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5.4.1^{*} EU request to ICES to provide F_{MSY} ranges for selected stocks in ICES subareas 5 to 10

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 for selected stocks in ICES subareas 5 to 10.

Request

The Commission is preparing long term management plans for western EU waters (ICES subareas 5 to 10). 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 stocks of the following species inhabiting western EU waters (including those straddling western EU waters and adjacent waters):

Black-bellied anglerfish (Lophius budegassa) in Divisions 8c and 9a White-bellied anglerfish (Lophius piscatorius) in Divisions 8c and 9a Blue ling (Molva dypterygia) in Subdivision 5b, and Subareas 6 and 7 Cod in Divisions 7e-k (Celtic Sea cod) Cod in Division 7a (Irish Sea) Cod in Division 6a (West of Scotland) European sea bass in Divisions 4bc, 6a, and 6d–h (Irish Sea, Celtic Sea, English Channel, and southern North Sea) Greenland halibut in Subareas 5, 6, 12 and 14 Haddock in Divisions 7b, c, e-k Haddock in Division 6b (Rockall) Hake in Division 3a, Subareas 4, 6 and 7 and Divisions 8a, b, d (Northern stock) Hake in Division 8c and 9a (Southern stock) Megrim (Lepidorhombus spp.) in Divisions 4a and 6a Four-spot megrim (Lepidorhombus boscii) in Divisions 8c and 9a Megrim (Lepidorhombus whiffiagonis) in Divisions 7b-k and $8a,b,d^{\dagger}$ Megrim (Lepidorhombus whiffiagonis) in Divisions 8c and 9a Nephrops in Division 6a (North Minch, FU 11) Nephrops in Division 6a (South Minch, FU 12) Nephrops in Division 6a (Firth of Clyde + Sound of Jura, FU 13) Nephrops in Division 7a (Irish Sea East, FU 14) Nephrops in Division 7a (Irish Sea West, FU 15) Nephrops in Division 7b, c, j, k (Porcupine Bank, FU 16) Nephrops in Division 7b (Aran Grounds, FU 17) Nephrops in Division 7a, g, j (South East and West of Ireland, FU 19) Nephrops in the Smalls (FU 22) Plaice in Division 7e (Western Channel)[‡]

^{*} Version 2; Section number corrected.

⁺ Version 3; When this request was made, megrim (*Lepidorhombus whiffiagonis*) in divisions 7.b-k and 8.a, b, d was classified as a category 3 stock by ICES. In the spring of 2016, ICES was able to re-classify it as a category 1 stock as a result of the benchmark, IBPMeg (ICES, 2016a) and F_{MSY} range were estimated (ICES, 2016b). In Version 4 values were rounded.

⁺ Version 4; Plaice in Division 7e is a category 3 stock; therefore, ICES developed proxy reference points rather than ranges (see ICES, 2016c, 2016d).

Sole in Divisions 8a, b (Bay of Biscay) Sole in Divisions 7f, g (Celtic Sea) Sole (Solea solea) in Division 7e (Western Channel) Sole in Division 7a (Irish Sea) Whiting in Division 7e-k Whiting in Division 7a (Irish Sea)^{*} Whiting in Division 6a (West of Scotland) The plausible values around F_{MSY} should be based on the stock biology, fishery characteristics and environmental conditions.

ICES is also requested to advise on safeguard values; i.e. reference points that are associated to stock situations to avoid, such as stock sizes below which there is a known risk of very slow or no recovery.

Elaboration on ICES advice

The F_{MSY} ranges [F_{Iower} , F_{upper}] are derived to deliver no more than a 5% reduction in long-term yield compared with the maximum sustainable yield (MSY). This choice is subjective but a justification is provided in the Basis of the Advice section below. This approach has already been applied in the ICES advice for MSY ranges for stocks in the Baltic Sea and North Sea (ICES, 2015a).

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; i.e. no reduction in F with SSB less than MSY $B_{trigger}$. 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 prevailing 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 Greenland halibut, black-bellied anglerfish (*Lophius budegassa*), and *Nephrops*, harvest rates based on yield models have been used.

