9.2.3.3 EU, Norway, and the Faroe Islands request to ICES on the management of mackerel (*Scomber scombrus*) in the Northeast Atlantic

Advice summary

ICES advises that the precautionary F_{MSY} range for the Northeast Atlantic (NEA) mackerel is F_{lower} = 0.15 and F_{upper} = 0.24. The range reflects the target F values that are expected to result in high long-term yield deviating at maximum 5% from the maximum sustainable yield (MSY). The range is dependent on implementing an MSY $B_{trigger}$ = 3.0 Mt. Other values of F_{upper} dependent on the choice of MSY $B_{trigger}$ are given in Table 9.2.3.3.1.

Request

The Coastal States are preparing a new long-term management strategy for the stock of mackerel in the North East Atlantic. This strategy would include target fishing mortalities expressed as a range rather than a single reference point.

ICES is requested to provide a plausible range of values around F_{msy} for the mackerel stock in the North East Atlantic, based on the stock biology (including possible density-dependent growth), fishery characteristics and environmental conditions.

ICES is also requested to update other reference points, including $B_{trigger}$, in light of the change from F_{msy} as a single reference point to F_{msy} as a range.

Given the uncertainty in stock level, growth patterns and recruitment, and taking into account the growing time series on tagging information (RFID), ICES is requested to perform the next (intermediate) benchmark in 2017.

The Coastal States would also like to inform ICES that they no longer consider that the existing management plan is appropriate, and that ICES should therefore give its advice based on the following objectives and timelines approach until a new management strategy is in place:

1. *The Parties agree to limit their fishing on the basis of a TAC corresponding to a fishing mortality rate within the range of fishing mortalities defined by ICES as being consistent with fishing at maximum sustainable yield, provided that the SSB at the end of the TAC year is forecast to be above the value of $B_{trigger}$.*
2. *Where the SSB is forecast to be below $B_{trigger}$, but above B_{lim}, the Parties agree to reduce the upper and lower bounds of the range of fishing mortality referred to in paragraph 1 by the proportion of SSB at the start of the TAC year to $B_{trigger}$.*
3. *Every effort shall be made to maintain a minimum level of SSB greater than B_{lim}. Where the SSB at the start of the TAC year is estimated to be below B_{lim} the TAC shall be set at a level corresponding to a fishing mortality rate consistent with the objective of rebuilding the SSB to above B_{lim} the following year. The Parties may also take additional management measures that are deemed necessary in order to achieve this objective.*

Elaboration on the advice

The F_{MSY} ranges [F_{lower}, F_{upper}] are derived under three conditions: (1) to deliver no more than 5% reduction in long-term yield compared with MSY; (2) to be consistent with the ICES precautionary approach F_{upper} is capped, so that the probability of SSB < B_{lim} is no more than 5%; and, as requested (3) the ICES MSY advice rule (AR) is applied throughout this evaluation, implying a linear reduction in F towards zero when SSB is below MSY $B_{trigger}$.

The resulting range estimated for the NEA mackerel, based on current biological characteristics and following the parameterization used in the ICES advice of February 2015 (ICES 2015a), is given in Table 9.2.3.3.1.

ICES provides MSY estimates, taking into account selectivity, recruitment, growth, and natural mortality under recent ecosystem conditions (ICES, 2014a — Section 1.2). Consequently, the advice is based on the recent stock dynamics. Other scenarios are documented in ICES (2015c). Because the long-term dynamics of the stocks are not clear, ICES advises that the F_{MSY} values and ranges provided should be considered applicable for at least the next five years.

The Northeast Atlantic (NEA) mackerel stock is currently characterized by low weight-at-age, late maturity, and early spawning compared to the historical mean. There is no firm scientific basis yet to indicate whether this situation should be considered permanent or transient (either returning to the previous state or continuing to change in the same direction). However, recent scientific publications have indicated that the growth of mackerel could be dependent on a number of factors, including the size of the mackerel stock and the size of the Norwegian spring-spawning herring stock (Jansen and Burns, 2015; Olafsdottir *et al.*, 2015).

