Northwest Atlantic Fisheries Organization

Serial No. N5518 **NAFO SCS Doc. 08/13**

SCIENTIFIC COUNCIL MEETING - JUNE 2008

Report of NAFO Scientific Council Study Group on Rebuilding Strategies for Greenland halibut

Instituto Español de Oceanografía/
Centro Oceanográfico de Vigo

February 21-23, 2008

Vigo, Spain

Participants in NAFO SC Study Group on Rebuilding Strategies for Greenland halibut:

Front (kneeling – L-R) : Fernando Gonzalez, Diana Gonzalez, Peter Shelton, Kiyoshi Katsuyama

Back (L-R) : Doug Butterworth, Brian Healey, Enrique de Cardenas, Jim Ianelli, Jean-Claude Mahé, Bill Brodie, Rob Scott, Antonio Vazquez, Bob Steinbock, Carmen Fernandez, Ricardo Alpoim, Iago Mosqueira, Noriaki Takagi, David Miller, Leo Strowbridge, Jim Baird, Bruce Chapman.

Missing from photo – José A. Suárez-Llanos

1. Opening - Introductions, meeting arrangements. The Chair welcomed all participants (Appendix I) to the meeting, and reviewed the meeting arrangements, agenda (Appendix II) and timetable, all of which were acceptable. The Chair invited any opening remarks, and Mr. Suarez-Lanos read an opening statement.

2. Background, Terms of Reference. The focus of the work is management strategy evaluation (MSE) for the Greenland halibut stock in NAFO Subarea 2 plus Divisions 3KLMNO. The Terms of Reference (Appendix III) were available to all participants for some time prior to the meeting (on the Wiki[1] site (http://nafo-mse-ghal.wikidot.com) used for Study Group (SG) communications), and were accepted as tabled. The Chair provided a brief background presentation on the Greenland halibut stock, its fishery and current status, and the development of the Scientific Council (SC) SG. The SG consists of members of SC, other scientists, invited experts, fishery managers, and representatives of the Greenland halibut fishing industry. Participation in the SG and meeting was at the invitation of the Chair. A substantial amount of work was conducted prior to the meeting, and in discussion on the Wiki site.

Discussion[2] focussed on recent effort restrictions and reductions in the fishery, tied to the decreasing TAC's in the NAFO Fisheries Commission rebuilding plan for this stock (Appendix IV). The number of vessels and fishing days had declined substantially in recent years (up to 83% in some EU fleet sectors), while CPUE increased in virtually all fisheries. It was noted that CPUE was not used as an index of abundance in the current stock assessment formulation, and that this issue had been examined by SC on a number of occasions. There was some discussion on the status of the resource, but it was noted that evaluation or re-assessment of the stock was not among the terms of reference of the SG. As it was important to consider the fishery in progressing with the MSE work, it was agreed that the CPUE issue would be revisited by the SG during the meeting.

3. Introductory presentations:

a. Overview of Management Strategy Evaluation. D. Butterworth gave an extensive presentation on MSE (alternatively termed Management Procedure Evaluation or MPE). This focussed on a detailed explanation of MSE, as well as examples from South African fisheries, including hake.

Main Conclusions of the presentation:

- The MSE approach can solve most, though not all, of the problems related to stock assessment and provides a better alternative than the traditional "best assessment + control rule" approach
- It does introduce some other difficulties, but these can be resolved by operating within a sound framework (e.g. regular reviews, exclusion of "back-tracking" within the development process)
- The greatest advantages of MSE are probably:
    - A sound basis to limit the extent of future TAC variations without compromising resource status
    - Properly addressing concerns about scientific uncertainty through simulation testing to ensure that feedback secures reasonably robust performance across a range of plausible alternative resource dynamics

The SG noted that this was a very comprehensive presentation that covered all aspects of MSE. A number of general as well as technical questions on the presentation were then discussed. Once the data and structural assumptions have been agreed for operating models (OM) to be used for testing purposes, it would be most unusual to change these, although there would be consideration if the model did not match the new data. If a retrospective pattern exists, it should be fixed in the assessment, rather than adjusting for it in the OM.

b. FLR methodology R. Scott gave an introductory presentation on FLR (Fisheries Libraries in R), augmented by a presentation by I. Mosquera. As noted on the FLR Website (www.flr-project.org), "The

[1] A wiki is a website which allows users to add and edit content collectively within a defined subject area.
[2] Throughout this report, italicized text indicates a summary of SG discussion

FLR library is a collection of tools in R that facilitates the construction of bio-economic simulation models of fisheries and ecological systems. It is a generic toolbox, but is specifically suited for the construction of simulation models for evaluations of fisheries management strategies". The programming language R provides an existing platform for statistical modeling with advanced graphical capabilities. A large public archive of user-written extensions to R substantially increases its capabilities. Two SG members are involved with FLR development, and this tool was used to do most of the modeling for this meeting.

