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REPORT

Joint Norwegian-Russian Fisheries Commission request to establish a management plan for capelin in the Barents Sea (subareas 1 and 2 excluding Division 2.a west of 5°W)

Institute of Marine Research – IMR

Polar branch of the FSBSI “VINRO” (“PINRO”)

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Joint Norwegian-Russian Fisheries Commission request to establish a management plan for capelin in the Barents Sea (subareas 1 and 2 excluding Division 2.a west of 5°W)

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Content

1 - Advice on establishing a management plan

Harvesting rules were assessed for capelin (*Mallotus villosus*) in the Barents Sea using a management strategy evaluation (MSE), a modeling framework that simulates population and fishery responses to management actions. The form of the current escapement rule is retained and is defined by $B_{escapement}$, the biomass that must escape to spawn with 95% probability after fishing is accounted. The MSE specifically tested four different $B_{escapement}$ values (100,000, 150,000, 200,000 and 400,000 tonnes) with and without three alternative fixed minimum quotas (25,000, 50,000 or 75,000 tonnes). All four $B_{escapement}$ values without fixed minimum quotas maintained a low risk (<5%) of spawning biomass falling below B_{lim}, the SSB below which recruitment is reduced, assuming historical capelin productivity, accurate survey estimates and survey precision is correctly estimated. However, a $B_{escapement}$ equal to 100,000 tonnes showed notably higher risk (of $SSB<B_{lim}$) if the survey is either biased high in reality or survey precision is underestimated by management. High probabilities of fishery closures resulted from $B_{escapement}$=400,000 tonnes. All of the alternative rules using fixed minimum quotas showed very high risk of SSB falling below B_{lim} and the model framework projected reduced future recruitment to the extent of stock collapse over the long term. In general, average catch decreased and the years with a closed fishery increased with higher $B_{escapement}$. When selecting a rule, managers should also consider the trade-offs with other consequences and potential impacts on the ecosystem given the critical role played by capelin as the key forage fish for various predators in the Barents Sea.

2 - Request

During a recent benchmark for capelin (*Mallotus villosus*) in the Barents Sea (ICES 2023), the biological reference point B_{lim} was changed from 200,000 to 68,000 tonnes to follow the standards for defining B_{lim} used by ICES (i.e. the SSB below which recruitment is reduced). Due to the redefinition of B_{lim}, the term $B_{escapement}$ was introduced as the reference point actually used in the present harvesting rule. $B_{escapement}$ corresponds to the minimum biomass that must be left to spawn each spring with at least 95% probability (which is in accordance with the precautionary principle) and is set by management. Due to unaccounted uncertainties in the assessment, $B_{escapement}$ is not necessarily equal to B_{lim}, but cannot be lower than B_{lim}. Thus, 200,000 tonnes was set as $B_{escapement}$ during the capelin benchmark, but alternative values for $B_{escapement}$ should be explored with an evaluation of the harvesting rule.

The Joint Norwegian-Russian Fisheries Commission (JNRFC) requested in 2023 the evaluation of alternative harvesting rules for Barents Sea capelin and that the results be used to inform managers in 2024. The Institute of Marine Research (IMR) developed a Management Strategy Evaluation framework (MSE) to evaluate the consequences of a set of harvesting rules, both of which were specified by the JNRFC.

3 - Elaboration on the advice

Based on discussions with industry and managers in Norway, a list of alternative harvest control rules to be tested was proposed. This list was adopted by Norwegian and Russian scientists and used in the evaluation.

The harvesting rules are as follows and specify different target escapements and the potential introduction of fixed minimum quotas, which would be taken in years when the fishery would otherwise be closed according to the escapement rule:

- **Harvest rule A**: Existing harvesting rule which states that with a 95% probability one must allow at least 200,000 tonnes ($B_{escapement}$) to have the opportunity to spawn. The capelin estimate from the ecosystem survey in autumn is used as a basis.
- **Harvest rule B**: Like **rule A**, but with alternative values for $B_{escapement}$ (400,000, 150,000, 100,000 tonnes).
- **Harvest rule C**: Like **rules A** and **B**, but where a minimum quota of 25,000, 50,000 or 75,000 tonnes is given each year anyway.

These three rules imply a greater number of unique harvesting rules equal to 16, as the four possible values of $B_{escapement}$ are individually tested, plus each $B_{escapement}$ paired with each of three possible fixed minimum quotas (4 + 4*3 = 16). A higher relative risk (in terms of falling below B_{lim} and complete stock collapse) can be inferred for rules with lower $B_{escapement}$ and fixed minimum quotas compared to the highest $B_{escapement}$ with fixed minimum quotas. Thus, after testing all four $B_{escapement}$ values without a fixed minimum quota, only the highest $B_{escapement}$ is tested with each of the fixed minimum quotas simulations. This approach avoided unnecessary simulation testing of lower $B_{escapement}$ with fixed minimum quotas that inherently carry greater risk.

