3.4.1* Norway/Russia request for evaluation of harvest control rules for Northeast Arctic cod and haddock and for Barents Sea capelin

Advice summary

ICES advises that the harvest control rules (HCRs) considered in this request for cod and haddock are all precautionary in accordance with the ICES standard that the annual probability of SSB falling below B_{lim} should be no more than 5%.

For cod, scenarios with a higher F (HCRs 3 to 10) than used presently (HCR 2) result in 1%–4% higher long-term median yield, but there is up to a threefold increase in interannual TAC variability. The median long-term SSB expected with the higher F HCRs is 4%–16% lower than under the HCR used presently. The HCR with the lowest F (HCR 1) leads to a 7% decrease in median long-term catch relative to HCR 2, lower interannual variability in TAC, and higher SSB.

For haddock, scenarios with a higher F (HCRs 3, 5, and 6) than under the one used presently (HCR 2) result in 0%–4% higher long-term median yield, with an increase in interannual TAC variability between 13% and 36%. The median long-term SSB expected with the higher F HCRs is around 20% lower than under the HCR used presently. HCRs 1 (lower target F) and 4 (10% limit on interannual TAC variation) lead to lower long-term catch, lower interannual TAC variability, and higher median long-term SSB than HCR 2.

For cod, yield is expected to decline relative to the 2015 TAC and SSB is expected to stabilize in the short term (next three years), whereas for haddock both yield and SSB are expected to decline in the short term for all the HCRs in the request.

For capelin, the HCRs based on the 90%, 85%, and 80% criteria are not precautionary in the ICES evaluation context by definition; only the rule implemented in the current management plan, corresponding to the 95% criterion, may be precautionary. An examination of the stock dynamics in recent decades, when the current HCR (based on 95% criterion) or the previous HCR (based on a similar escapement strategy) were in operation suggests that these HCRs resulted in sustainable exploitation. The overall effect of allowing a higher probability of SSB < B_{lim} would be that the fishery would be opened at a lower survey biomass (maturing capelin), the TAC would increase and the resulting spawning biomass would be lower, potentially increasing the risk of recruitment failure. The 2015 survey estimate for capelin was low and would have led to closure of the fishery in 2016 under all suggested HCRs.

Request

The Joint Norwegian-Russian Fisheries Commission (JNRFC) has previously agreed to revise the existing harvest control rules for Northeast Arctic cod and haddock and Barents Sea capelin by 2015. In order to provide background information for this revision, JNRFC asks ICES to explore the consequences of the following harvest control rules:

Northeast Arctic cod:

1. The existing harvest control rule, but with Ftarget=0.30 instead of 0.40 and removing the F>=0.30 constraint

2. The existing harvest control rule (Ftarget=0.40)

3. The existing harvest control rule, but with Ftarget=0.50 instead of 0.40

4. The existing harvest control rule (Ftarget=0.40), but with maximum 20% variation in TAC from year to year

5. The existing harvest control rule (Ftarget=0.40) but with no constraint on maximum variation in TAC from year to year and removing the F>=0.30 constraint.

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*6. The existing harvest control rule, but with increased F for high SSBs (F= Ftarget=0.40 for SSB between Bpa and 2*Bpa, then increasing linearly to F=0.60 at SSB=3*Bpa, equal to 0.60 for SSB above 3*Bpa) and with maximum 20% variation in TAC from year to year.*

*7. The existing harvest control rule, but with increased F for high SSBs (F= Ftarget=0.40 for SSB between Bpa and 2*Bpa, then increasing linearly to F=0.60 at SSB=3*Bpa, equal to 0.60 for SSB above 3*Bpa) and no constraint on maximum variation in TAC from year to year and removing the F>=0.30 constraint.*

*8. The existing harvest control rule, but with increased F for high cod SSBs if the capelin stock is low. F= Ftarget=0.40 for SSB between Bpa and 2*Bpa, irrespective of capelin stock size. If the capelin stock is low, then F should be increased linearly from 0.40 at SSB=2*Bpa to F=0.60 at SSB=3*Bpa, and set equal to 0.60 for SSB above 3*Bpa. Maximum 20% variation in TAC from year to year.*

*9. The existing harvest control rule, but with increased F for high cod SSBs if the capelin stock is low. F= Ftarget=0.40 for SSB between Bpa and 2*Bpa, irrespective of capelin stock size. If the capelin stock is low, then F should be increased linearly from 0.40 at SSB=2*Bpa to F=0.60 at SSB=3*Bpa, and set equal to 0.60 for SSB above 3*Bpa and no constraint on maximum variation in TAC from year to year and removing the F>=0.30 constraint.*

*10. The existing harvest control rule, but with increased F for high SSBs (F increasing linearly from Ftarget=0.40 for SSB=Bpa to 0.60 at SSB=5*Bpa, equal to 0.60 for SSB above 5*Bpa), no constraint on maximum variation in TAC from year to year and removing the F>=0.30 constraint.*

This gives a total of 10 different rules to be explored, one of which is the existing harvest control rule.