The SG discussed the various assessment methods available in FLR, noting that ADAPT and statistical catch at age were not yet available in R. There was also some discussion on technical aspects involving the executable files. For large, complex studies, multiple PC's can be used to reduce running time, as was done for this meeting. It was thought that the Greenland halibut work was the first major study initiated with this software, outside the team of FLR developers. The SG also considered some points on the usage of FLR versus other applications, such as AD Model Builder. Based on experience in some international cases, it was thought that, irrespective of the software application, a dedicated person was needed to write the computer code for the OM's at least, and that this person should be separate from those putting forward various potential Management Strategies and testing them against these OM's. Perhaps in some instances, support staff to assist in MSE development could be made available within the secretariat of the regional fisheries management organization. The SG noted the benefits found in other international organizations of having different persons from different institutes/countries participating in a semi-competitive way in putting forward and testing such potential MS's, thereby building on each others' experience and improving the end product.

c. Operating model structure. B. Healey gave a presentation on the operating models (OM) used for Greenland halibut. An OM represents a particular version of "reality", i.e. the true population is known exactly, and simulated data are generated by the OM. Fig. 1 shows how OM's fit into the overall MSE approach. Some considerations in the OM's used include:

- Biological processes (growth, maturation, natural mortality)
- Number of age groups (assessment models use ages 14 & older as a plus group) – with operating model, can model population out to any given maximum age.
- Plus group dynamics
- Fishery dynamics (selectivities at age, or partial recruitment – shape of the PR function with age, particularly at older ages, e.g. "dome-shaped PR").
- Stock-recruit dynamics
- Starting point for population (in this case 1975)

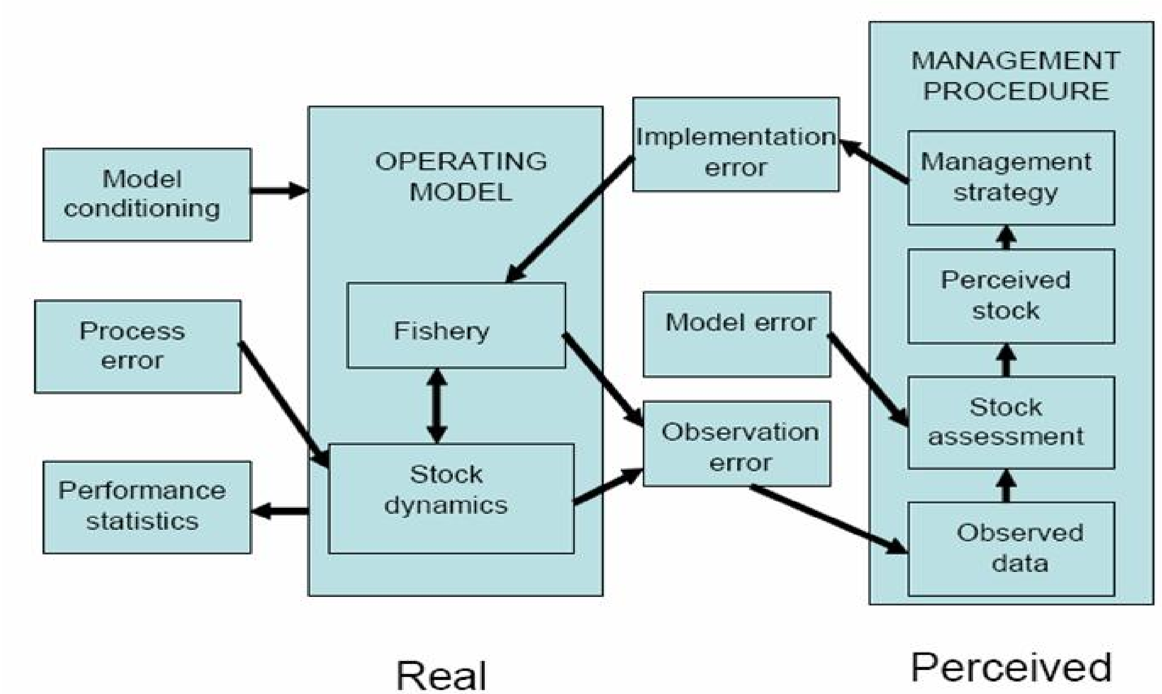

Fig 1. Schematic of the MSE process - adapted from the FLR website.

A key element of the OM's chosen for this stock was the use of three different "views" of the stock, which were focused on different hypotheses regarding stock-recruit dynamics. The differing views were labeled the current assessment view (CAV), less optimistic view (LOV), and more optimistic view (MOV) – see Fig. 2. The current indices were those used in the most recent XSA assessment of the stock based on the survey information, while the more optimistic index was a dummy index generated to represent a view of the stock that is more in line with that held by industry (i.e. in the absence of an accepted CPUE series in the SC stock assessment).

The XSA estimation of plus-group survivors was considered an undesirable approach to apply within the OM, and two alternate methods were considered: i) base the estimate on the previous year's catch from the plus group, or ii) use an F-assumption for the plus group (e.g. assume ratio of plus group F to that of oldest true age is constant). The XSA assumption is that F on the plus group is equal to F on the oldest "true" age. This can lead to abrupt differences in the number of survivors in the plus group, and is not helpful when trying to model SSB, particularly in this case where the plus group typically contributes 75% or more of the SSB, due to the old age at maturity. There was considerable discussion on this point on the wiki site prior to the SG meeting, and the decision was made to use the F-assumption approach (ii above).

Based on combinations of the 4 factors below, 24 OMs in total were considered:

2 Starting points for stock (current indices, optimistic indices)
2 levels of natural mortality (M=0.1, 0.2)
2 PR assumptions (decline at older ages is steep, or less steep with a flat portion)
3 Stock-Recruit mechanisms (segmented regression, depleted seg. reg., and average recruitment)

This yields 2 x 2 x 2 x 3 = 24 possible OMs (Table 1).