The resulting ranges are given in Table 5.4.1.1. These evaluations are all based on current biological conditions of growth, maturity, recruitment, and natural mortality. As the environment changes and species adapt, the values may need to be revised to reflect changing conditions. Fishery selectivity is based on estimates from recent 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} . Hence, in utilizing F_{MSY} ranges there are more advantages to fishing between F_{lower} and F_{MSY} than between F_{MSY} and F_{upper} .

With higher fishing mortalities, the following consequences occur:

- 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 Flower and FMSY. If this cannot be accomplished, an F

^{*} Version 4; Whiting in Division 7a is a category 3 stock; therefore, ICES developed proxy reference points rather than ranges (see ICES, 2016c, 2016d).

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 structural changes are required in the fishery to avoid the consequences listed. 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.

The stock dynamics are particularly uncertain for haddock in Division 6b (Rockall) and recruitment has been low during 2004–2012 (excepting the 2005 year class). In this period of recruitment, the probability of SSB being less than B_{lim} is >5%, even with no fishery. In 2013, ICES advised (ICES, 2013a) that when SSB is greater than B_{pa} , a maximum F of 0.2 would be required for the management to be consistent with the precautionary approach under a low recruitment regime. ICES is therefore unable to identify a precautionary range above this value and limits F_{upper} to 0.2. For Greenland halibut, black-bellied anglerfish (*Lophius budegassa*), seabass^{*}, and *Nephrops*, the calculations are based on deterministic yield models without quantitative evaluation of the probability of SSB < B_{lim} . Therefore, for these stocks, F_{upper} was set to F_{MSY} . For seabass in divisions 4b–c, 7a, and 7d–h, an upper limit is not currently available but work is ongoing to set an appropriate F_{upper} for this stock.

Table 5.4.1.1*F_{MSY} ranges for selected stocks in ICES subareas 5–10 [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 black-bellied anglerfish and Greenland halibut 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 code	Stock name	MSY F _{lower} with no AR	F _{MSY}	MSY F _{upper} with AR	MSY B _{trigger} (tonnes)	MSY F _{upper} with no AR
anp-8c9a	White anglerfish in divisions 8.c and 9.a (Cantabrian Sea, Atlantic Iberian Waters)	0.18	0.31	0.41	5400	0.41
bli-5b67	Blue ling in subareas 6–7 and Division 5.b (Celtic Seas, English Channel, and Faroes Grounds)	0.08	0.12	0.17	75000	0.14
bss-47‡	Seabass in divisions 4.b and c, 7.a, and 7.d– h (Central and South North Sea, Irish Sea, English Channel, Bristol Channel, Celtic Sea)				12673	
cod-7e-k	Cod in divisions 7.e–k (Eastern English Channel and Southern Celtic Seas)	0.23	0.35	0.55	10300	0.55
cod-iris	Cod in Division 7.a (Irish Sea)	0.23	0.37	0.63	10000	0.63
cod-scow	Cod in Division 6.a (West of Scotland)	0.11	0.17	0.25	20000	0.25
had-7b-k	Haddock in divisions 7.b–k (Southern Celtic Seas and English Channel)	0.26	0.40	0.60	10000	0.60
had-rock	Haddock in Division 6.b (Rockall)	0.13	0.20	0.20	10200	0.20
hke-nrth	Hake in subareas 4, 6, and 7 and divisions 3.a, 8.a, b, d (Northern stock) (Greater North Sea, Celtic Seas, Northern Bay of Biscay)	0.18	0.28	0.45	45000	0.45
hke-soth	Hake in divisions 8.c and 9.a (Southern stock) (Cantabrian Sea, Atlantic Iberian Waters)	0.17	0.25	0.36	11100	0.36
mgw-78§	Megrim in divisions 7b-k and 8a,b,d	0.12	0.19	0.29	41800	0.29

^{*} Version 4; The seabass stock was benchmarked after the release date of this advice. The F_{MSY} and respective ranges estimated in the original version of the advice are no longer valid. ICES did not update F_{MSY} and ranges.

⁺ Version 2; Table number corrected.

⁺ Version 4; Seabass values updated (ICES, 2016f) and values rounded for megrim (*Lepidorhombus whiffiagonis*) in divisions 7.b-k and 8.a, b, d.

[§] Version 3; Megrim (*Lepidorhombus whiffiagonis*) in divisions 7.b-k and 8.a, b, d added. In Version 4 values were rounded.