In cases 1-9 the following conditions should apply in the harvest control rule:

TAC for the quota year will be set to the average TAC level for the coming 3 years based on Ftarget.
if the spawning stock in the quota year falls below Bpa, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from Ftarget at Bpa, to F= 0 at SSB equal to zero. At SSB-levels below Bpa in any of the operational years (quota year, the year before and 3 years of prediction) there should be no limitations on the year-to-year variations in TAC.

In case 10 the following conditions should apply in the harvest control rule:

TAC for the quota year will be set to the average TAC level for the coming 2 years based on Ftarget.
If the spawning stock in the quota year falls below Bpa, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from Ftarget at Bpa, to F= 0 at SSB equal to zero.

In cases 8 and 9, the capelin stock will be considered as low when the total stock is below 1 million tonnes and the immature stock is below 500 thousand tonnes. The quota advice for cod would initially be given based on F= Ftarget=0.40, for all cod SSB values exceeding Bpa, when the cod assessment is carried out. Then the possible adjustment in F related to capelin stock size would be applied after the capelin stock assessment has been carried out.

Northeast Arctic haddock

1. The existing harvest control rule, but with Ftarget =0.27 instead of 0.35

2. The existing harvest control rule

3. The existing harvest control rule, but with Ftarget =0.43 instead of 0.35

4. The existing harvest control rule, but with a constraint of maximum 10% TAC variation from year to year instead of a 25% constraint which is presently used

5. The existing harvest control rule, but with no constraint of maximum TAC variation from year to year

6. The existing harvest control rule, but without limitation +25% (see note below).

This gives a total of 6 different rules to be explored, one of which is the existing harvest control rule.

In all cases the following condition should apply in the harvest control rule:
if the spawning stock in the quota year falls below Bpa, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from Ftarget at Bpa, to F= 0 at SSB equal to zero. At SSB-levels below Bpa in any of the operational years (quota year and the year before) there should be no limitations on the year-to-year variations in TAC.

Note: After clarification with clients rule 6, should be interpreted as:
6. The existing harvest control rule, with a constraint of -25% in TAC reduction from year to year but with no constraint for increases in TAC.

Barents Sea capelin

The existing harvest control rule with varying probabilities for the spawning stock biomass to be above 200 thousand tonnes (i.e. 80, 85, 90 or 95 %). This gives a total of 4 different rules to be explored, one of which corresponds to the existing harvest control rule.
The effect of each of the harvest control rules for cod stated above on the capelin yield should be explored.

For all stocks, information about yield, variability, risk levels, stock levels and size/age composition of catch and stock in a short, medium and long term perspective should be provided.

For the purpose of this advice the 'existing harvest control rule' is the following

Species and objective	***Norwegian and Russian text***	***Unofficial English Translation***
Cod *The management strategies for cod and haddock should take into account the following:* - *conditions for high long-term yield from the stocks* - *achievement of year-to-year stability in TACs* - *full utilization of all available information on stock development*	Annex 12 in the Protocol of the 45th Session of the Joint Russian–Norwegian Fisheries Commission October 2014	- *estimate the average TAC level for the coming 3 years based on* $\boldsymbol{F_{pa}}$*. TAC for the next year will be set to this level as a starting value for the 3-year period.* *The year after, the TAC calculation for the next 3 years is repeated based on the updated information about the stock development, however the TAC should not be changed by more than +/- 10% compared with the previous year's TAC. If the TAC, by following such a rule, corresponds to a fishing mortality (F) lower than 0.30 the TAC should be increased to a level corresponding to a fishing mortality of 0.30.*

		*If the spawning stock falls below **B_{pa}**, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from F_{pa} at B_{pa}, to F= 0 at SSB equal to zero. At SSB-levels below **B_{pa}** in any of the operational years (current year, a year before and 3 years of prediction) there should be no limitations on the year-to-year variations in TAC."* *Currently the accepted values are **B_{pa}** = 460,000 tons; **F_{pa}** = 0.4 per year*
Haddock *The management strategies for cod and haddock should take into account the following:* - *conditions for high long-term yield from the stocks* - *achievement of year-to-year stability in TACs* - *full utilization of all available information on stock development*	Protocol of the 45th Session of The Joint Norwegian Russian Fishery Commission, October 2014. B_{pa} and F_{MSY} were agreed at the 2012 meeting of the Joint Norwegian Russian Fishery Commission	- *TAC for the next year will be set at level corresponding to **F_{MSY}**.* - *The TAC should not be changed by more than +/- 25% compared with the previous year TAC.* - *If the spawning stock falls below **B_{pa}**, the procedure for establishing TAC should be based on a fishing mortality that is linearly reduced from **F_{MSY}** at **B_{pa}** to F= 0 at SSB equal to zero. At SSB-levels below B_{pa} in any of the operational years (current year and a year ahead) there should be no limitations on the year-to-year variations in TAC.* *Currently, the accepted values are **B_{pa}** = 80,000 t; **F_{MSY}** = 0.35 per year.*
Capelin *Assuring minimum spawning biomass*	Annex 12 in the Protocol of the 45th Session of the Joint Russian–Norwegian Fisheries Commission, October 2014	*The TAC for the following year should be set so that, with 95% probability, at least 200 000 t of capelin (**B_{lim}**) will be allowed to spawn."*