Reflecting the uncertainty in the temporal dynamics of the biological characteristics of the NEA mackerel stock, ICES has also evaluated a scenario where the biological characteristics gradually return to the historical mean (ICES, 2015c). It is worth noting that even though the parameterization of this scenario does not assume any relationship between stock size and growth, the consequences in the short term are assumed to be similar to those resulting from density-dependent growth, i.e. a decrease in stock size and an increase in growth rate. This scenario allows for a higher level of fishing mortality, leading to short-term differences in terms of higher yield; however, the difference in long-term yield is expected to be small (+3% with $B_{trigger}$ = 3.0 Mt). To cover a more complete range of potential biological scenarios, an alternative one with a continuing trend in the biological characteristics should also be investigated. This alternative scenario could be envisioned if the changes were caused by an external driver with a continuous trend. ICES acknowledges that simulations with inclusion of such a scenario would help in mapping the uncertainty related to changes in biological characteristics.

Management in a scenario that explicitly assigns the return to faster growth only to the stock size is based on a more demanding assumption than present management. Preliminary simulations indicate that with density-dependent growth taken into account in a management rule, fishing mortality could be slightly (about 10%) higher (ICES, 2015c).

A preliminary comparison of evaluations using 2014 and 2015 assessments shows sensitivity to the assumption on the recruitment model. This did not alter precautionary considerations (the probability of SSB < B_{lim}). The comparison showed an effect on MSY ranges of a magnitude at least similar to the growth changes. A full evaluation of the current stock–recruitment relationship has not been made.

As requested ICES has provided results for a range of alternative $B_{trigger}$ and the corresponding F_{upper} values (Table 9.2.3.3.1). These F_{upper} values are limited by precautionary considerations, and higher fishing mortalities will increase the probability of SSB < B_{lim} to levels > 5%. Increasing $B_{trigger}$ will allow for higher F_{upper}; however, at the same time it will lead to higher variability in yield (ICES, 2015a) as the SSB will be below $B_{trigger}$ in more years (ie. high $B_{trigger}$ values react to increased stock size and deplete these more quickly, taking potential catch earlier at the expense of lower catch later). If SSB is less than $B_{trigger}$ the advised F in that year is reduced, resulting in realized long-term mean Fs being very similar regardless of $B_{trigger}$ and F_{upper} (Table 9.2.3.3.2). F_{upper} values between 0.24 and 0.30, corresponding to $B_{trigger}$ values between 3.0 and 5.0 Mt all result in a long-term realized F of 0.23–0.24.

The differences in the long-term average yield are small (2–3%, Table 9.2.3.3.2), and the gains are only attainable in the short term. Taking into account the current state of the stock (SSB_{2014} = 4.1 Mt), ICES suggests that at the moment there is little to be gained by choosing a $B_{trigger}$ that is much above the current MSY $B_{trigger}$ (3.0 Mt).

Table 9.2.3.3.1 F_{MSY} ranges for NEA mackerel. The F_{lower} and F_{upper} values are derived to deliver no more than 5% reduction in long-term yield compared with F_{MSY}. The approach used conforms to the ICES MSY advice rule (AR), requiring F_{MSY} and F_{upper} to be reduced linearly towards zero when SSB is below MSY $B_{trigger}$. Options for F_{upper} depend on the choice of MSY $B_{trigger}$ and are given in the table; higher F and MSY $B_{trigger}$ values are associated with more variable year-to-year change in catch.

Stock	MSY F_{lower}	F_{MSY}	MSY F_{upper}	MSY $B_{trigger}$
NEA mackerel	0.15	0.22	0.24	3.0 Mt
			0.25	3.2 Mt
			0.26	3.5 Mt
			0.28	4.0 Mt
			0.30	5.0 Mt

Basis of the advice

Background

The work to answer this request is based on the simulations carried out for the Workshop on the NEA Mackerel Long-term Management Plan (ICES, 2015b).

