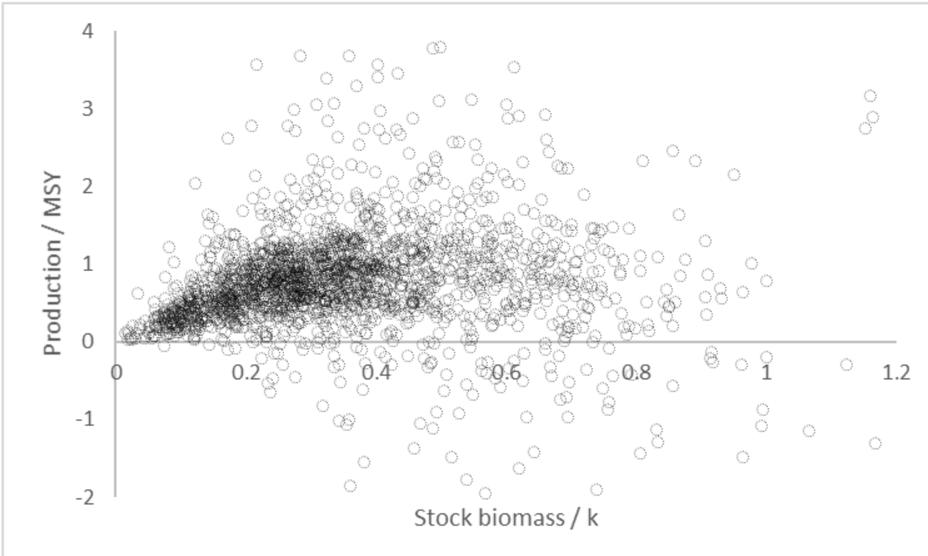
The model explained 59% of the variation in the F_{MSY} values. A model without taxg3 was almost as good explaining 46% of the variation and had only 2 parameters. However, the AIC and AICc were better for the 6 parameters model. Diagnostics from the run can be found in Figure 4. Linf_K is not significant at the 5% level but leaving it out gave worse AIC and AICc scores and the above mentioned 2 parameter model gave highly significant effects of both Linf_K and a50mat, indicating it is an influential parameter.

The above GLM models were done on F_{MSY} estimates obtained as the mean by stock from the SPMs, ecosystem, multi-species, or dynamic pool models, (column “i” in Table 3). We used the predicted values of F_{MSY} from this GLM modelling (column “j” in Table 3) as the final set of best estimates of F_{MSY} to use in management of the individual fish stocks. However, for those 9 stocks where ecosystem, multi-species, or dynamic pool models were also available, we used a mean of column “i” and “j” in order to put more weight on the non-GLM estimates of F_{MSY} for these stocks due to the availability of extra information from the ecosystem, multi-species, or dynamic pool models.

2.1.6 Combining the analysis

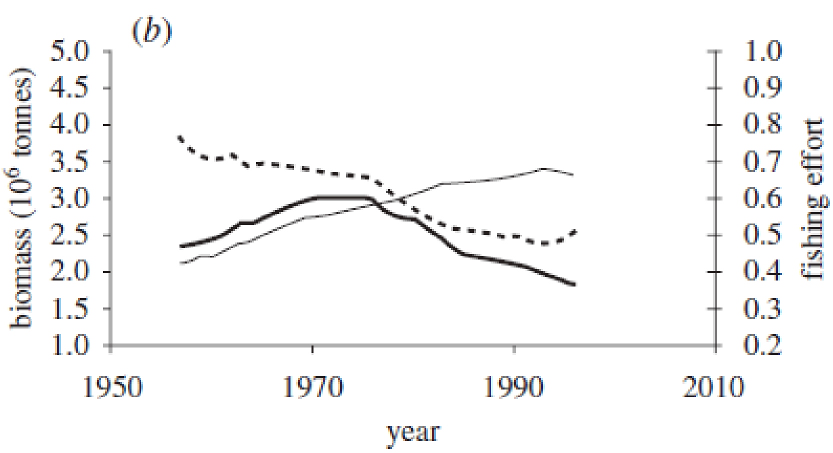
The results of the above approaches are given in Table (3). The final set of F_{MSY} values is in column “j” in Table (3) and the mean values is 0.38. This compares to 0.26 as a mean of the currently used F_{MSY} values (column “a” in Table 3) in management (2). Thus, including ecosystem functioning in terms of density dependent growth, maturity and cannibalism results in estimating F_{MSY} to be almost 50% higher than the current F_{MSY} values used in management. There are, however, quite some variation between stocks and for 5 stocks the new F_{MSY} are lower than the current F_{MSY} value, for 19 stocks the new F_{MSY} values is between 1 to 1.49 times current F_{MSY} value, for 17 stocks between 1.5 and 1.99 times the current F_{MSY} value, and for 7 stocks it is more than 2.0 times the current F_{MSY} value.