Stock code	Stock name	MSY F _{lower} with no AR	F _{MSY}	MSY F _{upper} with AR	MSY B _{trigger} (tonnes)	MSY F _{upper} with no AR
mgb-8c9a	Four-spot megrim in divisions 8.c and 9.a (Bay of Biscay South, Atlantic Iberian Waters East)	0.13	0.19	0.29	4600	0.29
mgw-8c9a	Megrim in divisions 8.c and 9.a (Cantabrian Sea, Atlantic Iberian Waters)	0.12	0.19	0.29	980	0.24
sol-bisc	Sole in divisions 8.a, b (Bay of Biscay North and Central)	0.18	0.33	0.49	10600	0.48
sol-celt	Sole in divisions 7.f and g (Bristol Channel, Celtic Sea)	0.15	0.27	0.42	2400	0.36
sol-echw	Sole in Division 7.e (Western English Channel)	0.16	0.29	0.34	2900	0.32
sol-iris	Sole in division .7a (Irish Sea)	0.16	0.20	0.24	3500	0.22
whg-7e-k	Whiting in divisions 7.b, c, e–k (Southern Celtic Seas and Eastern English Channel)	0.32	0.52	0.67	35000	0.58
whg-scow*	Whiting in Division 6.a (West of Scotland)	0.15	0.18^	0.18	44632	0.15

Stock code	Stock name	MSY Flower*	F _{MSY} *	MSY F _{upper} * with AR	MSY B _{trigger}	MSY F _{upper} * with no AR
anb-8c9a	Black-bellied anglerfish in divisions 8.c and 9.a (Cantabrian Sea, Atlantic Iberian Waters)	0.39× <i>r</i> **	r/2**	r/2**	0.25 × K**	r/2**
ghl-grn	Greenland halibut in subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)	0.39 × r **	r/2**	r/2**	0.25 × <i>K</i> **	r/2**
nep-11	Norway lobster in Division 6.a, FU 11 (West of Scotland, North Minch)	8.4%	10.8%	10.8%	540***	10.8%
nep-12	Norway lobster in Division 6a, FU 12 (West of Scotland, South Minch)	9.3%	11.7%	11.7%	1020***	11.7%
nep-13fc	Norway lobster in Division 6.a, FU 13fc (West of Scotland, the Firth of Clyde)	9.9%	15.1%	15.1%	580***	15.1%
nep-13sj	Norway lobster in Division 6.a, FU 13sj (West of Scotland, the Sound of Jura)	9.4%	12.0%	12.0%	160***	12.0%
nep-14	Norway lobster in Division 7.a, FU 14 (Irish Sea, East)	9.1%	11.0%	11.0%	350***	11.0%
nep-15	Norway lobster in Division 7.a, FU 15 (Irish Sea, West)	12.4%	18.2%	18.2%	3000***	18.2%
nep-16	Norway lobster in divisions 7.b, 7.c, 7.j, 7.k, FU 16 (West and Southwest of Ireland, Porcupine Bank)	5.0%	6.2%	6.2%	Not defined	6.2%
nep-17	Norway lobster in Division 7.b, FU 17 (West of Ireland, Aran Grounds)	7.4%	8.5%	8.5%	540***	8.5%
nep-19	Norway lobster in divisions 7.a, 7.g, 7j, FU 19 (Irish Sea, Celtic Sea, Eastern Southwest of Ireland)	8.3%	9.3%	9.3%	430***	9.3%
nep-22	Norway lobster in divisions 7.g, 7.f, FU 22 (Celtic Sea, Bristol Channel)	10.2%	12.8%	12.8%	990***	12.8%

^ F_{MSY} = 0.18 has been capped so that the probability of SSB < B_{lim} is no more than 5% when the ICES MSY AR is applied. If no AR rule was applied, the value would need to be capped at 0.15.

* Harvest rate (HR).

** 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.

*** Abundance in millions.

^{*} Version 3; Values updated based on new estimates (ICES, 2016f).

MSY reference points and ranges for megrim (*Lepidorhombus* spp.) in divisions 4.a and 6.a were provided by ICES in the March 2015 advice on MSY ranges for the North Sea and the Baltic Sea (ICES, 2015a). F_{MSY} reference points are not provided for plaice in Division 7e (Western English Channel) and whiting in Division 7a (Irish Sea); proxy reference points are provided in ICES (2016c, 2016d), but ranges are not defined.

