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6.2.3.1 EU request to ICES to provide F_{MSY} ranges for selected North Sea and Baltic Sea stocks

Advice summary

ICES provides precautionary F_{MSY} ranges that are derived to deliver no more than a 5% reduction in long-term yield compared with MSY.

Request

North Sea Request

The Commission is preparing a long-term management plan for the demersal fisheries in the North Sea. According to Art. 10 of Regulation (EU) No 1380/2013 on the Common Fisheries Policy a multiannual plan shall include quantifiable targets, a time frame to reach the targets and safeguards to ensure that the quantifiable targets are met.

ICES is requested to provide plausible values around F_{MSY} (range for F_{MSY}) for the following stocks:

- *Cod in Subarea IV (North Sea) and Divisions VIId (Eastern Channel) and IIIa West (Skagerrak)*
- *Saithe in Subarea IV (North Sea), Division IIIa (Skagerrak), and Subarea VI (West of Scotland and Rockall)*
- *Haddock in Subarea IV and Divisions IIIa West and VIa (North Sea, Skagerrak, and West of Scotland)*
- *Whiting in Division IIIa (Skagerrak-Kattegat)*
- *Whiting in Subarea IV (North Sea) and Division VIId (Eastern Channel)*
- *Sole in Division IIIa and Subdivisions 22–24 (Skagerrak, Kattegat, and the Belts)*
- *Sole in Division VIId (Eastern Channel)*
- *Sole in Subarea IV (North Sea)*
- *Plaice in Division VIId (Eastern Channel)*
- *Plaice in Subarea IV (North Sea)*
- *Plaice in Subdivision 20 (Skagerrak)*
- *Anglerfish in Division IIIa (Skagerrak and Kattegat) and Subareas IV (North Sea) and VI (West of Scotland and Rockall)*
- *Megrim in Divisions IVa (northern North Sea) and VIa (West of Scotland)*
- *Nephrops in Division IIIa (FU 3–4)*
- *Nephrops in Division IV (North Sea) by FU*
    - *Nephrops in Botney Gut-Silver Pit (FU 5)*
    - *Nephrops in Farn Deeps (FU 6)*
    - *Nephrops in Fladen Ground (FU 7)*
    - *Nephrops in Firth of Forth (FU 8)*
    - *Nephrops in Moray Firth (FU 9)*
    - *Nephrops in Noup (FU 10)*
    - *Nephrops in Norwegian Deeps (FU 32)*
    - *Nephrops off Horn's Reef (FU 33)*
    - *Nephrops in Devil's Hole (FU 34)*

The plausible values around F_{MSY} should be based on the stock biology, fishery characteristics and environmental conditions. ICES is also requested to update other reference points in light of the change from F_{MSY} as a single reference point to F_{MSY} as a range.

Baltic Sea Request

The Commission is preparing a long term management plan for herring, sprat and cod in the Baltic Sea. According to Article 10 of Regulation (EU) No 1380/2013 on the Common Fisheries Policy a multiannual plan shall include quantifiable targets, time frame to reach the targets also the safeguards to ensure that the quantifiable targets are met.
ICES is requested to provide plausible values around F_{MSY} (range for F_{MSY}) for the following stocks:

- *Cod in Subdivisions 22–24*
- *Cod in Subdivisions 25–32*
- *Herring in Subdivisions 22–24*
- *Herring in Subdivisions 25–29 (excluding Gulf of Riga) & 32*
- *Herring in the Gulf of Riga*
- *Herring in Subdivision 30 (Bothnian Sea)*
- *Herring in Subdivision 31 (Bothnian Bay)*
- *Sprat in Subdivisions 22–32*
- *Salmon in Subdivisions 22–31 (Main basin & Gulf of Riga)*
- *Salmon in Subdivision 32 (Gulf of Finland)*
- *Salmon in Subdivisions 22–32 combined*

The plausible values around F_{MSY} should be based on the stock biology, fishery characteristics and environmental conditions.
ICES is also requested to update other reference points in light of change from F_{MSY} as a single point to F_{MSY} as a range.