Elaboration on the advice

Cod

Using the agreed B_{lim} (220 000 t) the ten proposed HCRs are all found to be precautionary in accordance with the ICES standard, i.e. that the short-, medium-, and long-term probability of the SSB falling below B_{lim} is ≤ 5%. HCR 2 is the current harvest control rule and is used as the yardstick against which to compare the proposed rules on other performance measures such as yield, interannual variability of yield, and stock size.

The effect of varying the target fishing mortality is considered by comparing HCRs 1 (F_{target} = 0.3), 2 (F_{target} = 0.4, current rule), and 3 (F_{target} = 0.5). The median long-term yield is 7% less for HCR 1 and 4% more for HCR 3 than for the current HCR 2. The yield variability between consecutive years increases with increased fishing mortality; the mean change (%) in TAC almost doubles when increasing the target fishing mortality from F_{target} = 0.3 to F_{target} = 0.5. Median long-term SSB decreases by 27% when comparing F_{target} = 0.5 to F_{target} = 0.3.

The effect of allowing a less restrictive constraint on year-to-year variation in TAC but maintaining the F ≥ 0.30 constraint is investigated in HCR 4 (±20% TAC constraint instead of the ±10% in HCR 2), whereas HCR 5 drops both constraints. Median long-term yield is expected to increase by about 1% (HCR 4) and an additional 1% (HCR 5) relative to HCR 2. The variability in TAC between consecutive years increases by 43% (HCR 4) or 117% (HCR 5) relative to HCR 2. The median long-term SSB is lower in both cases.

In HCRs 6–10 the target fishing mortality is increased when the estimated spawning stock exceeds certain thresholds. For HCRs 6 and 7, the proportion of years with F increased above 0.4 (because cod SSB was higher than 2 × B_{pa}) was between 15% and 21%. For HCRs 8 and 9 which, in addition to cod SSB being higher than 2 × B_{pa}, require a low capelin stock for F to be increased above 0.4, this proportion was 5%–7%. The median long-term catch in HCRs 6–10 was 1%–2% higher than in HCR 2, but the interannual variability in catch increased considerably (48%–195% increase). Median long-term SSB is lower for all these HCRs relative to HCR 2.

For all HCRs, 3-year deterministic projections (years 2016–2018) were made using input from the 2015 stock assessment (ICES, 2015a). The corresponding catch and SSB levels are shown in Figure 3.4.1.1. The SSB at the end of the period (start of 2019) ranges from 1.0 million tonnes (HCR 3) to 1.3 million tonnes (HCR 1). These values are all close to the 2016 SSB (1.1 million tonnes), indicating a stable stock in the short term. These values are very high compared to B_{lim} (220 000 t), indicating that the risk of falling below B_{lim} in the short term is negligible.

Haddock

Using the agreed B_{lim} (50 000 t) all proposed HCRs are found to be precautionary in accordance with the ICES standard, i.e. the short-, medium-, and long-term probability that the SSB falls below B_{lim} is ≤ 5%. HCR2 is the current harvest control rule and is used as the yardstick against which to compare the proposed rules on other performance measures such as yield, interannual variability of yield, and stock size.

The effect of varying the target fishing mortality is considered comparing HCRs 1 (F_{target} = 0.27), 2 (F_{target} = 0.35, current rule), and 3 (F_{target} = 0.43). The median long-term yield is 3% less for HCR 1 and 2% more for HCR 3 than for the current HCR 2. The yield variability between consecutive years increases with increased fishing mortality; the mean change (%) in TAC from HCR 1 to HCR 3 is a 73% increase. The TAC constraint of ±25% is expected to be applied in about half of the years, on average. Median long-term SSB decreases by 38% when comparing F_{target} = 0.43 to F_{target} = 0.27.

Narrowing the TAC constraint to a ±10% year-to-year change (HCR 4) decreases the median annual long-term yield (6% decrease) relative to HCR 2. The yield loss is a result of the fact that in more than half of the years the TAC increase will be capped by the 10% constraint. The median long-term SSB will be higher (32% higher) than with HCR 2, but the tighter TAC constraint also delays the response when the stock decreases, resulting in high F, which in turn results in a higher probability of SSB falling below B_{lim}. This HCR gave less interannual variability in catches than HCR 2.