The consequences of the harvesting rules are assessed in a long-term perspective from autumn 1987 to spring 2023 (36 years of SSB at spawning time in the spring) where reports are requested on the following parameters:

- Average spawning biomass
- Average quota
- Probability of spawning biomass falling below B_{lim} (generally referred to as risk)
- Probability of spawning biomass falling below $B_{escapement}$
- Number of years in which fishing is not opened

The accuracy of these specific consequences relies on the stock estimate (i.e.Â the most important input to the harvest rule) being unbiased, the uncertainty of that estimate being correctly characterized, and the estimated B_{lim} being precise and accurate (ICES 2023); however, none of these three points can be guaranteed and are major uncertainties the requested harvest rules need testing against. Thus, the MSE analysis is conducted in two general parts:

harvest rules are simulation tested with a base scenario characterized by annual stock estimates being unbiased and survey errors being correctly assumed

only harvest rules that have low probability of falling below B_{lim} is <5% under the base scenario are simulation tested against two additional scenarios; one where surveys overestimate the true stock and one where survey estimates are assumed to be overly precise.

Additionally, a sensitivity analysis is conducted of historical risk to uncertainty in B_{lim}, and specifically involves projecting the historical 1 April SSB distributions under each alternative $B_{escapement}$ and then computing the proportions of instances where a random SSB value from this distribution is less than a random B_{lim}.

4 - Basis of the advice

4.1 - Methods

The assumptions and formulas used in the MSE are based on the current assessment method for capelin, a within-year forecast of the maturing biomass that is equal to the autumn survey estimate (*bifrost*). As *bifrost* accounts for predation mortality due to cod consumption and thus relies on estimates of historical cod abundance, a hindcast MSE was conducted which tests the proposed harvesting rules against the historical observed capelin productivity and conditions. In other words, this MSE addresses the question of how management could have performed in the past using today's assessment method and harvest rule. Additionally, the results are conditional on the implicit assumption that stock productivity in the future will approximate that in the 1987-2022 time series. In the event that there is evidence for systematic changes in productivity, then the HCR should be re-evaluated.

In short, the MSE simulates in each year the true conditions of the capelin stock (also referred to as the operating model); the possible mismatches between autumn survey observations and the 'true' stock; the full stock assessment method based on simulated observations, harvest rule, and quota calculation; and what is actually harvested from the 'true' stock based on the quota. Catches are assumed equal to the annual quotas within the MSE, as historical catches have closely adhered to the real advice. This simulation sequence is repeated over a number of years and allows feedback between years (e.g. previous years' catches directly impact future capelin abundance and reproduction). Once capelin population and fishing dynamics are projected over all years within the pre-specific time period (1987-2022), this sequence is repeated over and over again, each time with different conditions including different recruitment trajectories, different cod abundances and consumption rates, and different survey observations. The consequences of the harvesting rules are calculated over the many possible capelin stock and fishing trajectories.

The MSE framework was custom coded in and the analysis conducted with the R programming software. Code and data files of the MSE results are available on a public Gitlab repo (https://git.imr.no/MSE/barents_capelin_2024).

Technical details of the capelin MSE methodology and results are described in the report this document summarises **(CITE REPORT AND ADD TO REFERENCES LIST AT BOTTOM]** .

4.2 - Results and conclusions

Results based on historical capelin stock dynamics and correct survey assumptions (base scenario) showed all $B_{escapement}$ values without fixed minimum quotas to have low risk of falling below B_{lim} (68,000 tonnes) (Figure 1).