Basis of the advice

Background

This advice is based on work conducted in a workshop that was held 13–16 October 2015 in Brest, France (ICES, 2016e).

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, 2016e). 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 the annual probability of SSB < B_{lim} should be no more than 5%.

To develop suitable F_{MSY} ranges, ICES has used the following criteria:

- 1) MSY is interpreted as the 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 (Rockall haddock).
- 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} (the ICES Advice Rule). 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 (by which is meant the uncertainty associated with the advice) 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 (i.e. when the estimation of F_{MSY} is based on a deterministic calculation and there is no B_{lim} or no evaluation of the probability of SSB < B_{lim}), 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 5.4.1.1)	F _{MSY}	F _{lower} —F _{upper}
F _{MSY} < F _{P.05} < F _{upper}	(Figure 5.4.1.2)	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 define	d	F _{MSY}	F _{lower} —F _{MSY}

Results and conclusions

The results are summarized in Table 5.4.1.2. This table gives the initial values of F_{MSY} and the F_{MSY} upper and lower ranges based on 5% reduction in yield. The table also shows the F values that give a 5% probability of SSB falling below MSY $B_{trigger}$. This is provided both with and without ICES AR applied. The values of F_{MSY} and F_{MSY} upper are modified based on these precautionary considerations detailed in the text table above.

The first option in the text table above is illustrated by four-spot megrim in divisions 8.c and 9.a, for the situation where F_{MSY} is substantially lower than $F_{P.05}$ (Figure 5.4.1.1). For four-spot megrim the F_{MSY} is estimated at F = 0.19 with lower and upper ranges of 0.13 and 0.29, respectively. In this first case $F_{P.05}$ = 0.40, 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 Western English Channel sole in Division 7.e (Figure 5.4.1.2). The peak yield for this stock is obtained at $F_{MSY} = 0.29$; the yield reduces to 95% of the maximum at a lower F of 0.16 and at an upper F of 0.34. Above the upper F value, yield falls quickly. For this stock F_{MSY} is below, but close to F values that do not comply with ICES precautionary considerations. Without applying the advice rule, $F_{P.05}$ (the F value that leads to 5% probability of SSB < B_{lim}) is estimated to be 0.32. Therefore, without applying the advice rule, values of F greater than 0.32 would not be considered by ICES to be precautionary, and F_{upper} would be capped at $F_{P.05} = 0.32$.

The importance of ICES MSY advice rule (AR) leading to reduced realized F for stocks with a low $F_{P.05}$ is shown for sole in Division 7e (Figure 5.4.1.3). The comparatively higher yield at high F relative to Figure 5.4.1.2 is because real F does not follow the reference F, but real F 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 5.4.1.2. This shows that with the AR in place $F_{P.05}$ = 0.40 compared to $F_{P.05}$ = 0.32 without the AR. The substantial increase in biomass at higher Fs results from the inclusion of MSY B_{trigger}. This can be seen most clearly by comparing the right panels of Figures 5.4.1.2 and 5.4.1.3 at the point where a reference F of 0.6 was used.

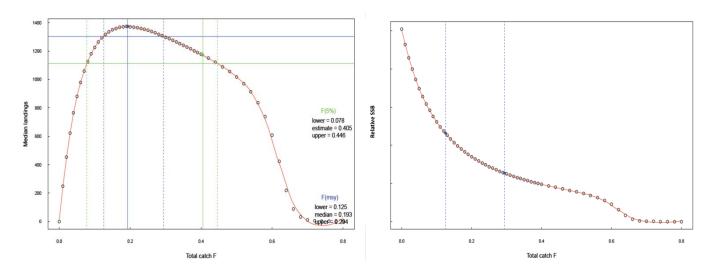


Figure 5.4.1.1^{*} Four-spot megrim in divisions 8.c and 9.a, with fixed F exploitation from catch F = 0 to 0.8. Left panel: Median landings yield (circles) and fitted curve (red) with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green vertical 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.