There was extensive discussion on the Operating Models prior to the meeting, based on discussions on the wiki site. It was recommended that major or key factors be identified relative to those which were not thought to be as important, i.e. first and second order factors. To assist in determining which aspects were important, deterministic projections, with constant catch, had been examined for a limited number of representative runs prior to the meeting. It was noted that no particular OM or set of OM's was being promoted. Results from the full set were available for examination, and no decisions had been made prior to the meeting as to what OM's are "best". Although other population models besides XSA could be examined, the work on this stock focused only on XSA, as this was the population model currently used in the SC assessments of this stock, and was available in the FLR package.

Table 1. Full set of operating models considered.

Ref. Sub-set	OM#	Starting Pt.	Stock-Recruit	*M*	PR decline
"Current View" CAV	1	Current indices	Segmented Regression	0.2	Mean 7-10
	2	Current indices	Seg Reg	0.2	Max 7-10
	3	Current indices	Seg Reg	0.1	Mean 7-10
	4	Current indices	Seg Reg	0.1	Max 7-10
	5	Current indices	Average Recruitment	0.2	Mean 7-10
	6	Current indices	Average Rec	0.2	Max 7-10
	7	Current indices	Average Rec	0.1	Mean 7-10
	8	Current indices	Average Rec	0.1	Max 7-10
"More Optimistic" MOV	9	Optimistic indices	Seg Reg	0.2	Mean 7-10
	10	Optimistic indices	Seg Reg	0.2	Max 7-10
	11	Optimistic indices	Seg Reg	0.1	Mean 7-10
	12	Optimistic indices	Seg Reg	0.1	Max 7-10
	13	Optimistic indices	Average Rec	0.2	Mean 7-10
	14	Optimistic indices	Average Rec	0.2	Max 7-10
	15	Optimistic indices	Average Rec	0.1	Mean 7-10
	16	Optimistic indices	Average Rec	0.1	Max 7-10
"Less Optimistic" LOV	17	Current indices	Depleted Seg Reg	0.2	Mean 7-10
	18	Current indices	Depleted Seg Reg	0.2	Max 7-10
	19	Current indices	Depleted Seg Reg	0.1	Mean 7-10
	20	Current indices	Depleted Seg Reg	0.1	Max 7-10
	21	Optimistic indices	Depleted Seg Reg	0.2	Mean 7-10
	22	Optimistic indices	Depleted Seg Reg	0.2	Max 7-10
	23	Optimistic indices	Depleted Seg Reg	0.1	Mean 7-10
	24	Optimistic indices	Depleted Seg Reg	0.1	Max 7-10

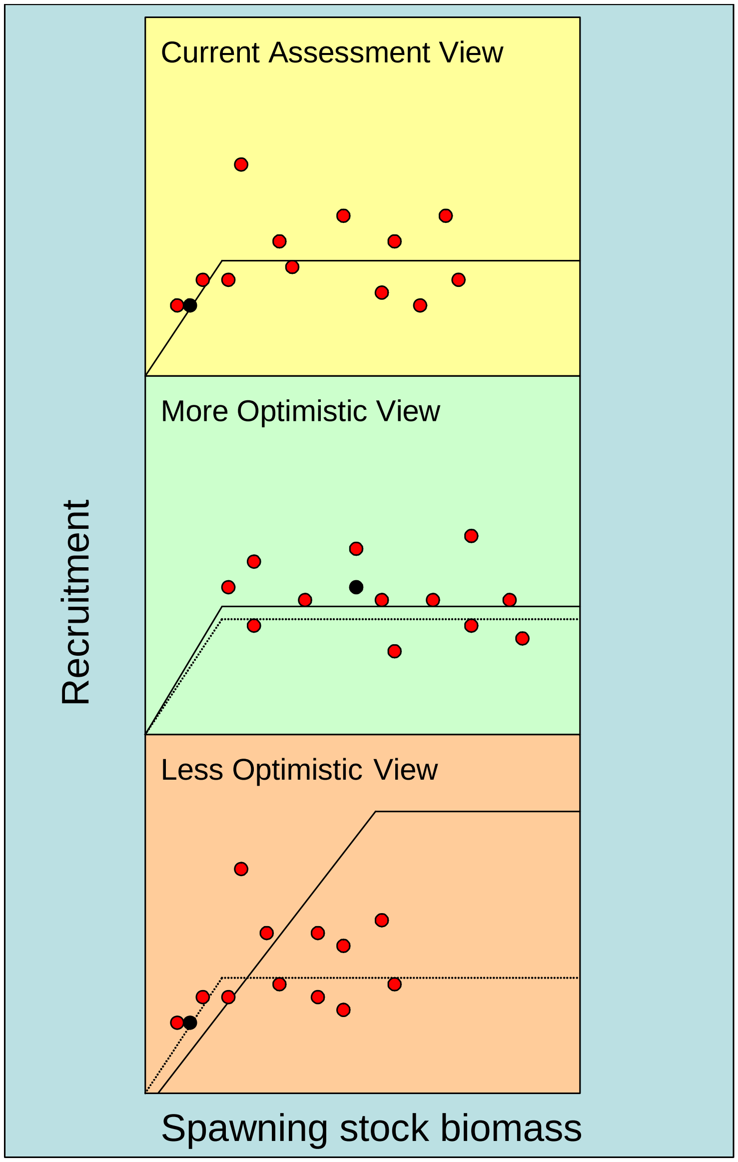

Fig. 2. Schematic showing stock recruit dynamics used to generate three sets of Operating Models. Note that these are schematics only, and not the actual S/R data. The black circle represent the current state of the stock. The broken line on the lower two plots represents the function in the top graph, for comparison. From B. Healey's presentation.

d. Overview of the G. halibut MSE. D. Miller presented an overview of the MSE for Greenland halibut. Fig. 3 shows the schematic outlining the simulation structure. Details of the modeling process were discussed at length by the SG.