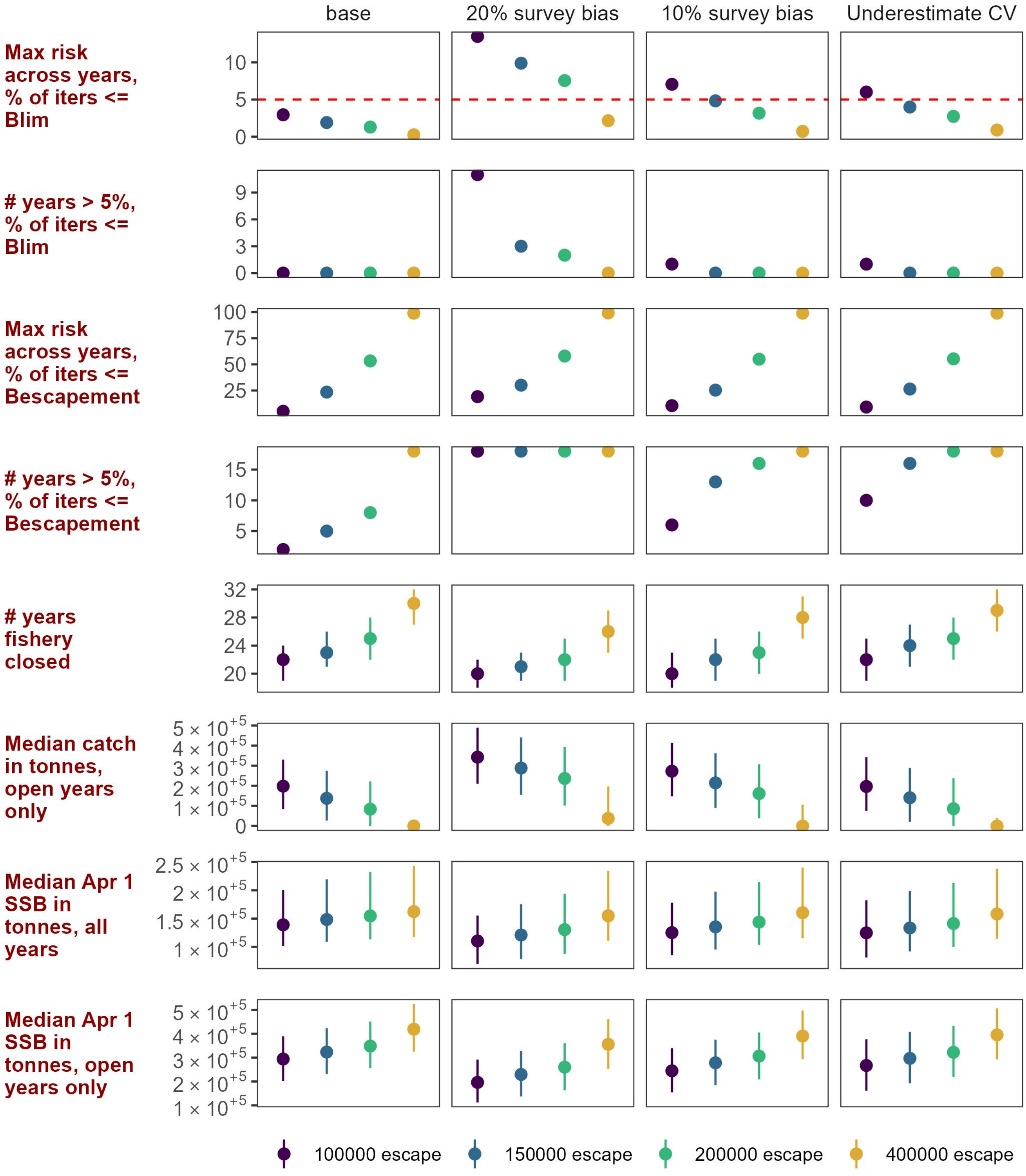

Figure 1: Consequences of the four Bescapement values without fixed minimum quotas under different scenarios. Rows represent the specific consequence and columns represent the values under the base scenario and three scenarios reflecting incorrect survey assumptions (two with overestimated survey biomass, and one with underestimated survey CV). Points represent either a percentage, number of years or a median where indicated. Lines represent the inner 90th quantile of the distributions if the statistic is not a percentage. Statistics are computed from 2,779 iterations.

The fixed minimum quotas were tested with $B_{escapement}$=400,000 tonnes, and the probability of stock collapse exceeded the 5% for all minimum quota values (Figure 2). All similar rules with a lower $B_{escapement}$ would have a higher chance of stock collapse. We therefore conclude that all of the fixed minimum quota rules have a high risk of causing SSB to fall below B_{lim} and stock collapse. We note here that the risk does not apply just to the capelin stock, but to the wider ecosystem, given the key role capelin play as a food source in the Barents Sea.