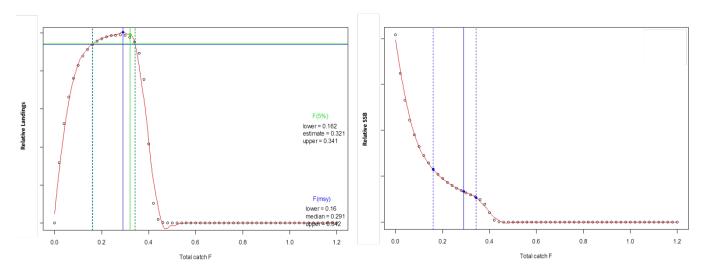


Figure 5.4.1.2⁺ Sole in Division 7e with fixed F exploitation from catch F = 0 to 1.2. Left panel: Median landings yield (circles) and fitted curve (red) with estimated reference points. Blue lines: F_{MSY} estimate (solid) and range at 95% of maximum yield (dotted). Green vertical line: F_{P.05} estimate (solid). Right panel: Median SSB. Units are not given for the *y*-axis as only relative values are considered reliable.

^{*} Version 2; Figure number corrected.

⁺ Version 2; Figure number corrected.

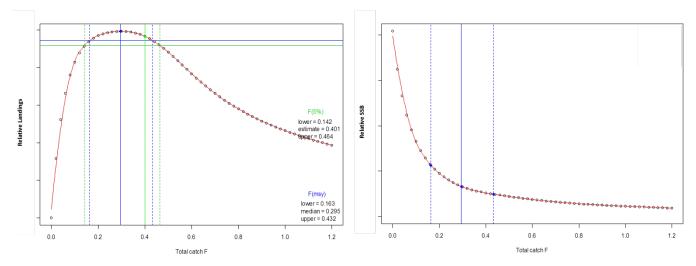


Figure 5.4.1.3* Sole in Division 7e with F exploitation (modified by F reduction when SSB is below MSY B_{trigger} at 2900 t from F = 0 to 1.2). Realized F is reduced as SSB declines, with high F reducing the catch advice according to the advice rule. Left panel: Median landings yield (circles) and fitted 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). The comparatively higher yield at high F relative to Figure 5.4.1.2 comes because real F is reduced due to lower biomass as the AR provides protection for the stock and F_{P.05} = 0.40 compared to F_{P.05} = 0.32 without the AR. Right panel: Median SSB. Units are not given for the *y*-axis as only relative values are considered reliable.

Yield curves such as those illustrated in Figures 5.4.1.1 to 5.4.1.3 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 5.4.1.2). For stocks with a defined B_{lim} or a plausible proxy, two precautionary $F_{P.05}$ were computed, one assuming a constant F exploitation and with the other assuming the implementation of the AR. The precautionary $F_{P.05}$ based on the AR shows an increase compared with the $F_{P.05}$ value in the option that omits the AR.

The F ranges over which the yield changes by no more than 5% are wide (Table 5.4.1.2). In some cases (e.g. northern hake) the upper limit can be much larger than F_{MSY} . The stocks fall into two main categories. Firstly, the cod and hake stocks, where F_{upper} is below precautionary reference points. Secondly, there are a number of stocks where precautionary considerations dominate and F_{upper} has to be reduced; e.g. all sole and whiting stocks.

^{*} Version 2; Figure number corrected.

Table 5.4.1.2*	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.