HCRs 5 and 6 both have F_{target} = 0.35 (as has HCR 2), but no constraint in year-to-year-change in TAC (HCR 5) or only a 25% constraint downwards (HCR 6). These HCRs gave more interannual variability in catches than HCR 2. HCR 5 gives the same median catch as HCR 2, whereas HCR 6 results in a 4% increase. Median long-term SSB decreases relative to HCR 2.

Yield will, irrespectively of the TAC constraint, be highly variable between years as a result of the strongly variable recruitment. Variability in TAC (and hence yield) will decrease with decreasing fishing mortality.

The stock–recruitment relationship is highly uncertain and the risks computed in this evaluation may have been underestimated. The risk calculated for HCR 3 (4.9%) is just below the boundary (5%) of the ICES criterion of ≤ 5% probability of SSB falling below B_{lim} and this suggests that lower F_{target} values are preferable.

For all HCRs, 3-year deterministic projections (2016–2018) were made using input from the 2015 stock assessment (ICES, 2015a). The corresponding catch and SSB levels are shown in Figure 3.4.1.3. The SSB at the end of the period (start of 2019) ranges from 230 000 t (HCR 3) to 350 000 t (HCR 1). These values are all below the 2016 SSB (640 000 t), but are still very high compared to B_{lim} (50 000 t), indicating that the risk of falling below B_{lim} in the short term is negligible.

Capelin

The request asks ICES to explore the behaviour of HCRs for 95%, 90%, 85%, and 80% probability of SSB > 200 000 tonnes (B_{lim}). The HCRs with 90%, 85%, and 80% probabilities of SSB > B_{lim} correspond, by definition, to risks of 10%, 15%, and 20% of SSB < B_{lim}, respectively, and are not precautionary in the ICES evaluation context; only the 95% rule may be precautionary.

Capelin stock dynamics are highly dependent on both predation from other stocks (influence of herring on recruitment and of cod on mortality of adult capelin) and on environmental factors. Due to this complexity a full evaluation of HCRs for capelin using long-term stochastic simulations has not been possible at this time. Also, the spawning stock is not measured directly and there is almost total spawning mortality; SSB can therefore only be calculated from the projection model. Thus, estimates of historical SSB levels for this stock are subject to more uncertainty than for most stocks.

However, over the last 35 years, recruitment has been adequate when capelin SSB was sufficiently high and the amount of young herring in the Barents Sea was low, creating good conditions for capelin recruitment. This suggests that both the current HCR (1999–present) and the previous HCR (ca. 1980–1998), based on a similar escapement strategy, resulted in sustainable exploitation.

Work on modelling species interactions between cod, herring, and capelin is ongoing. Until such work has led to significant improvements in the model, ICES does not consider that further simulations will generate more insight into the HCR performance.

The overall effect of an increased risk is that the fishery is opened at a lower survey biomass (maturing capelin), that the TAC is increased, and that the risk of recruitment failure is increased because of the lower spawning biomass. However, the risk of resulting reduced recruitment cannot be quantified. Using the 5% criterion, the HCR suggests that the fishery will be closed if the observed survey biomass (maturing capelin) result is below around 1.15 million tonnes. Each doubling of the risk from 5% to 10% and from 10% to 20% adds 50 000–60 000 t to the TAC and the minimum survey biomass that will allow a fishery is lowered by about 150 000 t. A cod–capelin model is used in these calculations and the results apply to the cod biomasses expected under current management and the current productivity of the Northeast Arctic cod stock, i.e. for an immature cod biomass of around 1.8 million tonnes. Immature cod is the major predator of adult capelin and the survival of maturing capelin depends on the size of the cod stock. The cod harvest control rules evaluated here predict only limited variation in the immature cod biomass and variation in capelin survival within that range is dominated by other factors; however, the general tendency is that capelin survival should increase if the immature cod biomass decreases and, thus, the TAC would be slightly higher than would be the case if the immature cod biomass increases.

The 2015 survey estimate for capelin was low and would have led to the closure of the fishery in 2016 under all suggested HCRs.

Basis of the advice

Background

This advice is based on work conducted in two ICES workshops. The first Workshop on Management Plan Evaluation on Northeast Arctic cod and haddock and Barents Sea capelin (WKNEAMP-1) was held 24–26 November 2015 in Murmansk, Russia (ICES, 2015b), and scoped the needed scientific work and agreed on the methods to be used. Subsequently, the second Workshop on Management Plan Evaluation on Northeast Arctic cod and haddock and Barents Sea capelin (WKNEAMP-2) was held 25–28 January 2016 in Kirkenes, Norway (ICES, 2016), to finalize the management strategy evaluation work. The work has been externally reviewed and a review report is included in the WKNEAMP-2 workshop report (ICES, 2016).

The methods and results are presented below. Although a full multispecies model with feedback between species was not available for testing the harvest control rules, single-species models with some multispecies effects were used.