The ICES guidelines to estimate ranges of values of F_{MSY} were established at ICES WKMSYREF3 (ICES, 2014b). For stocks where ICES advice is based on the MSY approach, ICES has developed an advice rule (AR) based on (1) the F_{MSY} fishing mortality reference point that provides the exploitation rate to give catch advice, and (2) a biomass reference point MSY $B_{trigger}$ which is used to linearly reduce F if the biomass in the TAC year is predicted to be lower than this reference value (ICES, 2014b). The ICES MSY AR is evaluated to check that the F_{MSY} and MSY $B_{trigger}$ combination results in maximum long-term yield subject to precautionary considerations, i.e. in the long term there should be an annual probability of less than 5% that SSB < B_{lim}.
To develop suitable F_{MSY} ranges ICES has used the following criteria:

1) MSY is interpreted as maximum long-term average yield from a sustainable stock. This implies variable catch from year to year from a stock above precautionary limits.
2) F refers to the total catch (landings plus discards) for all stocks where catch advice is based on F. For stocks for which catch cannot be estimated and discards are not included in the F, F refers to landings only.
3) F_{MSY} and the ranges F_{upper} and F_{lower} are calculated based on maximizing long-term average yield, where yield is taken to be the catch of fish at lengths above the minimum conservation or catch size (MCS). Where selection at MCS is not known, yield is taken to be the landings, reflecting discard practices in recent years.
4) The F_{MSY} ranges are derived based on yields within 95% of yields at F_{MSY}. The choice of 95% of yield is somewhat arbitrary, but is in line with a "pretty good" yield concept (e.g. Hilborn, 2010) and delivers less than 5% reduction in long-term yield compared with MSY.
5) The values around F_{MSY} are based on recent stock biology, fishery characteristics, and environmental conditions. ICES has applied current growth, maturation, and natural mortality typically based on values from the last ten years used in the stock assessments. Where recent trends have been observed, the ten-year period is reduced to reflect recent conditions (the last three years were used for the NEA mackerel). For simulated recruitment the earliest part of the time-series was not used because of the high uncertainty in the assessment for the period before 1990.
6) The ICES catch advice at F_{MSY} and at F_{upper} and F_{lower} will follow an advice rule based on F reduction when SSB in the TAC year is predicted to be below MSY $B_{trigger}$. This advice rule conforms to the current ICES MSY approach. ICES considers that to be in accordance with the precautionary approach there is a need for overarching precautionary considerations, and does not consider that F should be maintained at F_{MSY} when stock biomasses are below MSY $B_{trigger}$.
7) In order to be consistent with the ICES approach for estimating F_{MSY}, and taking into account advice error as well as biological and fishery variability, the values of F_{upper} and F_{MSY} are capped if they are not precautionary so that the probability of SSB < B_{lim} is no more than 5%. If the stock has no available precautionary criteria, the F_{MSY} range is constrained to a maximum of F_{MSY} and a minimum of F_{lower}.

The range was thus defined as follows (where $F_{P.05}$ is the value of F that corresponds to 5% probability of SSB < B_{lim}), with the case corresponding to the NEA mackerel highlighted in bold:

Case	Final F_{MSY}	F_{MSY} range
F_{upper} < $F_{P.05}$	F_{MSY}	F_{lower}–F_{upper}
F_{MSY} < $F_{P.05}$ < F_{upper}	**F_{MSY}**	**F_{lower}–$F_{P.05}$**
$F_{P.05}$ < F_{MSY}< F_{upper}	$F_{P.05}$	F_{lower}–$F_{P.05}$
$F_{P.05}$ cannot be defined	F_{MSY}	F_{lower}–F_{MSY}

In answer to the request ICES made the following assumptions regarding the approach detailed in the request:

- The first item of the proposal specifies SSB and $B_{trigger}$ as being at the end of a TAC year. These parameters are normally specified by ICES to be at spawning time. ICES assumes that the intention of the strategy is to have a 50% or greater probability of classifying SSB > $B_{trigger}$ at the end of the fishery year. For NEA mackerel ICES currently carries out this classification based on SSB in May in the TAC year; ICES will continue to use this basis unless advised that this is not what is intended.
- In the third item the strategy defines a requirement to bring SSB above B_{lim}, both at the start and the end of the TAC year. As in item 1 above ICES assumed that the purpose of this item is to test the SSB at the beginning of the year and have a greater than 50% probability of SSB > B_{lim} by the end of the fishery year. For NEA mackerel ICES currently carries out this classification based on SSB in May in the TAC year; ICES will continue to use this basis unless advised that this is not what is intended.
- ICES notes that the strategy specifies a $B_{trigger}$. The current plan has a $B_{trigger}$ of 2.2 Mt; the MSY $B_{trigger}$ currently accepted by ICES is 3.0 Mt. ICES is unsure whether it is intended that this $B_{trigger}$ should be maintained at 3.0 Mt or if the evaluation should consider other options. ICES has tested other candidates of MSY $B_{trigger}$ that are consistent with the ICES MSY approach.