There was no error structure applied in the catch or catch at age used in the analysis. The SG had a technical discussion around aspects of bootstrapping used, mostly for purposes of clarification. There was agreement that this was an adequate approach for expressing estimation error. The importance of the partial recruitment (PR) vector in the OM was highlighted, as low PR values at older ages could result in considerable biomass or spawner biomass in the population, sometimes referred to as "cryptic biomass".

The SG briefly discussed the appropriate levels of process error (P), observation error (O), and model error (M). No implementation error was included (see Fig. 1), although this could be added at a later date, once other aspects of the MSE have been established. It was also noted that implementation error could be considered in other forms as well (e.g. an amount that managers should remove from the TAC generated by a particular harvest strategy) and that it may not be necessary to include it in the OM. Alternatively, some management strategies could be included that had over-runs of the TAC at similar levels seen in the recent fishery, e.g. 20 to 25%. This is an ongoing issue that SC has had to deal with in its annual catch projections for management advice on this stock.

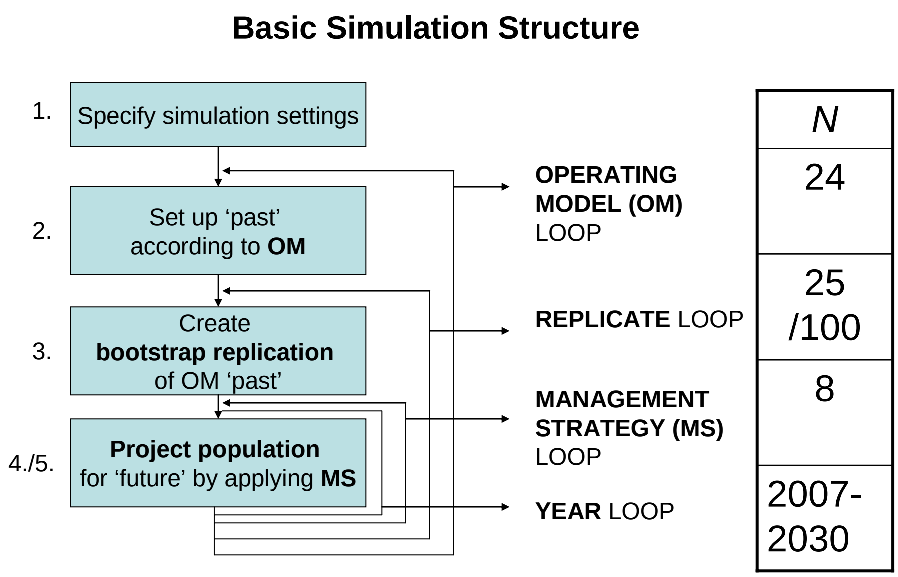

Fig 3. Simulation structure for Greenland halibut MSE modelling. From D. Miller's presentation.

As with the stock assessment, the SG treated Greenland halibut in SA 2 + Div. 3KLMNO as a single stock. Other assumptions regarding stock structure could be evaluated, but such spatial management aspects would require considerably more work, and could be an item for future development work.

To restrict the number of options being considered in the MSE, it was suggested to eliminate those options that did not perform satisfactorily in deterministic runs on the basis that they would not perform any better once uncertainty was included.

Following some discussion on the stock/recruit relationships (Fig. 2), the actual data used for the analysis was examined. It was noted that the segmented regression for CAV and MOV were very similar. This led to further discussion of the 3 "views" of the stock (CAV, MOV, and LOV). It was explained that two factors interacted to create the 3 "views": stock-recruit relationship (SRR) and starting point (numbers at age). The CAV and MOV "views" have the same SRR but the MOV has more optimistic starting numbers at age. Concerns were expressed (mainly about problems with residual patterns), over tweaking an assessment model with multiple indices to be more optimistic, and that it may be better to use just one optimistic index in an XSA (rather than averaging 4 *indices) to provide the more optimistic view (MOV). It was agreed that further thought was required on how best to capture the more optimistic view of the stock, particularly with respect to actual CPUE indices.*

The SG concluded that it would be better, from industry perspectives and for other reasons, to use an actual CPUE index than a dummy value. Although it may be acceptable to use a model with both CPUE and research vessel survey indices, it was considered unlikely that a model with CPUE only would be acceptable. Incorporating CPUE into the assessment properly (a job to be considered by SC) will likely be difficult, and will require some thorough work to validate the CPUE indices and how they relate to stock size. In terms of the MSE work, the most important requirement of the "CPUE XSA" based OMs, is a stock that is currently in a more healthy position (i.e. lower F, higher biomass & recruitment, etc.) than those produced from OMs conditioned on the current XSA. Because XSA cannot use age-aggregated indices (in its current setup at least), age-disaggregating CPUE indices for each year using the catch data proportions at age could be explored. An OM conditioned on this CPUE XSA would need to be internally self-consistent and be able to generate future index values.