Stock	Stock name	ned to be at or t	Preca	utionary F	, F _{MSY} , and F out Advice R	intervals	With AR	Options for upper bound, all limited by PA considerations F< F _{P.05}	
code		Source	F _{P.05}	F _{MSY}	95% below	95% above	F _{P.05AR}	95% yield, no AR	95% yield, with AR
anp-8c9a	White anglerfish in Divisions 8.c and 9.a (Cantabrian Sea, Atlantic Iberian Waters)	ICES (2016e)	0.46	0.31	0.18	0.41	1.0^	0.41	0.41
bli-5b67	Blue ling in Subareas 6–7 and Division 5.b (Celtic Seas, English Channel, and Faroes Grounds)	ICES (2016e)	0.14	0.12	0.08	0.17	0.18	0.14	0.17
bss-47†	Seabass in Divisions 4.b and c, 7a, and 7.d–h (Central and South North Sea, Irish Sea, English Channel, Bristol Channel, Celtic Sea)	ICES (2014a)		****	****			****	****
cod-7e-k	Cod in Divisions 7.e–k (Eastern English Channel and Southern Celtic Seas)	ICES (2016e)	0.55	0.35	0.23	0.55	0.63	0.55	0.55
cod-iris	Cod in Division 7.a (Irish Sea)	ICES (2016e)	1.00	0.37	0.23	0.63	1.01	0.63	0.63
cod-scow	Cod in Division 6.a (West of Scotland)	ICES (2016e)	0.54	0.17	0.11	0.25	0.65	0.25	0.25
had-7b-k	Haddock in Divisions 7.b–k (Southern Celtic Seas and English Channel)	ICES (2016e) ICES (2015b)	0.74	0.40	0.26	0.60	0.84	0.60	0.60
had-rock	Haddock in Division 6.b (Rockall)	ICES (2016e) ICES (2013b)	0.20	0.20	0.13	0.30	0.20	0.20	0.20
hke-nrth	Hake in Subareas 4, 6, and 7 and Divisions 3.a, 8.a, 8.b, and 8.d (Northern stock) (Greater North Sea, Celtic Seas, Northern Bay of Biscay)	ICES (2016e)	0.87	0.28	0.18	0.45	1.00	0.45	0.45
hke-soth	Hake in Divisions 8.c and 9.a (Southern stock) (Cantabrian Sea, Atlantic Iberian Waters)	ICES (2016e)	0.88^^	0.25	0.17	0.36	0.88^^	0.36	0.36
mgw-78‡	Megrim in Divisions 7.b-k and 8.a,b,d	ICES (2016b)	0.40	0.19	0.12	0.29	0.42	0.29	0.29
mgb-8c9a	Four-spot megrim in Divisions 8.c and 9.a (Bay of Biscay South, Atlantic Iberian Waters East)	ICES (2016e)	0.40	0.19	0.13	0.29	0.58	0.29	0.29
mgw-8c9a	Megrim in Divisions 8.c and 9.a (Cantabrian Sea, Atlantic Iberian Waters)	ICES (2016e)	0.24	0.19	0.12	0.29	0.40	0.24	0.29
sol-bisc	Sole in Divisions 8.a and 8.b (Bay of Biscay North and Central)	ICES (2016e)	0.48	0.33	0.18	0.49	0.59	0.48	0.49
sol-celt	Sole in Divisions 7.f and 7.g (Bristol Channel, Celtic Sea)	ICES (2016e)	0.36	0.27	0.15	0.42	0.43	0.36	0.42
sol-echw	Sole in Division 7.e (Western English Channel)	ICES (2016e)	0.32	0.29	0.16	0.34	0.40	0.32	0.34
sol-iris	Sole in Division 7.a (Irish Sea)	ICES (2016e)	0.22	0.20	0.16	0.24	0.26	0.22	0.24

^{*} Version 2; Table number corrected

⁺ Version 4; FMSY value not available after the IBPBass 2016 (ICES, 2016g).

⁺ Version 3; Megrim (*Lepidorhombus whiffiagonis*) in divisions 7.b-k and 8.a, b, d added. In Version 4 values were rounded. *ICES Advice 2016, Book 5*

Stock	Stock name	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}		
code	Stock hame	Source	F	F _{P.05} F _{MSY}	95%	95%	ED OF AD	95% yield,	95% yield,
			FP.05		below	above		no AR	with AR
whg-7e-k	Whiting in Divisions 7.b, c, e–k (Southern	ICES (2016e)	0.58	0.58 0.52	0.32	0.83	0.67	0.58	0.67
wng-7е-к	Celtic Seas and Eastern English Channel)					0.65			
whg- scow*	Whiting in Division 6a (West of Scotland)	ICES (2016f)	0.15	0.20	0.15	0.24	0.18	0.15	0.18