Results and conclusions

ICES performed long-term stochastic simulations showing that a maximum long-term yield of on average 676 kt is obtained for a fishing mortality $F_{bar,\ 4–8}$ of 0.22 (Figure 9.2.3.3.1). The actual values of yield that are expected to occur will depend on the realised recruitment and the values given in this document are only provided for comparison and should not be taken as expected values. The range of $F_{bar,\ 4–8}$ values between 0.15 and 0.29 are expected to deliver less than 5% reduction in long-term yield compared with MSY.

The implementation of the ICES MSY advice rule is explicitely stated in the request (bullet point 2); the F_{upper} value is therefore capped at the F that results in a 5% probablity of SSB less than B_{lim} ($F_{P.05}$).

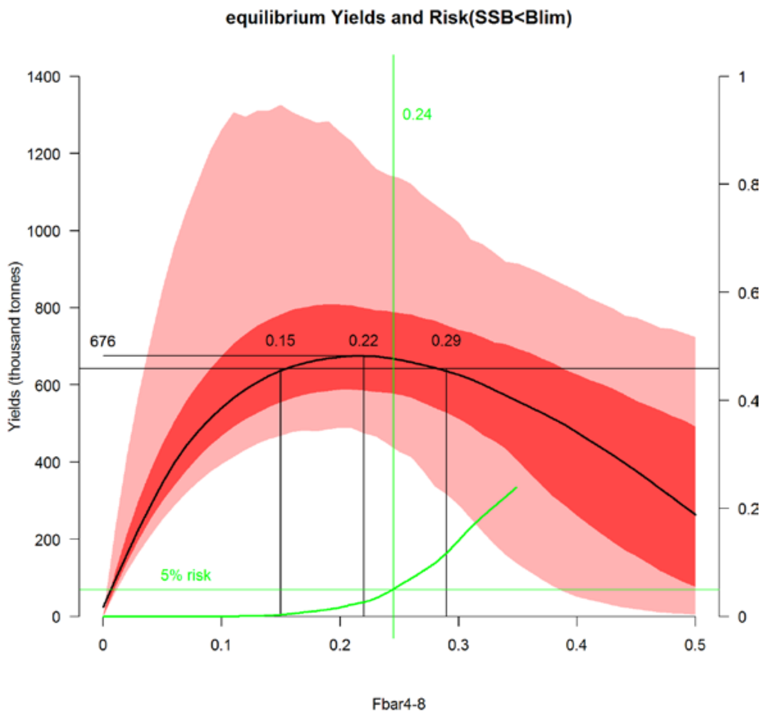

Figure 9.2.3.3.1 Equilibrium yields as a function of $F_{bar,\,4–8}$ (black line: median over the 1000 replicates, dark and light red area: 50% and 90% of the distribution among the 1000 replicates). The green line represent the probability of SSB< B_{lim}, calculated by implementing the ICES MSY advice rule with a MSY $B_{trigger}$ of 3.0 Mt in the simulations.

Table 9.2.3.3.2 Estimates of F_{MSY}, F at 95% of MSY above and below F_{MSY}, long-term realized F_{bar}, and percentage difference in long-term mean yield compared to MSY. All options are considered based on an upper bound on 95% MSY. Source: WKMACLTMP (ICES, 2015b).