Figure 2: Stock production vs. stock biomass



Note: Stock production vs. stock biomass, normalized to MSY and k (carrying capacity) respectively, for 53 data rich stocks except those 7 stocks filtered out in the RAM Legacy Stock Assessment Data Base analysis. For clarity, 17 out of 1901 data pairs were not included because they were outside the intervals on the axis but were quite evenly spread around the general pattern (approximately a parabola with a top point at [0.5,1] and going through [0.0] and [1.0]). The "general Thorson et al 2012" model (ϕ = 1.736) was used to get MSY and k by stock.

Figure 3: The "Great" Experiment



Note: Catch (thick line) vs. mean F (thin line) for 28 data rich groundfish stocks in the Northeast Atlantic by year. F gradually increased over the time considered and the catch followed the increasing path to start with, but then around the mid-1970s took a decreasing path, indicating that the F_{MSY} point had been surpassed. Stock biomass (spawning) is also shown (punctuated line). From (8, where F is called "fishing effort").

Table 1: Stocks considered in the present study

#	Stock name short	Stock full name
1	reb.27.1-2	Beaked redfish (*Sebastes mentella*) in subareas 1 and 2 (Northeast Arctic)
2	bli.27.5b67	Blue ling (*Molva dypterygia*) in subareas 6–7 and Division 5.b (Celtic Seas, English Channel, and Faroes grounds)
3	whb.27.1-91214	Blue whiting (*Micromesistius poutassou*) in subareas 1–9, 12, and 14 (Northeast Atlantic and adjacent waters)
4	cod.27.5a 1	Cod (*Gadus morhua*) in Division 5.a (Iceland grounds)
5	cod.27.7a	Cod (*Gadus morhua*) in Division 7.a (Irish Sea)
6	cod.27.7e-k	Cod (*Gadus morhua*) in divisions 7.e-k (eastern English Channel and southern Celtic Seas)
7	cod.27.47d20	Cod (*Gadus morhua*) in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, eastern English Channel, Skagerrak)
8	cod.27.1-2	Cod (*Gadus morhua*) in subareas 1 and 2 (Northeast Arctic)
9	cod.27.5b1	Cod (*Gadus morhua*) in Subdivision 5.b.1 (Faroe Plateau)
10	cod.27.22-24	Cod (*Gadus morhua*) in subdivisions 22–24, western Baltic stock
11	ldb.27.8c9a	Four-spot megrim (*Lepidorhombus boscii*) in divisions 8.c and 9.a (southern Bay of Biscay and Atlantic Iberian waters East)
12	reg.27.1-2	Golden redfish (*Sebastes norvegicus*) in subareas 1 and 2 (Northeast Arctic)
13	reg.27.561214	Golden redfish (*Sebastes norvegicus*) in subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)
14	had.27.5a	Haddock (*Melanogrammus aeglefinus*) in Division 5.a (Iceland grounds)
15	had.27.5b	Haddock (*Melanogrammus aeglefinus*) in Division 5.b (Faroes grounds)
16	had.27.6b	Haddock (*Melanogrammus aeglefinus*) in Division 6.b (Rockall)
17	had.27.7a	Haddock (*Melanogrammus aeglefinus*) in Division 7.a (Irish Sea)
18	had.27.7b-k	Haddock (*Melanogrammus aeglefinus*) in divisions 7.b-k (southern Celtic Seas and English Channel)