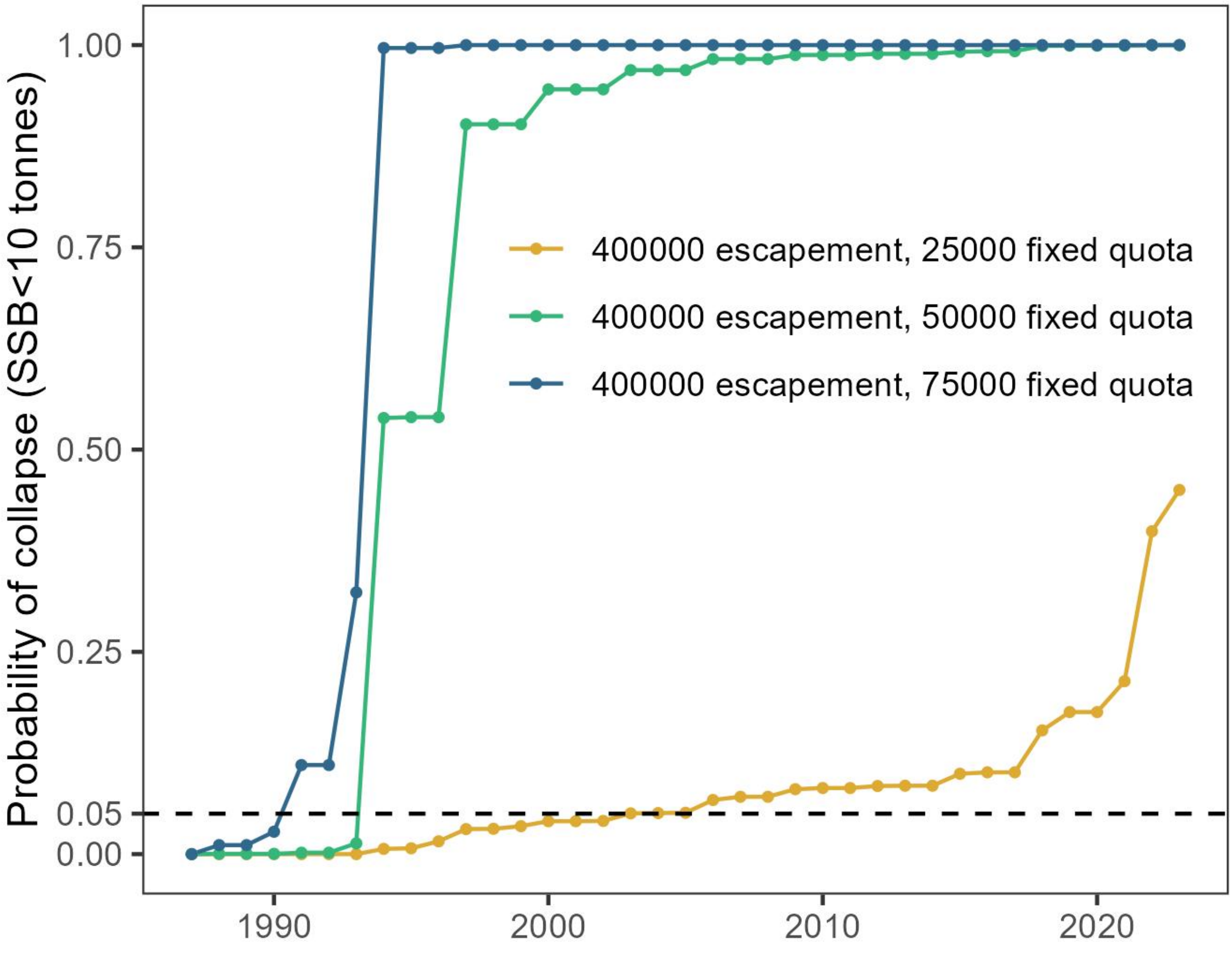

Figure 2: Annual proportions of iterations when 1 April SSB collapsed for a Bescapement=400,000 tonnes and different fixed minimum quotas. Collapse is defined as SSB dropping below 10 tonnes (i.e. effectively zero) and not recovering in the subsequent period. Proportions are computed over 2,779 iterations.

Evaluations based on biased survey indices (i.e. overestimating true stock biomass by 20% or 10%) showed higher risk of falling below B_{lim} with $B_{escapement}$=100,000 tonnes (>5%), while comparatively low risk was seen with the other $B_{escapement}$ values. Underestimated survey CV input to the stock assessment also resulted in $B_{escapement}$=100,000 tonnes showing risk greater than 5% of falling below B_{lim}.

An asymmetric trade-off is seen between average yield and average SSB, where greater gains in yield occur with less relative reductions in SSB as $B_{escapement}$ is increased. The average number of years of a closed fishery was similar for the three lowest escapement rules (100,000-200,000 tonnes) where medians were within 1-2 years of each other. Additionally, high probabilities of fishery closures resulted from $B_{escapement}$=400,000 tonnes. Overall, values of 150,000 and 200,000 tonnes for $B_{escapement}$ were showed to be most robust against key uncertainties in survey assumptions, and viable for the fishery (e.g. in terms of fishery openings).