Stock code	Stock name	Source	HR _{MSY} **	HR _{lower} ** 95% below	HR _{upper} ** 95% above	HR _{upper} ** no AR	HR _{upper} ** with AR
anb-8c9a	Black-bellied anglerfish in Divisions 8.c and 9.a (Cantabrian Sea, Atlantic Iberian Waters)	ICES (2016e)	r/2	0.39 × r	r/2*	r/2*	r/2*
ghl-grn	Greenland halibut in Subareas 5, 6, 12, and 14 (Iceland and Faroes grounds, West of Scotland, North of Azores, East of Greenland)	ICES (2016e)	r/2	0.39 × r	r/2*	r/2*	r/2*
nep-11	Norway lobster in Division 6.a, FU 11 (West of Scotland, North Minch)	ICES (2016e)	10.8%	8.4%	19.8%	10.8%*	10.8%*
nep-12	Norway lobster in Division 6.a, FU 12 (West of Scotland, South Minch)	ICES (2016e)	11.7%	9.3%	24.1%	11.7% *	11.7%*
nep-13fc	Norway lobster in Division 6.a, FU 13 _{fc} (West of Scotland, the Firth of Clyde)	ICES (2016e)	15.1%	9.9%	23.1%	15.1% *	15.1%*
nep-13sj	Norway lobster in Division 6.a, FU 13 _{sj} (West of Scotland, Sound of Jura)	ICES (2016e)	12.0%	9.4%	23.1%	12.0% *	12.0%*
nep-14	Norway lobster in Division 7.a, FU 14 (Irish Sea, East)	ICES (2016e)	11.0%	9.1%	25.3%	11.0%*	11.0%*
nep-15	Norway lobster in Division 7.a, FU 15 (Irish Sea, West)	ICES (2016e)	18.2%	5 12.4%	27.9%	18.2%*	18.2%*
nep-16	Norway lobster in Divisions 7.b, 7.c, 7.j, and 7.k, FU 16 (West and Southwest of Ireland, Porcupine Bank)	ICES (2016e)	6.2%	5.0%	24.0%	6.2%*	6.2%*
nep-17	Norway lobster in Division 7.b, FU 17 (West of Ireland, Aran Grounds)	ICES (2016e)	8.5%	7.4%	20.5%	8.5%*	8.5%*
nep-19	Norway lobster in Divisions 7.a, 7.g, and 7.j, FU 19 (Irish Sea, Celtic Sea, Eastern Southwest of Ireland)	ICES (2016e)	9.3%	8.3%	19.1%	9.3%*	9.3%*
nep-22	Norway lobster in Divisions 7.g and 7.f, FU 22 (Celtic Sea, Bristol Channel)	ICES (2016e)	12.8%	5 10.2%	24.0%	12.8%*	12.8%*

^ The exact value of $F_{p.05}$ has not been calculated, but the available calculations indicate it is around 1.

[^] Proxy value for F_{p.05}, calculated as the F that corresponds to B_{pa} in equilibrium, as it has not been possible to carry out a full stochastic evaluation for this stock.

* F_{MSY} range capped at F_{MSY} because it has not been possible to evaluate the probability of SSB < B_{lim} .

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

^{*} Version 3; Values for whiting in division 6.a updated based on new estimates (ICES, 2016f).

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, 2014b) and WKMSYREF3 (ICES, 2014c) and is documented in the report of WKMSYREF4 (ICES, 2016e). All of the stocks evaluated are in ICES category 1. These were evaluated using age-based stochastic simulation methods. For two stocks (Greenland halibut and black-bellied anglerfish) a biomass model was used to estimate exploitation rate relative to F_{MSY} . For these stocks, 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 yield-per-recruit analysis.

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. Three options were allowed (Ricker, Beverton–Holt, and segmented regression) which imply different dynamics at high biomass. In some cases, the weighting of each of the model options was determined statistically. Where this results in dynamics that are considered unrealistic and/or did not conform to the precautionary basis of B_{lim} , in most cases the choice of model was a segmented regression. Under these circumstances, 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 evaluation of ranges is based on a 5% reduction 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.

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

- a) landings where discards are unquantified but not negligible; e.g. Celtic Sea cod, Irish Sea sole^{*}; and
- b) landings where discards are known or negligible; e.g. haddock, hake, megrim, and whiting.

To maximize catch implies that it would be consistent with MSY to increase the proportion of the catch which is below the minimum conservation size (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.

Implementation of stochasticity

Descriptions of how to implement stochasticity, process and estimation uncertainty and correlated errors are provided in ICES (2013a), 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 sampling approach (randomly drawing from the values in the historical time-series). Uncertainties were included when estimating recruitment from stock–recruitment relationships as this is usually the main source of variation. Inclusion of stochastic draws from interannual 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}. The combined uncertainty in assessment and short-term forecast was included in the evaluations. This uncertainty was generally estimated from a number of stocks where 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 could be obtained. Details can be found in the WKMSYREF4 report (ICES, 2016e).