19	had.27.46a20	Haddock (*Melanogrammus aeglefinus*) in Subarea 4, Division 6.a, and Subdivision 20 (North Sea, West of Scotland, Skagerrak)
20	had.27.1-2	Haddock (*Melanogrammus aeglefinus*) in subareas 1 and 2 (Northeast Arctic)
21	hke.27.8c9a	Hake (*Merluccius merluccius*) in divisions 8.c and 9.a, Southern stock (Cantabrian Sea and Atlantic Iberian waters)
22	hke.27.3a46-8abd	Hake (*Merluccius merluccius*) in subareas 4, 6, and 7, and divisions 3.a, 8.a-b, and 8.d, Northern stock (Greater North Sea, Celtic Seas, and the northern Bay of Biscay)
23	her.27.5a	Herring (*Clupea harengus*) in Division 5.a, summer-spawning herring (Iceland grounds)
24	her.27.nirs	Herring (*Clupea harengus*) in Division 7.a North of 52°30′N (Irish Sea)
25	her.27.irls	Herring (*Clupea harengus*) in divisions 7.a South of 52°30′N, 7.g-h, and 7.j-k (Irish Sea, Celtic Sea, and southwest of Ireland)
26	her.27.3a47d	Herring (*Clupea harengus*) in Subarea 4 and divisions 3.a and 7.d, autumn spawners (North Sea, Skagerrak and Kattegat, eastern English Channel)
27	her.27.1-24a514a	Herring (*Clupea harengus*) in subareas 1, 2, 5 and divisions 4.a and 14.a, Norwegian spring-spawning herring (the Northeast Atlantic and Arctic Ocean)
28	her.27.28	Herring (*Clupea harengus*) in Subdivision 28.1 (Gulf of Riga)
29	her.27.20-24	Herring (*Clupea harengus*) in subdivisions 20–24, spring spawners (Skagerrak, Kattegat, and western Baltic)
30	her.27.25-2932	Herring (*Clupea harengus*) in subdivisions 25–29 and 32, excluding the Gulf of Riga (central Baltic Sea)
31	her.27.3031	Herring (*Clupea harengus*) in subdivisions 30 and 31 (Gulf of Bothnia)
32	lin.27.5a	Ling (*Molva molva*) in Division 5.a (Iceland grounds)
33	mac.27.nea	Mackerel (*Scomber scombrus*) in subareas 1–8 and 14 and Division 9.a (the Northeast Atlantic and adjacent waters)
34	meg.27.7b-k8abd	Megrim (*Lepidorhombus whiffiagonis*) in divisions 7.b-k, 8.a-b, and 8.d (west and southwest of Ireland, Bay of Biscay)
35	meg.27.8c9a	Megrim (*Lepidorhombus whiffiagonis*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)
36	ple.27.7a	Plaice (*Pleuronectes platessa*) in Division 7.a (Irish Sea)
37	ple.27.7d	Plaice (*Pleuronectes platessa*) in Division 7.d (eastern English Channel)
38	ple.27.420	Plaice (*Pleuronectes platessa*) in Subarea 4 (North Sea) and Subdivision 20 (Skagerrak)
39	ple.27.21-23	Plaice (*Pleuronectes platessa*) in subdivisions 21–23 (Kattegat, Belt Seas, and the Sound)
40	pok.27.5a	Saithe (*Pollachius virens*) in Division 5.a (Iceland grounds)
41	pok.27.5b	Saithe (*Pollachius virens*) in Division 5.b (Faroes grounds)
42	pok.27.1-2	Saithe (*Pollachius virens*) in subareas 1 and 2 (Northeast Arctic)
43	pok.27.3a46	Saithe (*Pollachius virens*) in subareas 4, 6 and Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)
44	sol.27.7a 1.2	Sole (*Solea solea*) in Division 7.a (Irish Sea)
45	sol.27.7d	Sole (Solea solea) in Division 7.d (eastern English Channel)