Cod and haddock: Methods

The request was addressed through simulations done in accordance with the ICES Guidelines for Management Strategy Evaluations (ICES, 2013). The focus is on the long-term dynamics of the cod and haddock stocks, which places the stock–recruitment relationship at centre stage. Short-term properties were investigated based on the most recent stock assessment results and deterministic forecasts. Due to the present high abundance of the stocks, the results for the medium and long terms lead to similar conclusions concerning the probability of SSB falling below B_{lim}.

Simulations of the behaviour of the proposed harvest control rules were conducted using the program NE-PROST; this is described in detail in the WKNEAMP-1 and WKNEAMP-2 workshop reports (ICES, 2015b, 2016). The biological models for cod and haddock are described in detail in WKNEAMP-2 (ICES, 2016). A minimum of 5000 individual runs of 100 years were made for each HCR. For long-term evaluations statistics were collected for the last 80 years. As a test of the realism of the simulations performed, the model output for both cod and haddock was checked against the observed historical development of the cod and haddock populations.

The simulation models that were used account for variation between years for the following processes:

1. Recruitment (stock–recruitment relationship, with periodicity over time included for cod and autocorrelation included for haddock); Random noise.
2. Density-dependent growth.
3. Density-dependent maturation.
4. Natural mortality (cod cannibalism).
5. For the cod HCRs that depend on capelin biomass (HCRs 8 and 9), the historically observed capelin dynamics were replicated in the simulation years.
6. Assessment error; Random noise.

Mortality on haddock due to cod predation was assumed constant over time and set at a value considered to be consistent with the range of cod stock biomasses expected under the cod HCRs.

The simulation model includes a constant selectivity pattern over time. This is because the preference for fishing grounds has not changed within the fleets in recent years, technical measures have not been changed, and the technology has not undergone major changes in recent years.

Banking and borrowing is part of the management from 2015. There is no experience with this system for these stocks that can be used as a basis to set up the simulations and, therefore, this was not included in the present evaluation.

Cod: Results and conclusions

Long-term results

The long-term results are summarized in Table 3.4.1.1. HCRs 1–10 correspond to the ten options in the request. HCR 2a is a repetition of run 2 (current HCR) but with inclusion of an implementation error (the realized catch is simulated to be 8% above the advised catch on average), representing the situation over the last ten years. Currently, there is good compliance with the regulations and this type of error was not further explored. This scenario demonstrates that the effect of the implementation error is similar to fishing with a higher F_{target}.

F_{MSY} is presently estimated at 0.40. F_{MSY} as defined by ICES is not directly comparable with target F or realised F from the ten HCR scenarios; however, the mean realised F from the ten HCRs (0.29–0.44) is below or close to F_{MSY}. Preliminary analysis shows that 0.4 may be a conservative estimate of F_{MSY}, but yield gain for higher fishing mortalities is expected to be around 5%.

Table 3.4.1.1[†] **Northeast Arctic cod**. Long-term simulation results. HCRs 1–10 correspond to points 1–10 in the Norway/Russia request. HCR 2a is a repetition of run 2 (current HCR), but with the inclusion of an implementation error. Settings in the simulations were B_{lim} = 220 000 t and B_{pa} = 460 000 t. All HCRs reduce F linearly from the target F to 0 when SSB< B_{pa}. Assessment error CV = 0.20. All catches and biomasses are in thousand tonnes.

	HCR										
	1	2	3	4	5	6	7	8	9	10	2a
Target F	0.30	0.40	0.50	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
F constraint (SSB > B_{pa})	≥ 0.30	≥ 0.30	≥ 0.30	≥ 0.30	N/A	≥ 0.30	N/A	≥ 0.30	N/A	N/A	≥ 0.30
TAC constraint in % (SSB > B_{pa})	± 10	± 10	± 10	± 20	N/A	± 20	N/A	± 20	N/A	N/A	± 10
Mean realised F	0.29	0.36	0.42	0.38	0.41	0.39	0.43	0.38	0.42	0.44	0.39
Prob (SSB < B_{lim}) in %	0.00	0.01	0.34	0.01	0.02	0.06	0.19	0.02	0.06	0.07	0.34
Prob (SSB < B_{pa}) in %	0.15	6.1	18.1	5.6	7.9	8.0	11.1	6.3	8.8	11.2	14.7
Mean catch	704	744	773	758	777	761	783	759	779	788	758
Median catch	704	754	787	758	768	761	764	759	767	770	763
Standard deviation of catch	96	137	178	153	197	171	235	158	210	265	196
5^{th} percentile of catch	550	490	455	501	468	473	429	493	457	378	421
Mean TSB	3329	3113	2944	3033	2926	3015	2897	3028	2917	2863	3030
Median TSB	3310	3082	2909	3010	2908	2995	2882	3006	2900	2848	2993
Mean SSB	930	810	717	756	689	745	669	753	683	649	767
Median SSB	900	754	654	727	678	716	658	724	672	637	696
Mean recruitment, millions age 3	893	893	890	893	892	892	891	892	892	892	890
Median recruitment, millions age 3	728	727	724	727	727	727	726	727	727	727	725
Mean annual change in TAC (%)	9.03	12.40	17.20	17.79	26.94	19.59	31.77	18.30	28.38	36.64	17.02
Mean annual change in catch (%)	9.03	12.40	17.18	17.79	26.94	19.59	31.76	18.30	28.38	36.64	21.76
Mean weight in catch (kg)	3.39	3.19	3.03	3.13	3.03	3.11	2.99	3.12	3.02	2.96	3.11
Mean M at age 3	0.49	0.46	0.43	0.45	0.43	0.45	0.43	0.45	0.43	0.42	0.44
% years where + TAC constraint applied	38.20	21.84	26.71	18.26	0.00	19.87	0.00	18.80	0.00	0.00	19.18
% years where - TAC constraint applied	28.74	19.85	14.22	11.89	0.00	12.79	0.00	12.19	0.00	0.00	15.97
% years where “Min F = 0.3” applied	0.00	21.61	14.74	11.49	0.00	11.80	0.00	11.61	0.00	0.00	23.58
% years where an F > 0.4 applied	n/a	n/a	n/a	n/a	n/a	20.99	15.46	6.92	5.16	79.89	n/a
% years where F = 0.6 applied	n/a	n/a	n/a	n/a	n/a	3.16	0.88	0.96	0.28	0.00	n/a