Elaboration on ICES advice

The F_{MSY} ranges [F_{lower}, F_{upper}] are derived to deliver no more than 5% reduction in long-term yield compared with MSY.

In order 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%. Two approaches have been used to derive the values of the cap on F_{upper}. One conforms to the ICES MSY advice rule (AR), and requires reducing F linearly towards zero when SSB is below MSY $B_{trigger}$. The second uses a constant F without an advice rule. Although the first often provides a wider F_{MSY} range, it requires the ICES MSY advice rule to be used.

The evaluations are based on average long-term yield and are adequate to estimate F_{MSY} under the current conditions. It should be noted that: (1) yield will fluctuate around an average, and (2) the estimated average yield is based on single-species considerations and may not hold in an ecosystem context. For megrim and *Nephrops* harvest rates based on yield models have been used.

The resulting ranges are given in Tables 6.2.3.1.1 and 6.2.3.1.2 for the Baltic and North Sea, respectively. These evaluations are all based on current biological conditions of growth, maturity, recruitment, and natural mortality. As the environment changes and stock biology adapts, the values will need to be revised to reflect the changing conditions. Fishery selectivity is based on estimates from recent years. The F_{MSY} values and ranges provided are considered applicable for at least the next five years.

There are considerations other than average long-term yield for fishing above or below F_{MSY}. In a single-species context fishing above F_{MSY} implies reduced stock biomass and this may be substantial where F_{upper} is much higher than F_{MSY}. So in utilizing F_{MSY} ranges there are more advantages to fishing between F_{MSY} and F_{lower} than between F_{MSY} and F_{upper}.

With higher fishing mortalities the following occurs:

- A need for increased fishing effort;
- Higher dependence of stock and yield on recruiting year classes and increased variability on catch opportunities;
- The size of the fish in the stock and the catch will be smaller on average;
- Greater probability of SSB being less than MSY $B_{trigger}$;
- A lower probability of density-dependent effects such as reduced growth or increased cannibalism.

For some mixed fisheries it may be difficult to reconcile the Fs on different stocks. An approach for maximizing long-term yield could be to attempt to reconcile F on a mixed fishery using Fs between F_{lower} and F_{MSY}. If this cannot be accomplished, F between F_{MSY} and F_{upper} could also be used in the short term. However, using F >F_{MSY} for the same stock in the long term implies that there are structural changes required in the fishery to avoid the consequences listed above. Moreover, in line with the request, F_{MSY} and the upper and lower ranges are calculated based on current fishery selectivity with the possibility of higher yields if selectivity is altered through changes in gear design, fishing area, or season.

F_{MSY} reference points are currently not available for whiting in Division IIIa, anglerfish in Division IIIa and Subareas IV and VI, and for some *Nephrops* stocks; proxies are being investigated, therefore ranges are not defined. The stock dynamics are particularly uncertain for whiting in the North Sea and in the past 11 years (2003–2013) recruitment has been low. In this period of recruitment the probability of SSB being less than B_{lim} is around 10%, even with no fishery. ICES is therefore unable to identify a precautionary F_{MSY} or range. Plaice in Subdivision 20 (Skagerrak) has recently been amalgamated with plaice in the North Sea. The estimated F_{MSY} values for plaice in the North Sea can be used for the combined area.

ICES will respond to the part of the request concerning Baltic salmon at the end of May, together with the annual advice for Baltic stocks. Currently, there is no agreed assessment for cod in Subdivisions 25–32, and no F_{MSY} reference point or range is currently available. These will be provided once an agreed assessment becomes available.

Table 6.2.3.1.1 F_{MSY} ranges for Baltic Sea [F_{lower}, F_{upper}] derived to deliver no more than 5% reduction in long-term yield compared with F_{MSY}. Two approaches have been used to derive the values of F_{upper}. One conforms to the ICES MSY advice rule (AR), and requires reducing F_{MSY} and F_{upper} linearly towards zero when SSB is below MSY $B_{trigger}$ (framed). The second (grey) uses a constant F without an advice rule. Although the first provides a wider range, it requires the ICES MSY advice rule to be used.