#	Stock name short	Stock full name
46	sol.27.7e	Sole (*Solea solea*) in Division 7.e (western English Channel)
47	sol.27.7fg	Sole (*Solea solea*) in divisions 7.f and 7.g (Bristol Channel, Celtic Sea)
48	sol.27.8ab	Sole (*Solea solea*) in divisions 8.a-b (northern and central Bay of Biscay)
49	sol.27.4	Sole (*Solea solea*) in Subarea 4 (North Sea)
50	sol.27.20-24	Sole (*Solea solea*) in subdivisions 20–24 (Skagerrak and Kattegat, western Baltic Sea)
51	spr.27.22-32	Sprat (*Sprattus sprattus*) in subdivisions 22-32 (Baltic Sea)
52	mon.27.78abd	White anglerfish (*Lophius piscatorius*) in Subarea 7 and divisions 8.a-b and 8.d (Celtic Seas, Bay of Biscay)
53	mon.27.8c9a	White anglerfish (*Lophius piscatorius*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)

Table 2: Stocks of ICES category 1, excluded from the present study

Stocks	Reasons for exclusion from the present analysis
All sandeel , capelin and Norway pout stocks, and sprat in the North Sea	Short lived stocks managed by an escapement target approach, where F_{MSY} is not used.
Sardine and anchovy	Forage fish, even as adults.
Whiting	Stock definitions in general uncertain. For the largest stock – the North Sea stock – very precise RV survey indices, but for large parts of the time series in substantial conflict with the VPA type stock trends. Uncertainties about the amount of industrial catches for fish meal and oil, historically.
Greenland halibut (*Reinhardtius hippoglossoides*) in subareas 5. 6. 12. and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)	Only relative Fs in the assessment.
Spurdog	The present project does not deal with elasmobranchs. They have life history parameters very different from teleost fish species, e.g. an extremely low fecundity compared to teleost fish species.
Tusk	Only relative F used in assessment – therefore not relevant with an absolute F_{MSY}.
Black-bellied anglerfish (*Lophius budegassa*) in divisions 8.c and 9.a (Cantabrian Sea, Atlantic Iberian waters)	Only relative F used in assessment – therefore not relevant with an absolute F_{MSY}.
Megrim (*Lepidorhombus* spp.) in divisions 4.a and 6.a (northern North Sea, West of Scotland)	Only relative F used in assessment – therefore not relevant with an absolute F_{MSY}.
Cod (*Gadus morhua*) in Division 6.a (West of Scotland)	Recent catch estimates used in the assessment are adjusted to account for area misreporting and include estimates of discards. These two components account for approximately 80% of the total catch in recent years. No biological sampling is available from the misreported component of the landings. In addition, the total catches of cod from pots and traps are unknown. In the past (between 1991 and 2005), catches were considered unreliable and are estimated within the assessment.
Cod (*Gadus morhua*) in NAFO Subarea 1. inshore (West Greenland cod) and Cod (*Gadus morhua*) in ICES Subarea 14 and NAFO Division 1.F (East Greenland. South Greenland)	2018 is first year of an analytical assessment which seem not to have stabilized yet. The population dynamics of these stocks are furthermore very temperature dependent being at the border of what cod can tolerate of cold water.
Herring (*Clupea harengus*) in divisions 6.a and 7.b–c (West of Scotland. West of Ireland)	A very depleted stock where even very low Fs for many years seems not to be able to rebuild the stock or stocks because it is supposed to consist of more than one stock.
All *Nephrop* stocks	These are shellfish and have very different population dynamics, not considered in the present study.
Horse mackerel (*Trachurus trachurus*) in Subarea 8 and divisions 2.a, 4.a, 5.b, 6.a, 7.a–c,e-k (the Northeast Atlantic)	Too dominated by spasmodic recruitment.
Horse mackerel (*Trachurus trachurus*) in Division 9.a (Atlantic Iberian waters)	F is lower than half of the natural mortality in most of the time series.

Stocks	Reasons for exclusion from the present analysis
Seabass (*Dicentrarchus labrax*) in divisions 4.b–c, 7.a, and 7.d–h (central and southern North Sea, Irish Sea, English Channel, Bristol Channel, and Celtic Sea)	A large part of the catch estimated. According to ICES Advise 2018: "Poor catch data quality, owing to limited sampling of the discards and recreational removals, leads to additional uncertainty in the assessment. The discard values are estimated from sampling programmes where sampling is variable across fleets and years. Anecdotal information suggests that total discards could be considerably underestimated."