Table 1: Consequences of the four Bescapement values under each modelled scenario as shown in Figure 1. Values are shown as

either percentage, number of years, or tonnes of biomass (SSB and catch) where indicated. Values within parantheses represent the inner 90th quantile of the distributions if the statistic does not involve risk. Statistics are computed from 2,779 iterations.

	B escapement				
Scenario	**Performance statistic**	**400,000**	**200,000**	**150,000**	**100,000**
base					
	# years fishery closed	30 (27-32)	25 (22-28)	23 (21-26)	22 (19-24)
	Median Apr 1 SSB in tonnes, all years	162304 (117083-243275)	154684 (113177-232209)	148316 (109088-219342)	138997 (101068-200200)
	Median Apr 1 SSB in tonnes, open years only	419090 (325021-524477)	348465 (256093-451350)	323381 (231819-423435)	294156 (202937-389294)
	Median catch in tonnes, open years only	0 (0-23463)	83705 (0-221736)	137700 (27115-274179)	198154 (83869-330338)
	Max risk across years, % of iters <= Blim	0.25	1.30	1.91	2.95
	# years > 5%, % of iters <= Blim	0	0	0	0
	Max risk across years, % of iters <= Bescapement	98.88	53.26	23.46	5.11
	# years > 5%, % of iters <= Bescapement	18	8	5	2
20% survey bias					
	# years fishery closed	26 (23-29)	22 (19-25)	21 (19-23)	20 (18-22)
	Median Apr 1 SSB in tonnes, all years	154954 (110649-234429)	130484 (87480-193623)	120942 (78282-175286)	110339 (69298-155407)
	Median Apr 1 SSB in tonnes, open years only	355875 (252592-461294)	260129 (163297-360703)	229554 (137202-327787)	196294 (112274-291914)
	Median catch in tonnes, open years only	37718 (0-196847)	236476 (101925-392160)	288236 (155335-440787)	342380 (210244-489475)
	Max risk across years, % of iters <= Blim	2.16	7.56	9.90	13.49
	# years > 5%, % of iters <= Blim	0	2	3	11
	Max risk across years, % of iters <= Bescapement	99.14	57.90	30.08	19.11
	# years > 5%, % of iters <= Bescapement	18	18	18	18
10% survey bias					
	# years fishery closed	28 (25-31)	23 (20-26)	22 (19-25)	20 (18-23)
	Median Apr 1 SSB in tonnes, all years	160346 (115253-240217)	143808 (103386-214596)	135428 (95235-197631)	125140 (85057-178129)
	Median Apr 1 SSB in tonnes, open years only	390400 (293827-497328)	306204 (208686-405521)	278432 (184472-375215)	244755 (154490-339768)
	Median catch in tonnes, open years only	0 (0-104901)	161268 (38112-307102)	214501 (90164-361781)	272587 (147605-413757)

	B				
Scenario	**Performance statistic**	**400,000**	**200,000**	**150,000**	**100,000**
	Max risk across years, % of iters <= Blim	0.72	3.17	4.82	7.05
	# years > 5%, % of iters <= Blim	0	0	0	1
	Max risk across years, % of iters <= Bescapement	98.92	54.91	25.33	10.51
	# years > 5%, % of iters <= Bescapement	18	16	13	6
Underestimate CV					
	# years fishery closed	29 (26-32)	25 (22-28)	24 (21-27)	22 (19-25)
	Median Apr 1 SSB in tonnes, all years	158223 (114366-238249)	141217 (99842-213043)	133438 (91864-199289)	124809 (81223-182359)
	Median Apr 1 SSB in tonnes, open years only	395372 (292485-506378)	322320 (219853-433022)	296999 (192316-408601)	267063 (161381-376941)
	Median catch in tonnes, open years only	0 (0-40183)	86029 (0-237459)	140563 (21163-289069)	196624 (75240-342175)
	Max risk across years, % of iters <= Blim	0.90	2.73	3.99	6.01
	# years > 5%, % of iters <= Blim	0	0	0	1
	Max risk across years, % of iters <= Bescapement	98.96	55.24	26.41	9.18
	# years > 5%, % of iters <= Bescapement	18	18	16	10

5 - References

ICES. 2023. Benchmark workshop on capelin (WKCAPELIN). ICES Scientific Reports, 5: 282.X

38

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