Short-term results

In order to illustrate the behaviour of the ten HCRs in the short term, deterministic projections based on the inputs and outputs from the 2015 stock assessment were performed. The resulting catch and SSB are shown in Figure 3.4.1.1. All scenarios result in a decline in catch. HCR 3 shows the smallest decline in catch and, in turn, the lowest SSB at the end of the projection period. HCRs 6 to 10 result in higher catch than HCR 2 as cod SSB is currently above 2 × B_{pa}.

[†] Version 2; Table number corrected

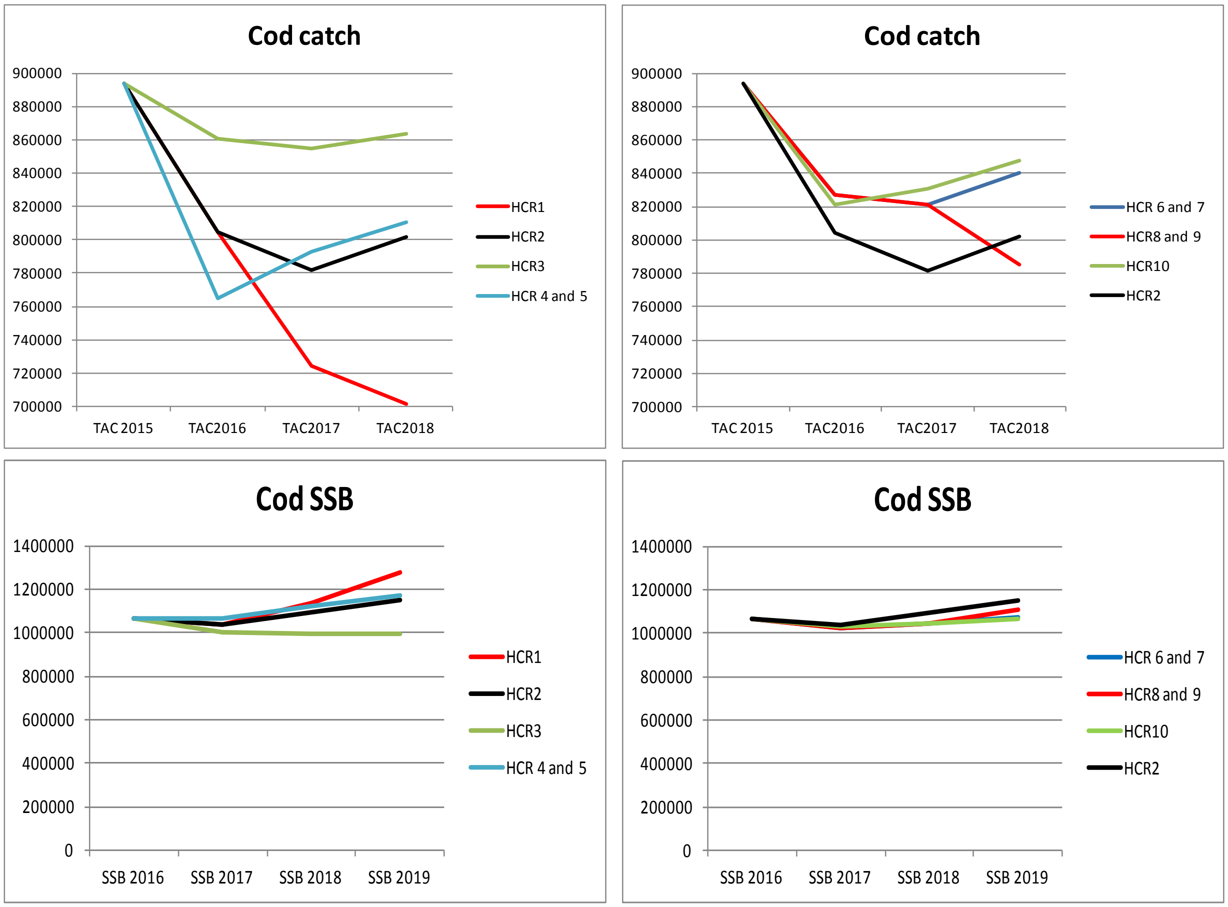

Figure 3.4.1.1[‡] **Northeast Arctic cod**. Expected short-term catch and SSB levels (tonnes) with the ten HCR proposals. For rules 8 and 9, a capelin stock below 1 million tonnes in autumn 2016 and a recovery of the capelin stock to above 1 million tonnes in autumn 2017 is assumed.

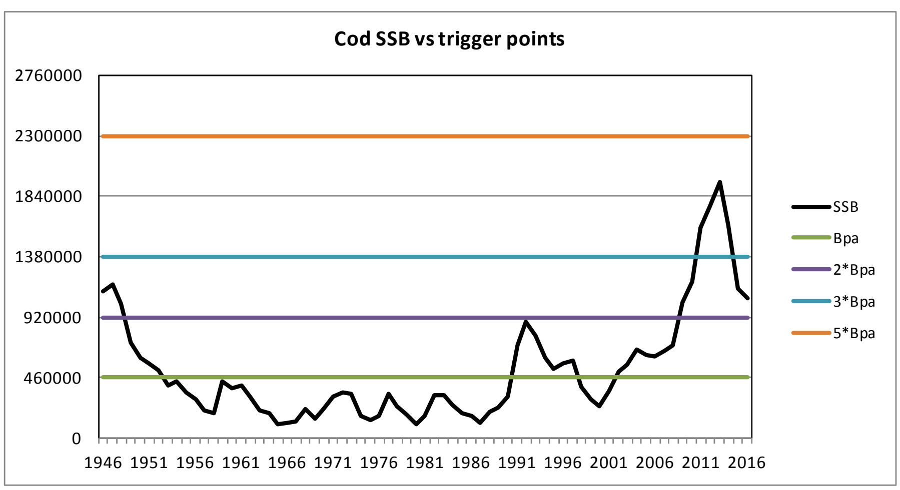

Figure 3.4.1.2[§] **Northeast Arctic cod**. SSB (tonnes) versus trigger points used in HCRs 6–10.

[‡] Version 2; Figure number corrected

[§] Version 2; Figure number corrected

Figure 3.4.1.2 shows the SSB for the period 1946–2015 in relation to trigger points used in the different HCRs. The 5 × B_{pa} level (used in HCR 10) has never been reached historically and the 2 × B_{pa} level (used in HCRs 6–9) only in the first few years around 1946 and during the most recent period. 