Stock	Precautionary F, F_{MSY}, and F intervals				Long-term realized F_{bar}	% difference in long-term mean yield compared with MSY
	$B_{trigger}$	F_{MSY}	F_{lower}	F_{upper}		
NEA mackerel	3.0 Mt	0.22	0.15	0.24	0.23	3%
	3.2 Mt			0.25	0.23	2%
	3.5 Mt			0.26	0.24	2%
	4.0 Mt			0.28	0.24	2%
	5.0 Mt			0.30	0.23	2%

Methods

Simulation tool

ICES has used the stochastic simulation model developed for the long-term managment plan evaluation (ICES, 2015b) to estimate F_{MSY} and appropriate ranges. This tool was designed to offer a realistic representation of the dynamics of the NEA mackerel stock and of its exploitation, and to mimic as closely as possible the stock assessment and management procedures to be evaluated. The simulation tool was parameterized to give a correct representation of the natural sources of variability in the stock (e.g. recruitment and growth variability) and of the uncertainty in the system. This was done by incorporating stochasticity in the starting conditions, in the future biology of the stock (recruitment, weights, maturity, proportion of mortality before spawning time) and of the fishery characteristics (selection pattern), and in the observation and stock assessment parts of the model. Parameterization of the simulation was based on the 2014 NEA mackerel assessment (ICES, 2014c).

Simulations were run in parallel for 1000 iterations (replicates of the stock), each having their own equally likely starting conditions and individual biological and exploitation parameters.

Recruitment was generated using stock–recruitment functions with a log-normal error distribution. The historical stock–recruitment pairs (covering the years 1990–2012) did not give clear support for any particular stock–recruitment model formulation. Therefore, the approach developed for the previous management plan evaluation (Simmonds *et al.*, 2011) was adopted here. The method consisted in estimating a probability for a selection of model formulations (Beverton and Holt, Ricker, and segmented regression), to assign randomly one model formulation to each of the 1000 iterations according to these probabilities, and to estimate the shape, auto-correlation, and variance parameters individually for each iteration.

Changes were observed in the mackerel biology in the last decade, characterized by trends towards low weights-at-age, earlier spawning, and later maturation (ICES, 2014d). In the simulations, assumptions on the future biology were based on the average of the last three years (2011–2013) with additional auto-correlated random variations parameterized on the full time-series.

The future age selectivity of the fishery was simulated using resampling of the historical period (2000–2013) by blocks of years.

The stock assessment process was mimicked to estimate the state of the stock in the simulations, providing a basis to give advice according to the management strategies investigated. Stock assessment error matrices were applied to the “true" abundance and fishing mortality-at-age and resulted in temporally auto-correlated errors on SSB and F_{bar}.

A series of test runs was conducted to validate the model and investigate the effect of the main assumptions.

Extra information

Density-dependent growth and environmental effects

The request specifically asked that the advice should be based on the stock biology (including possible density-dependent growth), fishery characteristics, and environmental conditions. The numerical part of this evaluation is based on current biological conditions of the stock, with slow growth and late maturation. Other biological scenarios are discussed, but full numerical evaluations have not been carried out.

Recent scientific work has provided some support for density-dependent growth in NEA mackerel. Jansen and Burns (2015) have found a negative relation between juvenile size and both the biomass of the adults and the abundance of juveniles. Olafsdottir *et al.* (2015) investigated mackerel growth between ages 3 and 8 and described a marked reduction in growth, which was found to be concomitant with trends in the size of both the NEA mackerel and the Norwegian spring-spawning herring stocks. The authors also included temperature as an explanatory factor for the changes in growth and concluded that its effect was not significant.

However, this converging evidence for a density-dependent effect should be supported by studies aimed at identifying the actual mechanisms (e.g. reduction of the food available per capita due to the increased number of conspecific individuals, increased feeding migration distances due to the increased competition for space). Studies based on actual field observations (fish distribution, stomach contents, plankton abundances, physical factors) combined with experimental work and bio-energetic modelling will help to better understand these mechanisms.

The influence of other factors may have acted in combination with the increasing stock size on mackerel growth. The carrying capacity of the ecosystem may also have varied due to the effect of environmental changes (changes in prey abundance, in competing species abundance, and changes in the geographical extension of the suitable habitat for mackerel). In addition, growth, as all physiological processes, is directly influenced by the local physical conditions (e.g. temperature) experienced by the fish. Furthermore, many of the potential drivers are correlated with each other, which makes the interpretation of causal links challenging (see Pastoors *et al.* (2015) for further discussion).

Until we have a good understanding of the density-dependent and the density-independent (i.e. environmental) factors that govern the changes in mackerel biology and population dynamics (growth, but also recruitment regime, migration time, etc.), it seems difficult to incorporate adequately any of those factors in the simulations carried out to give advice on the appropriate levels of exploitation. In absence of a clear indication of reversibility of the recent changes, ICES currently uses simulations based on recent biological conditions.