^{*} Version 4; Text updated to exclude seabass.

Additional information

The F_{MSY} ranges are derived based on a 5% reduction of yield 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 the use of precision may result in perverse incentives to know less in order to achieve wider ranges.

MSY $B_{trigger}$ is the parameter in the ICES advice rule that triggers a reduced fishing mortality relative to F_{MSY} . The evolution in the determination of MSY $B_{trigger}$ requires contemporary data with fishing at F_{MSY} to identify the normal range of fluctuations in biomass when stocks are fished at this fishing mortality rate. Because MSY $B_{trigger}$ is intended to safeguard against an undesirable or unexpected low SSB when fishing at F_{MSY} , the trigger reference point should be based on the natural variation in SSB and the assessment uncertainty once F_{MSY} has been reached. Consequently, as stocks consistently achieve fishing mortality at F_{MSY} , the values of MSY $B_{trigger}$ will likely be revised together with the estimates of F_{upper} .

ICES has started a process to progressively update MSY $B_{trigger}$ from current values (typically B_{pa}) towards values consistent with the range of biomasses observed when fishing at F_{MSY} . The scheme was applied to all stocks in the request for which it was possible to simulate the distribution of SSB when fishing at F_{MSY} (as the scheme requires calculating the 5th percentile of this distribution). The scheme resulted in MSY $B_{trigger} = B_{pa}$ for all stocks except for white anglerfish (anp-8c9a), for which MSY $B_{trigger}$ is considerably above B_{pa} . MSY $B_{trigger}$ values are presented in Table 5.4.1.1. The B_{pa} reference point is not available for *Nephrops* or the two stocks assessed with a biomass dynamic model (black-bellied anglerfish, anb-8c9a; Greenland halibut, ghl-grn). For the latter two stocks, MSY $B_{trigger}$ is set at 50% B_{MSY} , where B_{MSY} is a model parameter estimated as part of the stock assessment. For *Nephrops* stocks, MSY $B_{trigger}$ is mostly set at the lowest observed abundance (if the stock has shown no signs of stress at that abundance); for a few *Nephrops* stocks, preliminary MSY $B_{trigger}$ values were set based on the 5th percentile of a distribution fitted to the observed abundances.

The precautionary biomass reference point, B_{lim} , has been systematically reviewed. For a few stocks (had-rock, hke-nrth, hkesoth, mgw-8c9a, sol-echw, and sol-iris) values of B_{lim} have been revised. Values of B_{lim} have been provided for stocks for which this reference point was previously undefined (anp-8c9a, bli-5b67, sol-bisc, and sol-7fg). When B_{lim} values have been revised or defined, B_{pa} values were revised accordingly (ICES, 2016e). For stocks with MSY $B_{trigger} = B_{pa}$, the MSY $B_{trigger}$ values were also revised accordingly.

The evaluation of Rockall haddock was carried out initially using the full range of recruitment, which indicated an F_{upper} value of approximately 0.30. However, recent recruitment has been very low and an evaluation of the precautionary considerations with recent (ten years) recruitment indicated that only much lower Fs could be considered precautionary. ICES carried out a detailed management plan evaluation in 2013 which indicated that F = 0.2 was the highest F that could be considered precautionary (ICES, 2013b); therefore, F_{MSY} and F_{upper} were capped at 0.20.

Due to the complexity of the assessment model it was not possible at this time to carry out full stochastic evaluations for southern hake. It was possible to estimate F_{MSY} and F ranges with the inclusion of only partial stochastic elements. Comparisons with northern hake indicated that the estimates of F_{MSY} and F_{upper} were both well below any candidate values for $F_{p.05}$ for southern hake and, as such, the estimated values were considered to be precautionary and used to define the ranges.

The evaluation for whiting in the West of Scotland, using the full range of recruitment indicates that high long-term yield can be obtained at Fs higher than $F_{P.05}$ (where $F_{P.05} = 0.15$ if no AR is applied or = 0.18 if AR is applied), but as these would not be considered precautionary, F_{MSY} was capped at $F_{P.05}$. The stock dynamics are particularly uncertain for this stock and recent recruitment (2002–2013) has been low.

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* Version 4; Reference added.