Stock	MSY F_{lower}	F_{MSY}	MSY F_{upper} with AR	MSY $B_{trigger}$ (thousand t)	MSY F_{upper} with no AR
Cod in Subdivisions 22–24	0.15	0.26	0.45	38.4*	0.45
Herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring)	0.16	0.22	0.28	600	0.22
Herring in Subdivision 28.1 (Gulf of Riga)	0.24	0.32	0.38	60	0.32
Herring in Subdivision 30 (Bothnian Sea)	0.11**	0.15**	0.18**	316	0.15**
Herring in Division IIIa and Subdivisions 22–24 (Western Baltic Spring Spawners)	0.23	0.32	0.41	110	0.41
Sprat in Subdivisions 22–32 (Baltic Sea) [a)]	0.19	0.26	0.27	570	0.21

[a)] Year range of stock-recruitment curve: 1992–2013.

* Version 2: Value corrected.

** Version 3: Value updated (ICES, 2015d).

Table 6.2.3.1.2 F_{MSY} ranges for North Sea [F_{lower}, F_{upper}] derived to deliver no more than 5% reduction in long-term yield compared with F_{MSY}. Two approaches have been used to derive the values of F_{upper}. One conforms to the ICES MSY advice rule (AR), and requires reducing F_{MSY} and F_{upper} linearly towards zero when SSB is below MSY $B_{trigger}$ (framed). The second (grey) uses a constant F without an advice rule. Although the first provides a wider range, it requires the ICES MSY advice rule to be used. For megrim the advice is based on a biomass dynamic model and MSY quantities are fractions of model parameters. The *Nephrops* advice is based on harvest rate (HR).

Stock	MSY F_{lower}	F_{MSY}	MSY F_{upper} with AR	MSY $B_{trigger}$ (thousand t)	MSY F_{upper} with no AR
Cod in Subarea IV (North Sea), Division IIIa (Skagerrak), and Division VIId	0.22*	0.33*	0.49*	165*	0.42*,^
Haddock in Subarea IV and Divisions IIIa and VIa (Northern Shelf)	0.25	0.37	0.52	88	0.51
Plaice in Subarea IV (North Sea)	0.13	0.19	0.27	230	0.27
Plaice in Division VIId	0.18*	0.25*	0.34*	25.8*	0.34*
Saithe in Subarea IV, and Divisions IIIaN and VIa [$$]	0.21[$$]	0.36[$$]	0.492[$$]	150[$$]	0.419[$$]
Sole in Division IIIa and Subdivisions 22–24 (Kattegat sole) [a]	0.19[$]	0.23[$]	0.26	2.6[$]	0.22[$]
Sole in Subarea IV (North Sea)	0.11	0.20	0.37	37	0.37
Sole in Divisions VIId	0.16	0.30	0.41	8	0.39
	MSY F_{lower} [b]	F_{MSY} [b]	MSY F_{upper} [b] with AR	MSY $B_{trigger}$	
Megrim in Divisions IVa and VIa	0.39 × r [d]	r/2 [d]	r/2 [d]	0.25 × *K* [d]	
Nephrops in FUs 3 and 4	0.056^^	0.079^^	0.079^^	-	
Nephrops in FU 6	0.070^^	0.081^^	0.081^^	858 [c]	
Nephrops in FU 7	0.066*	0.075*	0.075*	2767 [c]	
Nephrops in FU 8	0.106^^	0.163^^	0.163^^	292 [c]	
Nephrops in FU 9	0.091^^	0.118^^	0.118^^	262 [c]	

[a] Year range for estimation of stock–recruitment curve: 1992–2013.
[b] Harvest rate (HR).
[c] Abundance (millions).
[d] *r* is the intrinsic biomass growth rate and *K* is carrying capacity. These values are directly estimated from the stock assessment and change when the assessment is updated.
* Version 4: Value updated (ICES, 2015e).
^ This value corresponds to 5% probability of SSB < B_{lim} assuming the observed poor recruitment from 1998 to 2014.
^^ Version 4: Values not rounded.
[$] Version 5: Values updated; note: F_{MSY} = 0.23 has been capped by F_{pa}.
[$$] Version 6: Values updated (ICES, 2016b).