Further consideration should also be given to tweaking the existing assessment to something more positive and then generating an index proportional to the selectivity weighted biomass (a "CPUE" index). This would involve examining the residual patterns of the indices and selecting "optimistic periods" of these indices on which to base the model, then using the variance around the fitted parts to generate future index values.

The SG considered some details of the XSA approach, and the effect of changing the shrinkage on population numbers in the estimation model. It was decided to keep the estimation consistent with the current assessment formulation of XSA.

e. Management strategies considered. P. Shelton gave a presentation on management strategies, suggesting that good strategies would "satisfy most desired objectives across a range of measures most of the time, while avoiding undesirable things happening nearly all of the time". Under MSE, management strategies are evaluated by examining how they perform on a simulated fishery. In general, there are two types of strategies:

1. Fixed: TAC doesn't change with perceived state of stock
2. Feedback-control: TAC adjusted +/- based on perceived state of stock using preset rules.

The second generally outperforms the first, depending on the amount of uncertainty.

The management strategy is applied based on the simulated perceived state of the stock and the impact is evaluated with respect to the simulated true stock. A strategy is acceptable if it performs well across a range of possible realities regarding the true operating model and the level of process error, estimation error and model error.

Table 2. List of Management strategies considered in the G. halibut MSE.

	Type	Rule
1	Fixed TAC	TAC = 8,000t
2	Fixed TAC	TAC = 16,000t
3	Fixed TAC	TAC = 32,000t
4	Variable F	Fstatus quo
5	Fixed F	F0.1
6	Model-free Variable TAC-rule	*
7	XSA-Based PA variable F-rule	*
8	Rebuilding plan variable TAC-rule	*

* Descriptions of management strategies from Table 2:

6. The model-free variable TAC rule is defined as:
TAC(y) = TAC(y-1) * (1 + lambda *slope), where slope is the annual proportional change of an abundance index, and lambda was chosen to give a reasonable change in TAC over time.

7. If SSB>Beta then F=F0.1, else if SSB<0.5 Beta then F=0.5*F0.1, else F=(SSB/Beta)*F0.1, where Beta is the estimated breakpoint of a segmented regression fit to the SR data (Fig. 4).

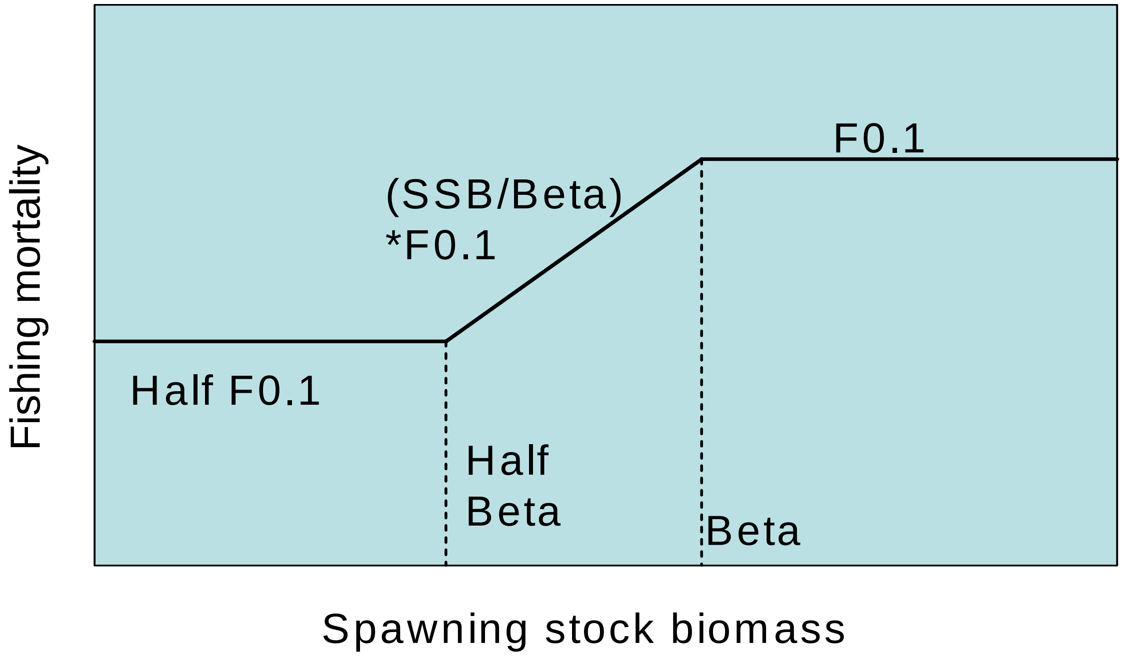

Fig. 4. XSA-Based PA variable F rule proposed (from P. Shelton's presentation).

8. For the Fisheries Commission rebuilding plan variable-TAC rule implemented in the MSE: If the XSA estimate of 5+ biomass in year y+1 differs by 15% or more from the biomass in y-2, y-5, or y-8 then the TAC in y+1 is adjusted up or down by 15%. This rule would only be evaluated every three years to bring about TAC stability. The 15% was based upon the maximum TAC adjustment specified in the FC rebuilding plan (Appendix IV).