Figure 4: Diagnostics of the GLM model used to link life history parameters to F_{MSY}

```
Call:
glm(formula = fmsy ~ factor(taxg3) + linf_k + a50mat, data = Datalogx)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.71388  -0.19248  -0.00189   0.25372   0.65794

Coefficients:
                           Estimate Std. Error t value Pr(>|t|)
(Intercept)                 -0.3807     0.3881  -0.981 0.331814
factor(taxg3)flatfish       -0.6295     0.1906  -3.302 0.001862 **
factor(taxg3)forage fish    -0.7003     0.1880  -3.724 0.000534 ***
factor(taxg3)other gadoids  -0.3984     0.1513  -2.634 0.011465 *
factor(taxg3)other_tax      -0.5154     0.2258  -2.283 0.027125 *
linf_k                       0.2091     0.1145   1.826 0.074375 .
a50mat                      -0.5800     0.1125  -5.156  5.2e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.1143869)

    Null deviance: 12.7648  on 52  degrees of freedom
Residual deviance:  5.2618  on 46  degrees of freedom
AIC: 43.987
```

Table 3: Estimates of F_{MSY} by stock and method

		Fmsy									
		ICES 2018	Froese et al. SPM (2016)	RAM Legacy Data-base Schaefer	RAM Legacy Data-base Thorson Taxo-nomic	RAM Legacy Data-base Thorson general	Eco-system model	Dynamic pool models, e.g. PROST	Average of b, average(c-e), f and g	GLM of h, based on life history para-meters	Final recommended Fmsy values - column i unless there are ecosystem or dynamic pool estimates then a mean of column h and i
#	Stock name short	a	b	c	d	e	f	g	h	i	j
1	reb.27.1-2	N/A	0.06	0.14	0.20	0.15	N/A	N/A	0.11	0.13	0.13
2	bli.27.5b67	0.12	0.11	N/A	N/A	N/A	N/A	N/A	0.11	0.22	0.22
3	whb.27.1-91214	0.32	0.37	0.31	N/A	0.28	N/A	N/A	0.33	0.44	0.44
4	cod.27.5a 1	N/A	0.63	0.45	0.39	0.44	N/A	0.70	0.59	0.43	0.51
5	cod.27.7a	0.44	0.95	0.75	N/A	0.66	N/A	N/A	0.83	0.76	0.76
6	cod.27.7e-k	0.35	0.56	0.51	N/A	0.47	N/A	N/A	0.52	0.63	0.63
7	cod.27.47d20	0.31	0.70	0.73	0.41	0.68	0.87	0.70	0.72	0.71	0.71
8	cod.27.1-2	0.40	0.55	0.51	0.46	0.50	N/A	0.60	0.55	0.38	0.47
9	cod.27.5b1	0.32	0.36	0.57	0.52	0.57	N/A	N/A	0.46	0.60	0.60
10	cod.27.22-24	0.26	0.62	N/A	N/A	N/A	N/A	N/A	0.62	0.51	0.51
11	ldb.27.8c9a	0.193	0.33	0.33	0.24	0.32	N/A	N/A	0.31	0.44	0.44
12	reg.27.1-2	0.0525	0.10	N/A	N/A	N/A	N/A	N/A	0.10	0.14	0.14
13	reg.27.561214	0.097	0.14	0.11	0.08	0.10	N/A	N/A	0.12	0.14	0.14
14	had.27.5a	v	0.47	0.33	N/A	0.31	N/A	N/A	0.40	0.38	0.38
15	had.27.5b	0.165	0.28	0.39	0.36	0.39	N/A	N/A	0.33	0.46	0.46
16	had.27.6b	0.20	0.31	N/A	N/A	N/A	N/A	N/A	0.31	0.39	0.39
17	had.27.7a	0.27	0.41	N/A	N/A	N/A	N/A	N/A	0.41	0.43	0.43
18	had.27.7b-k	0.40	0.87	N/A	N/A	N/A	N/A	N/A	0.87	0.67	0.67
19	had.27.46a20	0.19	N/A	0.47	0.71	0.51	0.58	N/A	0.57	0.35	0.46
20	had.27.1-2	0.35	0.43	0.30	0.24	0.29	N/A	N/A	0.35	0.26	0.26
21	hke.27.8c9a	0.25	0.59	0.51	0.43	0.50	N/A	N/A	0.54	0.65	0.65
22	hke.27.3a46-8abd	0.28	0.82	0.42	0.28	0.40	N/A	N/A	0.59	0.64	0.64
23	her.27.5a	0.22	0.23	0.25	0.29	0.26	N/A	N/A	0.25	0.28	0.28
24	her.27.nirs	0.27	0.43	0.57	0.66	0.58	N/A	N/A	0.52	0.32	0.32
25	her.27.irls	0.26	0.34	0.30	0.41	0.32	N/A	N/A	0.34	0.40	0.40
26	her.27.3a47d	0.26	0.58	0.23	0.29	0.24	0.50	N/A	0.45	0.32	0.38
27	her.27.1-24a514a	0.157	N/A	0.16	0.13	0.16	N/A	N/A	0.15	0.23	0.23
28	her.27.28	0.32	0.34	0.53	0.52	0.53	N/A	N/A	0.43	0.31	0.31
29	her.27.20-24	0.31	0.33	0.29	N/A	0.27	N/A	N/A	0.30	0.30	0.30
30	her.27.25-2932	0.22	0.21	0.18	0.15	0.18	0.35	N/A	0.24	0.25	0.25
31	her.27.3031	0.21	N/A	0.19	0.17	0.19	N/A	N/A	0.19	0.30	0.30
32	lin.27.5a	0.286	0.34	0.43	N/A	N/A	N/A	N/A	0.39	0.32	0.32
33	mac.27.nea	0.21	0.36	0.37	0.39	0.37	N/A	0.40	0.38	0.39	0.39
34	meg.27.7b-k8abd	0.191	0.37	0.35	0.34	0.35	N/A	N/A	0.36	0.33	0.33