Basis of the advice

Background

Work to answer these two requests is based on a workshop that was held in Charlottenlund, Denmark on 17–21 November 2014 (ICES, 2014b). Several values calculated in this workshop were revised at ICES benchmark workshops in 2015.

For stocks where ICES advice is given based on the MSY approach ICES has developed an advice rule (AR) based on the F_{MSY} fishing mortality reference point, that provides the exploitation rate to give catch advice, and 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 < 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 total F for catch (landings plus discards) for all stocks where catch advice based on F is given. 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. For simulated recruitment the full time-series was used unless there was evidence of change having occurred for more than ten years (Baltic sprat and Kattegat sole).
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}):

Case		Final F_{MSY}	F_{MSY} range
$F_{upper} < F_{P.05}$	(Figure 6.2.3.1.1)	F_{MSY}	F_{lower}–F_{upper}
$F_{MSY} < F_{P.05} < F_{upper}$	(Figure 6.2.3.1.2)	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}

Results and conclusions

The first option in the text table above is illustrated by plaice in Subarea IV (North Sea plaice), for the situation where F_{MSY} is substantially lower than $F_{P.05}$ (Figure 6.2.3.1.1). For North Sea plaice the F_{MSY} is estimated at F = 0.19 with lower and upper ranges of 0.13 and 0.27, respectively. In this first case $F_{P.05}$ = 0.48, which is well above the upper range value and there is thus no need to modify the F_{upper} value.

The second option in the table above is illustrated here for saithe in Division IIIa and Subareas IV and VI (Figure 6.2.3.1.2). The peak yield for this stock is obtained at F_{MSY} = 0.36; the yield reduces to 95% of the maximum at a lower F of 0.21 and at a higher F at 0.647. Above the higher F value, yield falls quickly. For this stock F_{MSY} is below, but close to Fs that do not comply with ICES precautionary considerations. The F value which leads to the probability of SSB< B_{lim} = 5% ($F_{P.05}$) is estimated to be F = 0.492, assuming constant F exploitation at all SSB levels. Fs greater than this value would not be considered by ICES to be precautionary; the F_{upper} value is therefore capped at $F_{P.05}$.

The importance of ICES MSY advice rule (AR) leading to reduced realised F for stocks with a low $F_{P.05}$ is shown for saithe in Division IIIa and Subareas IV and VI (Figure 6.2.3.1.3). The comparatively higher yield at high F relative to Figure 6.2.3.1.2 is because real F does not follow the reference F, but is reduced due to the implementation of the AR at lower biomass. The AR provides protection for both the stock and the yield that is not provided by the fixed F regime of Figure 6.2.3.1.2. This shows

that with the AR in place $F_{P.05}$ = 0.492 compared to F = 0.419 without the AR. There is a substantial increase in biomass at higher Fs that results from the inclusion of MSY $B_{trigger}$. This can be seen most clearly by comparing the right panels of Figures 6.2.3.1.2 and 6.2.3.1.3 at the point where a reference F of 0.6 was used.