The SG considered that the eighth strategy (Table 2) would not work if the reduction in TAC (15%) was equal only to the percentage decline in the stock, and that the stock would eventually collapse under this scenario. It was also thought by some that discontinuous rules may cause problems, and that rules should be continuous, i.e. not knife-edge at 15%. The SG had a brief discussion of the 15% strategy in the existing rebuilding plan, noting that it was meant to apply in both decreasing and increasing stock sizes. Further, the FC plan does not contain any rules or measures to indicate when to apply the 15% strategy.

f. Performance measures proposed. P. Shelton gave a presentation on the suggested performance measures. Simply stated in the MSE context, performance measures evaluate how well a particular management strategy is performing, relative to other strategies. They should relate easily to the fishery and be meaningful to stakeholders and managers. The objective of many fishery management policies is to balance three conflicting objectives, and performance measures should consider these:

- High annual catches
- Low risk of unintended depletion
- Maximum industrial stability

Seventeen performance measures were considered, split between those that are fishery related and those that are stock related (Table 3).

4. Presentation and discussion of results

It was proposed that all 8 management strategies be considered, but that the number of operating models be reduced, to consider only runs with M=0.2, and mean PR. This reduced the number of OM's from 24 to a more manageable number of 6, to which all 8 management strategies would be applied .

It was also obvious that a second iteration, or Phase 2, of the Ghal MSE work would be required following the SG meeting, and that the SG would probably not be in a position to make firm recommendations to SC regarding preferred management strategies at the end of the current meeting. Any deficiencies identified by the SG could be addressed before such recommendations could be made.

There was additional discussion on the CPUE, and it was noted that F appears to be increasing during a period of decreasing effort. There were some suggestions to overlay CPUE on assessment output, and that this would be of benefit in guiding future decisions on operating models. It was noted that it was important to take into account the selectivity of the commercial CPUE data relative to the survey data or XSA output. For example, a plot of the Canadian fall survey index aggregated over ages 5 to 10 shows good correspondence with the recent increase observed in CPUE data (Fig. 5), although 5+ Biomass from XSA in the most recent assessment does not show the same trend.

Table 3. Performance measures used in Greenland halibut MSE. The first eight (yellow) are fishery-related, the last nine (light brown) are stock-related.

Average TAC to 2010 (3 year projection)
Average TAC to 2018 (rebuilding plan)
Average TAC to 2030 (long term)
CV in TAC to 2010 (3 year projection)
CV in TAC to 2018 (rebuilding plan)
CV in TAC to 2030 (long term)
Weighted mean age in the catch
Catch as Fraction of MSY
Ratio of 5+ biomass in 2010 to average 1975-99
Ratio of 5+ biomass in 2018 to average 1975-99
Ratio of 5+ biomass in 2030 to average 1975-99
5+ biomass growth rate to 2010
5+ biomass growth rate to 2018
5+ biomass growth rate to 2030
Weighted mean age in the population
At or above rebuilding target
Biomass as fraction of Bmsy

a. Discussion of performance measures

The SG concluded that 17 performance measures (PM's) were too many to examine in the time available, and that a subset would be defined. This would be revisited following some preliminary examinations of OM's, to determine if any PM's were particularly informative, or not. It was thought that there may be "information overload" in trying to evaluate 24 operating models, 8 management strategies and 16 performance measures – a total of 3072 combinations.

Regarding the plots of population growth rate, it was noted that these were useful, but raised a question of how much recovery was wanted, relative to the amount of catch to be sacrificed. There was also a question on how firm the 140,000 t target was in the rebuilding plan, and whether or not the MSE work might provide a better, or more biologically sound, target. A further suggestion that was agreed was to examine the absolute annual variation in catches, to remove the offsetting influence of positive and negative fluctuations.

A 10-year time horizon was noted as being important to industry, e.g. to 2018 as defined in the rebuilding plan, as typical for vessel amortization, and within that time period, a 2-3 year window is also important in terms of market and other economic considerations.

The need for clear and understandable display of performance measures was emphasized. Involvement of industry and managers is key in the process. The process could also be broadened to include representatives of environmental non-government organizations (ENGO's). It is important to show a range of options, target the audience, and be as brief as possible in displaying the results.

It was concluded that the performance measures chosen were generally acceptable. Two additional ones considered to be important were a CPUE predictor (if possible), and an optimum fish size. The SG noted that economic indicators such as these have been included in recovery plans for some other stocks.

b. Discussion of operating models[3]

Preliminary results from selected OM's were examined and it was obvious that two of the management strategies, namely Fstatusquo and Constant TAC=32,000 t, performed poorly, resulting in no stock recovery and a rapid collapse in the case of a constant 32Kt TAC. *Following some discussion on how to group and examine outputs, it was decided to run through all available OM's. Further discussion of the importance of catch and CPUE focused again on ways to simulate CPUE. It was noted that the relationship between abundance and CPUE was not understood, or else it would be possible to include CPUE in the stock assessment. There was a suggestion that selectivity-weighted biomass might be a useful fishery CPUE proxy. C/F was also suggested as a possible proxy. The SG noted that document (NAFO SCR 08/01) prepared by the NAFO Secretariat outlined the distribution of fishing effort (based on VMS data from the NRA). It was suggested that the Scientific Council meeting in June 2008 review this analysis before further evaluation. A concern also was raised that these data are not in the public domain, thus preventing anyone other than the NAFO Secretariat carrying out any analyses. This would make the work difficult to peer-review.*

Based on the output from the runs, an extended time lag was evident between improved recruitment and improved SSB. The S/R concerns are clearly important, and should be revisited in the "Phase 2" issues.