		Fmsy									
		ICES 2018	Froese et al. SPM (2016)	RAM Legacy Data-base Schaefer	RAM Legacy Data-base Thorson Taxo-nomic	RAM Legacy Data-base Thorson general	Eco-system model	Dynamic pool models, e.g. PROST	Avera ge of b, averag e(c-e), f and g	GLM of h, based on life history para-meters	Final recommended Fmsy values - column i unless there are ecosystem or dynamic pool estimates then a mean of column h and i
#	Stock name short	a	b	c	d	e	f	g	h	i	j
35	meg.27.8c9a	0.191	0.15	0.18	N/A	N/A	N/A	N/A	0.17	0.34	0.34
36	ple.27.7a	0.169	0.21	0.42	0.57	0.45	N/A	N/A	0.35	0.29	0.29
37	ple.27.7d	0.25	0.27	N/A	N/A	N/A	N/A	N/A	0.27	0.29	0.29
38	ple.27.420	0.21	0.47	0.36	0.30	0.35	N/A	N/A	0.40	0.35	0.35
39	ple.27.21-23	0.37	0.55	N/A	N/A	N/A	N/A	N/A	0.55	0.28	0.28
40	pok.27.5a	N/A	0.31	0.19	v	0.17	N/A	N/A	0.25	0.31	0.31
41	pok.27.5b	0.30	0.37	0.34	0.25	0.32	N/A	N/A	0.34	0.34	0.34
42	pok.27.1-2	N/A	0.49	0.32	0.30	0.32	N/A	N/A	0.40	0.32	0.32
43	pok.27.3a46	0.36	0.54	N/A	N/A	N/A	0.33	N/A	0.44	0.33	0.38
44	sol.27.7a 1.2	0.20	0.18	0.27	0.17	0.26	N/A	N/A	0.21	0.36	0.36
45	sol.27.7d	0.256	0.48	0.63	N/A	0.68	N/A	N/A	0.57	0.34	0.34
46	sol.27.7e	0.29	0.26	0.21	N/A	0.20	N/A	N/A	0.23	0.33	0.33
47	sol.27.7fg	0.27	0.31	0.44	0.60	0.47	N/A	N/A	0.41	0.31	0.31
48	sol.27.8ab	0.33	0.43	0.38	0.27	0.36	N/A	N/A	0.39	0.32	0.32
49	sol.27.4	0.20	0.38	0.40	0.38	0.40	N/A	N/A	0.39	0.32	0.32
50	sol.27.20-24	0.23	0.38	0.28	0.22	0.27	N/A	N/A	0.32	0.32	0.32
51	spr.27.22-32	0.26	0.42	0.30	0.34	0.31	0.40	0.45	0.40	0.38	0.39
52	mon.27.78abd	0.28	0.41	N/A	N/A	N/A	N/A	N/A	0.41	0.30	0.30
53	mon.27.8c9a	0.24	0.63	0.27	0.21	0.26	N/A	N/A	0.44	0.30	0.30