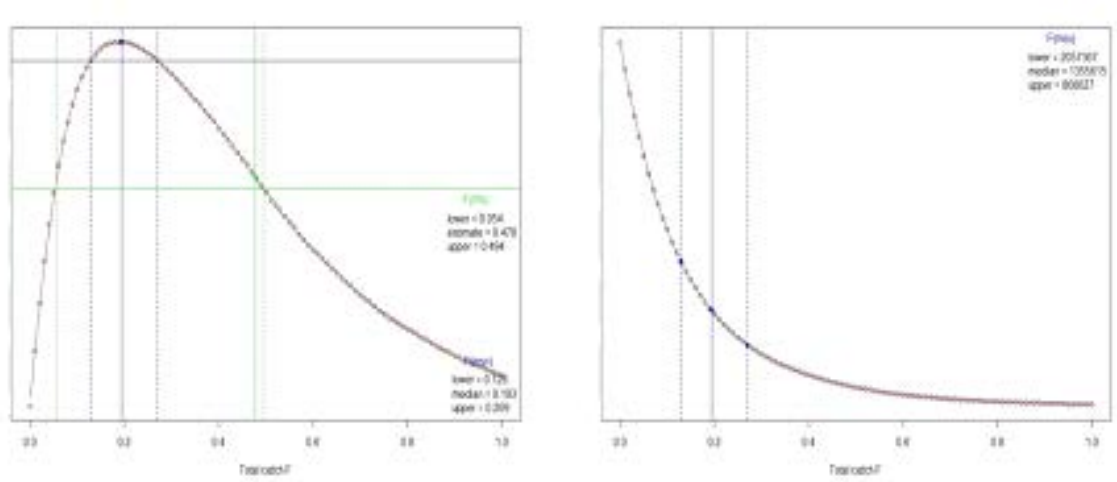

Figure 6.2.3.1.1* Plaice in Subarea IV (North Sea), with fixed F exploitation from catch F = 0 to 1.0. Left panel: Median landings yield (circles) and fitted curve (red) with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green vertical line: $F_{P.05}$ estimate (solid). Right panel: Median SSB. Units are not given for the *y*-axis as only relative values are considered reliable.

* Version 4: The figure was replaced by another stock that no longer represents the example given in the original version of the request.

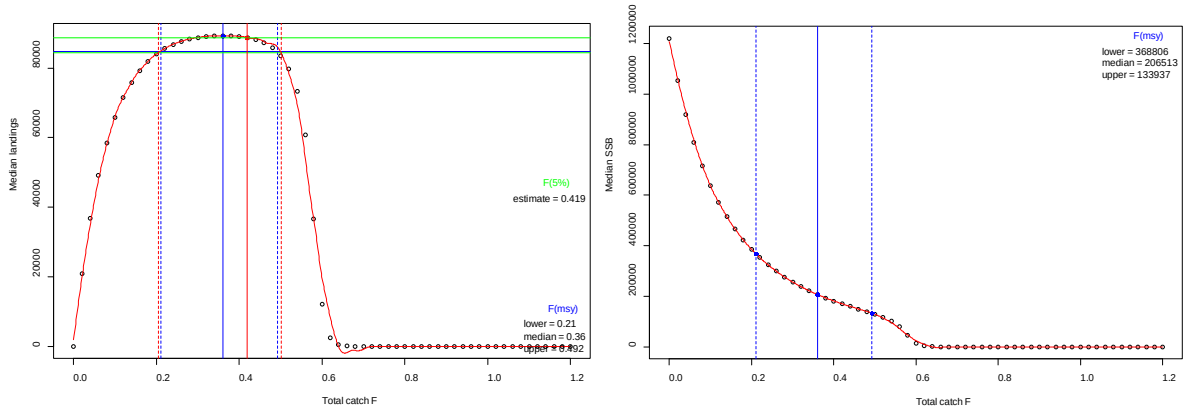

Figure 6.2.3.1.2 Saithe in Division IIIa and Subareas IV and VI, with fixed F exploitation from catch F = 0 to 1.2. Left panel: Median landings yield (circles) and fitted curve (red) with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted), with the upper bound restricted to $F_{P0.05}$ (dotted). Red vertical line: $F_{P.05}$ estimate (solid). Right panel: Median SSB. Units are not given for the *y*-axis as only relative values are considered reliable. *

* Version 6: The figure was updated (ICES, 2016b).