The SG considered other ways to evaluate or calibrate the OM's, such as a plot of constant catch vs. a percentage of the 2019 benchmark (e.g. 140,000 t). Although the constant catch scenarios appear to be non-starters, such a plot should be helpful in diagnosing what the trade-off is between catch and recovery. Managers evaluate the trade-offs, based on this information, and on the agreed objectives for managing the resource. One difficulty with ad hoc

[3] (This section also includes some text related to the evaluation of management strategies and performance measures, as these discussions were often intertwined within the SG).

decisions is that often there is no strategy for how to react or manage when "things get bad". Trade-offs and also ad-hoc management are important issues.

In discussing how to proceed with the next phase of the work, it was concluded that a focus on operating models was paramount. Plausibility and impact are important considerations, and robustness tests were considered to be useful. OM's could be categorized by high, medium, and low rankings in terms of how likely it is that they represent reality. The importance of closely evaluating the properties of candidate OM's was emphasized. Following further discussion on OM's and their properties, a list of fourteen major points for consideration was developed, and summarized in Table 4.

Table 4. Points for consideration in developing the Operating Models

- How to resolve lack of fit of XSA with survey indices?
- Tweaking the assessment model has important consequences.
- Natural mortality estimate makes a difference (e.g. M=0.1 or 0.2).
- OM's must cover the full range of perceptions of the stock.
- Need to concentrate on how to generate future "projected" data from previous point.
- Need to include CPUE, somehow, in conditioning the OM's.
- Stock structure is important – is there one homogeneous stock?
- Consider using correlated error in the OM.
- How to account for error in catches during a reference period?– could use range.
- How do effort restrictions affect the fishery?
- Shape of partial recruitment vector is important.
- Is there ageing error, particularly in the older ages and what is the impact?
- Important to have correct biological data (weights, maturities, etc.)
- Beware of "hockey stick" (segmented regression) stock recruit curves because of the discontinuities this may generate in MSE output particularly for intended constant *F* strategies.

The importance of including CPUE was once again emphasized. This would promote stakeholder buy-in with regard to the MSE exercise, particularly if a real CPUE index could be agreed, instead of a dummy one. The basic problem in including CPUE is that its relationship to stock abundance or biomass is unknown, and thus SC has not been able to accept CPUE as an index for this stock. Industry perspectives, from virtually all fleets, are that CPUE has increased substantially in recent years, and that this view is not reflected in the stock assessments. There was considerable discussion on this point, following presentation of Fig. 5 which showed that ages 5-10 aggregated from the Canadian fall survey showed an increasing trend in recent years, similar to reported CPUE series. The SG agreed that it was important to include CPUE or a proxy in the MSE, and in fact that the MSE process was ideal for the situation currently existing with this stock, i.e. where there were conflicting views exist regarding stock status.