3 × B_{pa} (used in HCRs 6–9) has only been reached during the most recent period. Fishing mortality from the early 1960s to the late 1990s has been on average around F_{lim} (0.74). The recent high peak in SSB was reached during a period with F around 0.3. The results of the long-term simulations indicate that SSB will be above 2 × B_{pa} in 15% to 20% of the years (HCRs 6 and 7).

Haddock: Results and conclusions

Long-term results

The long-term results are summarised in Table 3.4.1.2. HCRs 1–6 correspond to the six options as given in the request. The influence of an implementation error was not investigated.

F_{MSY} is presently estimated at 0.35. F_{MSY} as defined by ICES is not directly comparable with the target F or realised F from these six HCR scenarios; however, the mean realised F from the six HCRs (0.25–0.39) is below or close to F_{MSY}. Preliminary analysis shows that 0.35 may be a conservative estimate of F_{MSY}, but yield gain for higher fishing mortalities is expected to be around 5%.

Table 3.4.1.2[**] **Northeast Arctic haddock.** Long-term simulation results. HCRs 1–6 correspond to points 1–6 in the JNRFC request. Settings in the simulations were B_{lim} = 50 000 t and B_{pa} = 80 000 t. All HCRs reduce F linearly from the target F to 0 when SSB< B_{pa}. Assessment error: CV = 0.25. All catches and biomasses are in thousand tonnes.