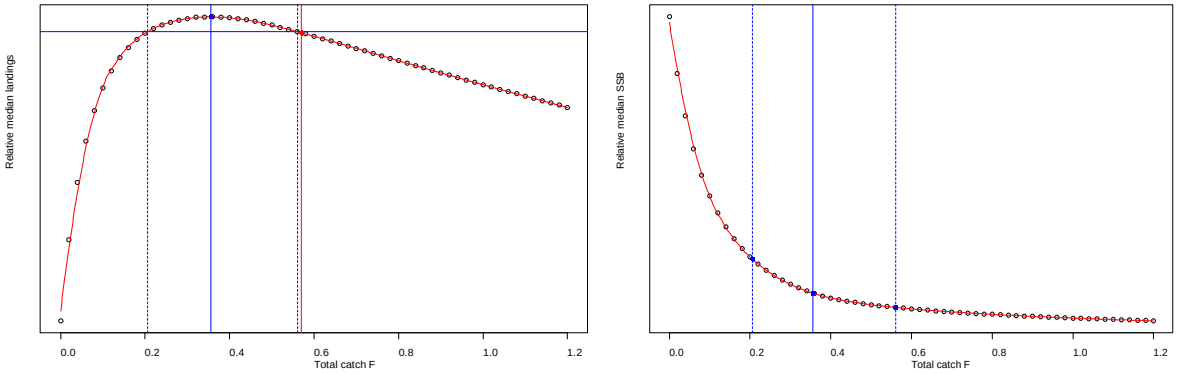

Figure 6.2.3.1.3 Saithe in Division IIIa and Subareas IV and VI, with F exploitation (modified by F reduction when SSB is below MSY $B_{trigger}$ at 200 000 t) from F = 0 to 1.2. Realised F is reduced as SSB declines with high F reducing the catch advice according to the advice rule. Median landings yield (circles) and fitted curve (red) with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Red vertical line: $F_{P.05}$ estimate (solid). The comparatively higher yield at high F relative to Figure 6.2.3.1.2 comes because real F is reduced due to lower biomass as the AR provides protection for the stock and $F_{P.05}$ = 0.57 compared to F = 0.39 without the AR. Units are not given for the *y*-axis as only relative values are considered reliable.

Yield curves such as those illustrated in Figures 6.2.3.1.1 to 6.2.3.1.3 were computed for all stocks with age-based assessments. Estimates of F_{MSY}, together with the upper and lower Fs that give 95% of maximum yield were computed for all the stocks (Table 6.2.3.1.3). For stocks with a defined B_{lim} or a plausible proxy, the precautionary $F_{P.05}$ was also computed, assuming constant F exploitation and with the implementation of the AR. The precautionary $F_{P.05}$ thus calculated based on the AR shows an increase compared with the similar $F_{P.05}$ value in the option that omits the AR.

The F ranges over which the yield changes by no more than 5% are wide (Table 6.2.3.1.3). In some cases (e.g. North Sea sole) the upper limit can be much larger than F_{MSY}. The stocks fall into three main categories. Firstly, the Western Baltic cod and North Sea plaice, where F_{upper} is well below any precautionary considerations. Secondly, there are a number of stocks where precautionary considerations dominate and F_{upper} has to be reduced substantially, e.g. herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring). Lastly, in the case of most stocks F_{upper} is at or just below $F_{P.05}$.

Table 6.2.3.1.3 Estimates of F_{MSY}, F at 95% of MSY above and below F_{MSY}, and $F_{P.05}$ with and without the ICES advice rule (AR). All options are considered based on an upper bound on 95% MSY, with all options constrained to be at or below $F_{P.05}$ with or without the AR. Source refers to 1: WKBALTCOD (ICES, 2015a), 2: WKNSEA (ICES, 2015b), 3: WKMSYREF3 (ICES, 2014b), 4: WKPLE (ICES, 2015c), 5: WGBFAS (ICES, 2015d)***, 6: WGNSSK (ICES, 2015e)^, 7: IBPSOLKAT (ICES, 2016a), 8: WGNSSK (ICES, 2016b) $$$.