Table 4: Notes on Table 3

Cell	Issue
1b-53b	F_{MSY} from (*14*) translated into the F-unit used by ICES typically the mean F over some core exploited age groups. Based on Froese et al F/F_{MSY} from Surplus production models, divided by ICES actual F values from assessments. Mean values over 2000–2012.
19b	Spasmodic recruitment and difficult for SPM – (*14*) time trend varies too much from the ICES assessment.
19c 19d 19e	Spasmodic recruitment but time series longer than in (*14*) and time trend in SPM in line with ICES assessment, so just OK for SPM.
31b	Assessed as two separate stocks sd 30 and SD31 in 2016 when (*14*) did their analysis but now ICES has combined them to one stock, therfore no value here from (*14*).
32b	F historically too low compared to M and therefore filtered out.
33b	Spasmodic recruitment and thus not suitable for SPM.
27b	A few very large year classes. Exploitation pattern changed at lot over time. A large 0 and 1 group fishery in the 1970s.
7f 19f 26f 42f	Most complete model: Multispecies F_{MSY} (*29*, Figure 4 and Table 2 combined).
30f and 51f	Most complete model: Multispecies F_{MSY} (*30*). The options assuming constant relationship in F between the three stocks cod, herring and sprat (that of 1996).
51g	From (*26*). Effects of multispecies and density-dependent factors on MSY reference points: example of the Baltic Sea sprat. Option with density dependence in growth and mortality, and cod (age 2+) biomass 200 000 t. Cod biomass probably a bit lower the coming 5 years, but the analysis was only sensitive to larger cod biomass.

2.2 Credits

Henrik Sparholt (HS), Bjarte Bogstad (BB), Villy Christensen (VC), Jeremy Collie (JC), Rob van Gemert (RvG), Ray Hilborn (RH), Jan Horbowy (JH), Daniel Howell (DH), Michael Melnychuk (MM), Søren Anker Pedersen (SAP), Claus Reedtz Sparrevohn (CRS), Gunnar Stefansson(GS) and Petur Steingrund (PS).

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Henrik Gislason (HG), John Pope (JP), Mogens Skou (MS), Carl Walters (CW).

Table 5: Credit details

Issue	Contribution
Conceptualization	Lead: HS Supporting: all co-authors, CW, HG, JP
Formal analysis	Equal: HS, MM, RvG, JH Supporting: all co-authors, HG, JP
Funding acquisition	Equal: HS, BB, DH, SAP, CRS
Investigation	Equal: HS, JH, VC, DH, RvG, MM, SAP, GS, CRS, PS, JC Supporting: all co-authors, HG, JP
Methodology	Equal: HS, MM, RvG, VC, DH, GS, JH, JC Supporting: all co-authors, CW, HG, JP
Project administration	Equal: HS, SAP, CRS, BB, DH Supporting: all co-authors
Software	Equal: MM, HS, RvG, VC Supporting: BB, JP
Supervision	Lead: HS Supporting: all co-authors
Validation	Lead: HS Supporting: all co-authors, CW, HG, JP
Visualization	Equal: HS, MM, JH, RvG, SAP, CRS, Supporting: all co-authors
Writing – original draft	Lead: HS Supporting: all co-authors
Writing – review and editing	Lead: HS Supporting: all co-authors, MS

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Sammenfatning

De videnskabelige populationsmodeller der i dag anvendes i fiskeriforvaltningen over det meste af verden, tager generelt ikke højde for interaktionerne mellem økosystemets forskellige komponenter. Det fører til en undervurdering af det fiskeritryk kaldet ”F_{MSY}”, der giver det optimale bæredygtige udbytte kaldet MSY (Maximum Sustainable Yield). Forskningen af marine økosystemmer indikerer, at undervurderingen kan være betydelige, hvilket resulterer i et stort tab af bæredygtigt udbytte. Dette sker på et tidspunkt, hvor den globale befolkning kræver mere mad. Fiskeprodukter er sunde og har et lavt CO_2-fodaftryk i forhold til det animalske protein, der produceres på land. Velforvaltet fiskeri er relevant for hele 10 ud af de 17 FN verdensmål for bæredygtig udvikling for 2030.