	HCR					
	1	2	3	4	5	6
Target F	0.27	0.35	0.43	0.35	0.35	0.35
TAC constraint % (SSB > B_{pa})	±25	±25	±25	±10	N/A	'+':N/A;' –' 25
Mean F realised	0.25	0.32	0.38	0.28	0.35	0.39
Prob (SSB < B_{lim}) in %	0.6	2.3	4.9	3.3	0.8	3.4
Prob (SSB < B_{pa}) in %	3.5	9.7	16.7	10.7	6.9	13.9
Mean catch	125	130	133	115	136	138
Median catch	106	109	111	103	109	113
Standard deviation of catch	81	91	98	74	100	103
Mean TSB	611	543	495	673	476	448
Median TSB	512	440	388	539	403	373
Mean SSB	331	273	233	391	218	195
Median SSB	276	214	171	282	192	167
Mean recruitment age 3, millions	228	228	227	227	228	227
Median recruitment age 3, millions	136	135	135	135	136	135
Mean annual change in catch, %	26.1	36.1	45.1	32.4	40.9	49.0
Mean weight in catch, kg	1.59	1.52	1.46	1.59	1.49	1.45
% of years '+' TAC constraint applied	37.0	38.2	37.6	58.2	0.0	0.0
% years '–' TAC constraint applied	21.5	17.9	13.2	16.8	N/A	22.8

[**] Version 2; Table number corrected

Short-term results

In order to illustrate the behaviour of the six HCRs in the short term, deterministic projections based on the inputs and outputs from the 2015 stock assessment were performed. The resulting catch and SSB are shown in Figure 3.4.1.3. All scenarios result in a decline in catch in response to the declining stock size. HCRs 3 and 4 show the smallest decline in catch, but the highest decline in SSB.

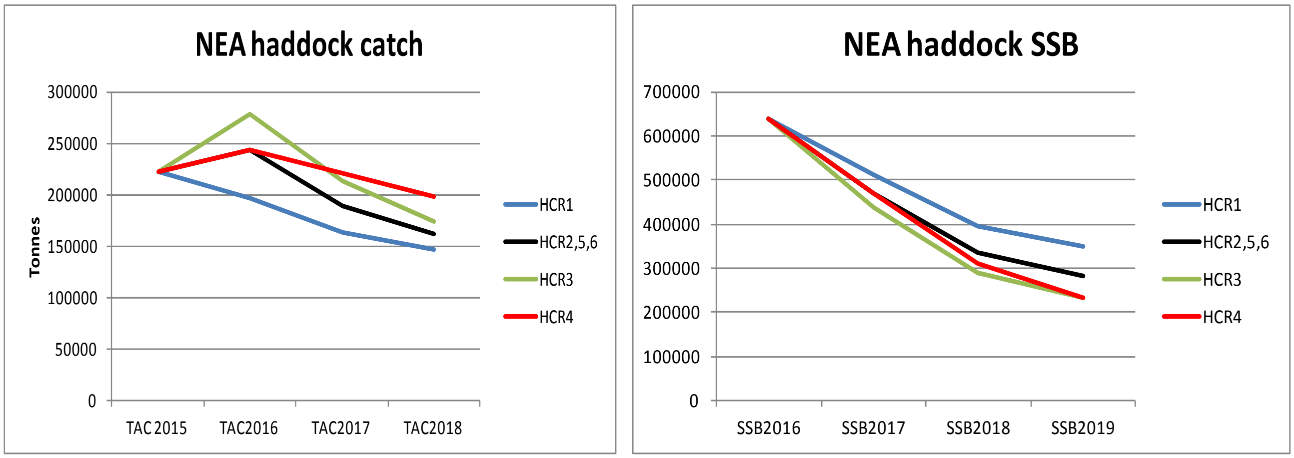

Figure 3.4.1.3[††] **Northeast Arctic haddock**. Catch 2015–2018 and SSB 2016–2019 for the six HCRs. When calculating the 2016 TAC, constraints on annual change in TAC were taken into account based on the 2015 TAC.

Capelin: Methods

For a general evaluation of the effect of the change in risk, a simplified model of the present HCR was used in order to facilitate exploration. The approximation is as follows:

$$TAC = \begin{cases} 0 & if\ S \times b \times u < B_{lim} \\ S \times b - \dfrac{B_{lim}}{u} & otherwise \end{cases}$$

where ‘S’ is the biomass of the maturing component of the stock as measured by the survey around 1 October. The ‘b’ parameter accounts for cod predation, other capelin mortality and growth in the period 1 October–1 April and is accounted for through an assessment model (Gjøsæter *et al.*, 2002). The ‘u’ parameter accounts for the uncertainty in the estimate of the SSB (1 April) generated by survey results ‘S’ uncertainty, as measured at around 1 October, and projection of the survey biomass until the capelin spawns around 1 April. An average ‘b’ parameter was estimated and the parameter ‘u’ was adjusted to reflect different probabilities of SSB > 200 000 t (B_{lim}).

Capelin: Results and conclusions

Based on the simplified model and using the 5% risk criterion in the HCR, a survey biomass (maturing capelin) result below ca. 1.15 million tonnes suggests that the fishery will be closed. Each doubling of the risk from 5% to 10% and from 10% to 20% adds 50 000–60 000 t to the TAC and the minimum survey biomass that will allow a fishery is lowered by about 150 000 t. This applies to cod biomasses which are expected under current management and current productivity of the Northeast Arctic cod stock, i.e. for an immature cod biomass around 1.8 million tonnes.

[††] Version 2; Figure number corrected

Sources and references

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