Stock	Source	Precautionary F, F_{MSY}, and F intervals estimated without Advice Rule (AR)				With AR	Options for upper bound, all limited by PA considerations $F < F_{P.05}$	
		$F_{P.05}$	F_{MSY}	95% below	95% above	$F_{P.05AR}$	95% yield, no AR	95% yield, with AR
Cod in Subdivisions 22–24	1	0.57	0.26	0.15	0.45	0.66	0.45	0.45
Cod in Subarea IV (North Sea), Division IIIa (Skagerrak), and Division VIId	5^^	0.42#	0.33^^	0.22^^	0.49^^	0.52#, ^	0.42^^,#	0.49^^
Haddock in Subarea IV and Divisions IIIa and VIa (Northern Shelf)	3	0.51	0.37	0.25	0.52	0.55	0.51	0.52
Herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring)	3	0.22	0.22	0.16	0.31	0.28	0.22	0.28
Herring in Subdivision 28.1 (Gulf of Riga)	3	0.32	0.32	0.24	0.38	0.38	0.32	0.38
Herring in Subdivision 30 (Bothnian Sea)	5	0.15**	0.15**	0.11**	0.17**	0.18**	0.15**	0.18**
Herring in Division IIIa and Subdivisions 22–24 (Western Baltic Spring Spawners)	3	0.46	0.32	0.23	0.41	0.52	0.41	0.41
Plaice in Subarea IV (North Sea)	3	0.48	0.19	0.13	0.27	0.56	0.27	0.27
Plaice in Division VIId	5^^	0.35^^	0.25^^	0.18^^	0.34^^	0.42^^	0.34^^	0.34^^
Saithe in Subarea IV and Divisions IIIaN and VIa	8$$$	0.419$$$	0.36$$$	0.21$$$	0.498$$$	0.492$$$	0.419$$$	0.498$$$
Sole in Division IIIa and Subdivisions 22–24 (Kattegat sole) [S–R short time-series: 1992–2013]	7$$	0.22$$	0.23$$	0.19$$	0.29$$	0.26$$	0.22$$	0.26
Sole in Subarea IV (North Sea)	2	0.38	0.20	0.11	0.37	0.42	0.37	0.37
Sole in Division VIId	3	0.39	0.30	0.16	0.43	0.41	0.39	0.41
Sprat in Subdivisions 22–32 (Baltic Sea) [S–R time-series: 1992–2013]	3	0.21	0.26	0.19	0.34	0.27	0.21	0.27
			HR_{MSY}	HR_{lower}				
Megrim in Divisions IVa and VIa	3		r/2	0.39 × r				$r/2$[a)]
Nephrops in FUs 3 and 4	3		0.079$	0.056$				0.079[a)]
Nephrops in FU 6	3		0.081$	0.070$				0.081[a)]
Nephrops in FU 7	3		0.075^^	0.066^^				0.075[a)]
Nephrops in FU 8	3		0.163$	0.106$				0.163[a)]
Nephrops in FU 9	3		0.118$	0.091$				0.118[a)]

HR is the harvest rate and *r* the intrinsic biomass growth rate.

[a)] F_{MSY} range capped at F_{MSY} because it has not been possible to evaluate the probability of $SSB < B_{lim}$.

** Version 3: Value updated.

*** Version 3: New reference added.

^ Version 4: New reference added.

^^ Version 4: Value updated.

This value corresponds to 5% probability of $SSB < B_{lim}$ assuming the observed poor recruitment from 1998 to 2014.

$ Version 4: Value not rounded.

$$ Version 5: Values updated; note: F_{MSY}=0.23 has been capped by F_{pa}.

$$$ Version 6: Values updated.

Methods

ICES has used long-term stochastic simulations to estimate F_{MSY} and appropriate ranges. The methodology used for stocks with age-based assessments follows the approaches developed in ICES WKMSYREF2 (ICES, 2014a) and is documented in the report of WKMSYREF3 (ICES, 2014b). Most of the stocks evaluated are ICES category 1 stocks. These were evaluated using age-based stochastic simulation methods. For megrim a biomass model was used to estimate exploitation rate relative to F_{MSY}. For this stock 95% yield-based intervals occur at specific fractions of F_{MSY} and are not available on an absolute scale. For *Nephrops* stocks for which F_{MSY} ranges are provided these are based on proxies from Y/R analysis. For stocks in assessment categories 3–5 (whiting in Division IIIa, anglerfish, and some *Nephrops* stocks), MSY reference points are not currently available and ranges are not provided.

The stock–recruitment relationship is crucial in the estimation of F_{MSY}, F_{MSY} ranges, and the risk of falling below precautionary biomass reference points. Therefore, substantial effort was dedicated to the estimation of appropriate stock–recruitment relationships. Generally, three options were allowed (Ricker, Beverton–Holt, and segmented regression) which imply different dynamics at high biomass. The weighting of each of the model options was determined statistically. Where this results in dynamics that are considered unrealistic, the choice of model is often a segmented regression (e.g. whiting and sole in the North Sea). Under these conditions precautionary considerations are dominated by the slope to the origin and F_{MSY} is controlled either by precautionary limits or by a maximum in the yield-per-recruit.