During the long-term management plan evaluation (ICES, 2015c) an alternative scenario for the future biology of the stock was presented. In this scenario, all biological characteristics were modelled so that their baseline level (i.e. when not considering the stochastic yearly variations) would return progressively from the current level to the long-term historical average. If the recent changes in growth are indeed due to the large size of the stock, a recovery of the mean weights-at-age might be expected if the stock size decreases from the current high level.

Simulations based on the return to faster growth and earlier maturation indicate that F_{MSY} = 0.24 would maximize the long term yields, and that F values between F_{lower} = 0.17 and F_{upper} = 0.28 would result in less than 5% reduction in long-term yield compared with MSY and still be precautionary. These changes would be expected whatever the reason for the return to historical biological conditions.

The effect of density on fish growth can also be directly incorporated in the population model used in a management strategy evaluation. The framework used by ICES (2015b) does not have this possibility at the moment, but ICES (2015c) investigated the magnitude of the effect of density-dependent growth using another modelling framework parameterized for the NEA mackerel stock, allowing fish size-at-age to be directly dependent on the stock size at any given time. The preliminary results indicate that in the range of potential F_{MSY}, the effect on yield of density-dependent growth appears to be between 5% and 10%.

Sources and references

ICES. 2014a. Report of the ICES Advisory Committee, 2014. ICES Advice 2014, Book 1.

ICES. 2014b. Report of the Joint ICES–MYFISH Workshop to consider the basis for F_{MSY} ranges for all stocks (WKMSYREF3), 17–21 November 2014, Charlottenlund, Denmark. ICES CM 2014/ACOM:64. 147 pp.

ICES. 2014c. Report of the Working Group on Widely Distributed Stocks (WGWIDE), 26 August–2 September 2014, ICES Headquarters, Copenhagen, Denmark. ICES CM 2014/ACOM:15.

ICES. 2014d. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 17–21 February 2014, Copenhagen, Denmark. ICES CM 2014/ACOM:43.

ICES. 2015a. EU, Norway, and the Faroe Islands request to ICES to evaluate a multi-annual management strategy for mackerel (*Scomber scombrus*) in the Northeast Atlantic. *In* Report of the ICES Advisory Committee, 2015. ICES Advice 2015, Book 9, Section 9.2.3.1.

ICES. 2015b. Report of the EU Workshop on the NEA Mackerel Long-term Management Plan (WKMACLTMP), 24–27 June and 17–19 November 2014, Copenhagen, Denmark. ICES CM 2014/ACOM:63.

ICES. 2015c. Report of the Working Group on Widely Distributed Stocks (WGWIDE), 25–31 August, 2015, Pasaia, Spain. ICES CM 2015/ACOM:15.

Jansen, T., and Burns, F. 2015. Density dependent growth changes through juvenile and early adult life of North East Atlantic Mackerel (*Scomber scombrus*). Fisheries Research, 169 (2015): 37–44.

Olafsdottir, A. H., Slotte, A., Jacobsen, J. A., Oskarsson, G. J., Utne, K. R., and Nøttestad, L. 2015. Changes in weight-at-length and size-at-age of mature Northeast Atlantic mackerel (*Scomber scombrus*) from 1984 to 2013: effects of mackerel stock size and herring (*Clupea harengus*) stock size. ICES Journal of Marine Science, published online. doi: 10.1093/icesjms/fsv142.

Pastoors, M. A., Brunel, T., Skagen, D., Utne, K., Enberg, K., and Sparrevohn, C. R. 2015. Mackerel growth, the density dependent hypothesis and implications for the configuration of MSE simulations: results of an ad-hoc workshop in Bergen, 13–14 August 2015. Working Document to ICES Working Group on Widely Distributed Stocks (WGWIDE), 25–31 August 2015, AZTI-Tecnalia, Pasaia, Spain.

Simmonds, E. J., Campbell, A., Skagen, D., Roel, B. A., and Kelly, C. 2011. Development of a stock–recruit model for simulating stock dynamics for uncertain situations: the example of Northeast Atlantic mackerel (*Scomber scombrus*). ICES Journal of Marine Science, 68: 848–859.