Vi foreslår en tilgang, der er enke og videnskabeligt forsvarlig, som fjerner kendte skævheder i den nuværende tilgang. Vi eksemplificerer tilgangen gennem en analyse af fiskebestandene i det nordøstlige Atlanterhav.

Den foreslåede tilgang omfatter tæthedsafhængig vækst, reproduktion og kannibalisme, og er stadig baseret på enkeltarts bestandsvurderinger. Forvalterne behøver derfor ikke at overveje balancen mellem bestandene for at bruge det foreslåede sæt F_{MSY}-værdier. Dermed undgår de udfordringen med at prioritere blandt fiskebestandene, som uvægerligt favoriserer nogle fiskerflåder eller lande på bekostning af andre.

Vi har evalueret virkningen af vores tilgang for fiskeriet i det nordøstlige Atlanterhav (FAO-område 27). Fiskeriet og fiskebestandene i dette område er blandt de mest velmoniterede i verden. Vi fokuserede på de 53 vigtigeste fiskebestande i området. Vi har ikke inkluderet industrifisk som tobis og spærling i disse analyser, da F_{MSY} ikke anvendes i forvaltningen af disse bestande. Vi anvendte fem metoder til at estimere F_{MSY} for hver af de 53 fiskebestande: A) de veletablerede såkaldte ”Surplus Production Models” sammen med tidsserier for fangst og biomasse fra de årlige standard bestandsvurderinger, B) ekstraktion af F_{MSY} fra litteraturen om økosystemanalyser, C) direkte beregninger baseret på sub-modeller for tæthedsafhængig vækst, reproduktion og kannibalisme, D) det "store eksperiment", hvor fiskeripresset på fiskebestandene i det nordøstlige Atlanterhav steg langsomt, og fangsterne steg i første omgang, men faldt derefter, efterhånden som fiskeripresset krydsede grænsen til overfiskning, og E) generaliseret lineær regression, der forbinder F_{MSY} fra A)-C) med livs historiske parametre.

F_{MSY}-estimaterne er blevet udviklet, så de kan anvendes direkte i den årlige rådgivningsproces til at vejlede forvalterne. De nye F_{MSY}-værdier er væsentligt højere (gennemsnit 0,38 per år) end de nuværende F_{MSY}-værdier (gennemsnit 0,26 per år), der anvendes af forvaltningen. Dette svarer til en næsten 50 % stigning i fiskeripresset. Det gennemsnitlige fiskeripres svarende til de nye F_{MSY} værdier er på niveau med fiskeripresset i 1950erne og begyndelsen af 1960erne, og ca. 30 % lavere end i de overfiskede 1980-2000.

Vi konkluderer, at forvaltningen af fiskeriet i det nordøstlige Atlanterhav ved hjælp af de nye F_{MSY} værdier vil øge de bæredygtige fangster med flere millioner t om året sammenlignet med en forvaltning baseret på de nuværende F_{MSY} værdier.

Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen K
www.norden.org

Global fisheries catches can be increased after rebuilding of fish populations

The fish stock assessment models generally do not account for several important ecosystem interactions, leading to an underestimation of the fishing pressure that lead to the maximum sustainable yield (MSY), a central reference points in fisheries management. Ecosystem and multispecies research indicate that it could result in foregone sustainable yield. This is unfortunate because an increasing global population is demanding more food, and because fish products are healthy and have a low carbon footprint compared to most meat produced on land. Well-managed fisheries are relevant for as many as 10 of the 17 United Nations Sustainable Development Goals for 2030.

We propose an approach that is simple and scientifically sound, which removes the known biases in current methodology. We exemplify the approach through an analysis of the fish populations in the Northeast Atlantic Ocean.

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