The median yield was used as the basis for performing the maximization of yield. Although the evaluations are based on 95% of yield, the estimated absolute yields and biomasses are heavily dependent on the recruitment, growth, and natural mortality assumptions and may not be realised in practice.

Three definitions of yield were used to estimate F_{MSY}:

a) catch equal landings (eg. herring and sprat);
b) landings (plaice, Western Baltic cod, North Sea sole, haddock, and whiting);
c) catch (landings + discards) above minimum catch or conservation size (MCS), e.g. North Sea cod.

To maximize catch implies that it would be consistent with MSY to increase the proportion of the catch which is below MCS and hence this approach seems undesirable. It was considered preferable to maximize catch above MCS, but as data were not generally available current landings were used as the basis for F_{MSY} estimation for most stocks.

Implementation of stochasticity

Descriptions of how to implement stochasticity, process and estimation uncertainty and correlated errors are provided in ICES (2013), Kell *et al*. (2005), and Punt *et al*. (2015). Variability in biological parameters such as growth, maturation, and natural mortality were included using a random draw approach. Uncertainties were included when estimating recruitment from stock–recruitment relationships as this is usually the main source of variation. Inclusion of stochastic draws from inter-annual variability in recruitment is required for precautionary considerations. This stock–recruitment variability was through parametric distributions and also included a range of functional forms. In the estimation of the probability of avoiding a stock size below B_{lim}, it was necessary to include realistic estimates of the uncertainty (including the short-term forecast), in particular when the F_{MSY} range is likely to result in biomasses approaching B_{lim}. This uncertainty was generally estimated from a comparison of the forecast F, based on catches taken over the last ten years, and the resulting F taken from the most recent assessment. Combined assessment and advice error were included in the evaluations.

Additional information

The F_{MSY} ranges are derived based on yields within 95% of yields at F_{MSY}. It is important to understand that this interval is not a statistical confidence interval. Other methods could be used to derive F_{MSY} ranges, i.e. the precision of F_{MSY}, but this has substantial statistical difficulties that need to be overcome.

ICES has carried out a management plan evaluation for the TAC-setting procedure for Western Baltic herring. This evaluation was based on an single value of F_{MSY} = 0.28 for Western Baltic herring, and concluded that the TAC-setting procedure was precautionary for North Sea herring and Western Baltic herring, but only for the latter if the transfer of TAC from Division IIIa to Subarea IV was greater than 10% for the C-fleet. Historically, the transfer has been between 40% and 50%. Until further evaluations of the management plan are carried out ICES will continue to base its advice for the TAC-setting procedure on F_{MSY} = 0.28.

The evaluation for North Sea whiting, using the full range of recruitment (from 1990), indicates that high long-term yield can be obtained at Fs higher than $F_{P.05}$ = 0.24, but as these would not be considered precautionary F_{upper} would be capped at 0.24. The stock dynamics are particularly uncertain for this stock and recent recruitment (2003–2013) has been low. Using this period of recruitment there is around 10% probability of SSB falling below B_{lim}, even with no fishery. Therefore, ICES is unable to identify a suitable F_{MSY} candidate or range. However, ICES carried out management plan evaluations in 2013 and concluded that F = 0.15 is considered precautionary under the assumption that recruitment stays within a medium–low range. At this fishing mortality, stock dynamics are strongly dependent on natural mortality. The management plan evaluation of F = 0.15 also indicated that there was about a 20% probability of SSB falling below B_{lim} under a more pessimistic scenario of continuously low recruitment. For the time being, ICES will continue to base its advice for the TAC-setting procedure on a management plan that includes F = 0.15.

Estimated values for North Sea plaice are provided, which do not include the Skagerrak. Preliminary investigations for the amalgamated area indicate that there are no major differences compared to the ranges provided for plaice in the North Sea.

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* Version 4: Source added.
** Version 5: Source added.
***Version 6: Source added.