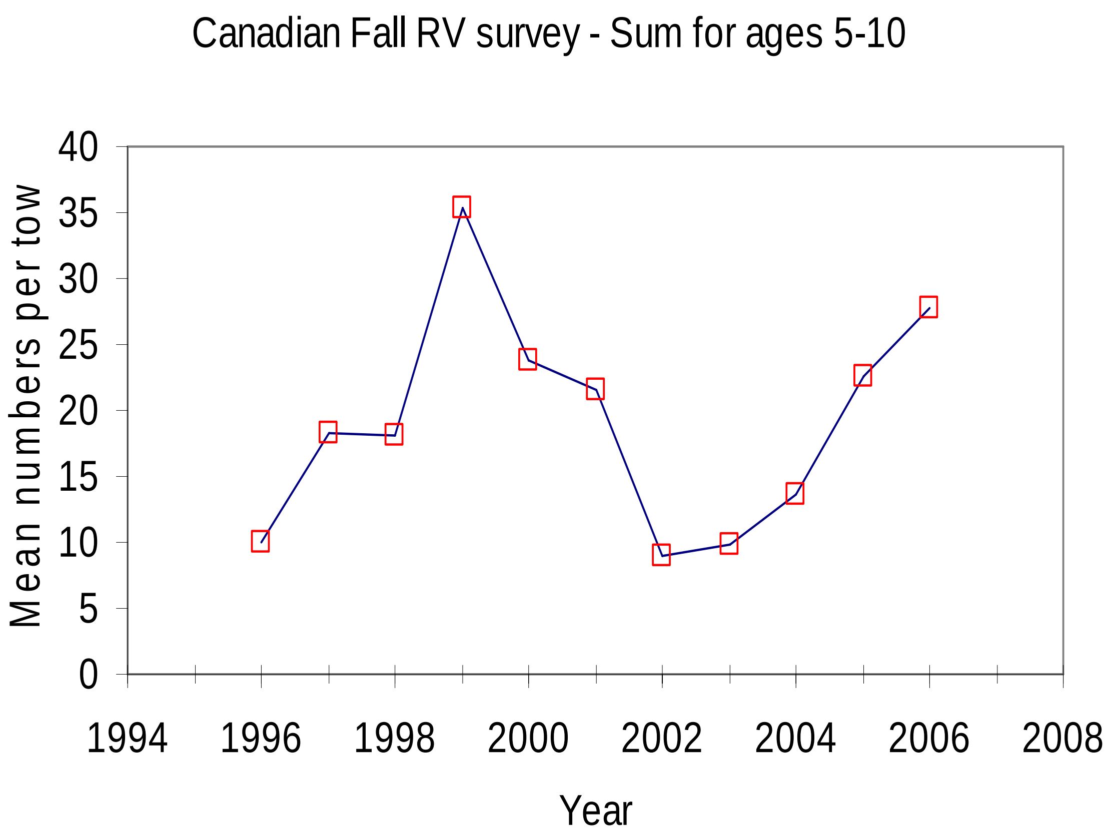

Fig. 5 Plot of mean numbers per tow aggregated over ages 5-10 (main ages contributing to the fishery) for the Canadian fall RV survey. The increase in the recent period is also reflected by CPUE trends from the fishery.

The SG considered other ways to reflect a more optimistic view of the Greenland halibut stock, such as weighting of indices, adjusting the shrinkage in XSA runs, further examination of the retrospective pattern, that may not be possible to correct, etc. However there was no consensus on how to proceed, although it was noted that some of these options will be examined in terms of the NAFO SC assessment of this stock in June 2008.

The SG considered some alternative approaches, including exploratory statistical catch at age analyses (SCAA) that were presented. A Bayesian approach was also shown. However, it was decided to stay with the FLR –XSA approach at present although a number of advantages of an SCAA, particularly in management strategy evaluation, were discussed.

There was considerable discussion on how best to present and evaluate the various management strategies (MS) and operating models, and their combinations. It was concluded that it was necessary to look at the various MS under each OM in turn, and that it was also informative to examine a single MS with varied OM's. It was agreed to examine the deterministic plots as soon as possible in the meeting, once extracted from the FLR output. However, to reduce the information presented to a reasonable amount, it was agreed to look at 3 OM's representative of CAV, MOV and LOV (1, 9, and 17 – see Table 1), all 8 MS's, and 4 PM's (average catch, coefficient of variation on absolute catch, ratio of Biomass in terminal year of projection (e.g. 2030 or 2018) to average Biomass in 1975-99 (representative of the rebuilding target set by Fisheries Commission), and Coefficient of variation on fishing mortality Results were presented for deterministic and stochastic runs.

Fig. 6 shows the deterministic results of projections to 2030. The SG noted that these could be "tuned" if desired, e.g. to all achieve a target biomass by a certain time. Other options included looking at shorter time lines (e.g. to 2018, which is the duration of the current FC Rebuilding Plan), which would be less dependent on assumptions about future recruitment. The SG looked at MS 5-8 for this shorter time frame (Fig. 7), and briefly discussed comparisons with the results from MS 5-8 with the longer time series.

The SG noted that it also would be useful for the experts in MSE to provide their experience in how the process eventually plays out, i.e. what are the likely interactions between science (NAFO SC) and fishery managers (NAFO FC) based on existing MSE work. In that regard, it was recommended that at least a reference to a "real-life example" of MSE be included in our SG report. Butterworth and Geromont (2001) evaluated management procedures for the Namibian hake fishery. Other papers which have considered MSE include Butterworth and Punt (1999) and Rademeyer et al. (2007).

It was agreed that the MSE SG was a valuable exercise, particularly with regard to the joint involvement of industry, managers and scientists in the evaluation of results. It is essential that MSE does not turn into a "black box" (just based on a deterministic formula), noting that the approach is not always an easy concept to grasp. The process was generally regarded as a positive and comprehensive one, which should interest NAFO Fisheries Commission. Other discussions addressed the issue of credibility of the assessment and management of the resource. All agreed that the work on MSE for this stock should continue, as an iterative process. In the interim, discussion of the preliminary results obtained would be useful, even if the final product will take a further year of work.

There was some discussion on increased involvement of commercial fishing vessels in surveys of the resource, along with research vessels. Although there would be issues of standardization, it was noted that such indices exist for some stocks in Canadian waters, and that such an approach may help to bridge the current gap between industry's and scientists' views of this resource.

Discussion of stochastic results:

There was some debate about the S/R curves used in the modeling, and their impact on the results. Some members of the group felt that the hockey stick (segmented regression) method may introduce instability, and that Beverton Holt (BH) or Ricker models in which R changed smoothly with SSB would be more suitable. It was also noted that there did not appear to be large differences in results (OM 1 and OM 17) between runs using segmented regression, or depleted segmented regression. Others felt that there were different problems introduced by using BH or Ricker (large virgin biomass B_0, for example, in BH runs). The SG agreed to flag this as an area for further exploration (see Table 4).

In interpreting the stochastic results (MS 5-8, OM 1, 9, 17), it was suggested that the lower error bars, particularly for predicted future resource abundance, should be examined (Figs 8,9). Although 25 replicates was thought to be on the low side for these analyses, it was considered acceptable for "first-cut" comparison purposes at this meeting. Typically 100 replicates or more should be run, although this requires substantial computing time.

The line plots, representing the means of the replicates in Figs 10-12, can usefully allow for direct comparisons of MSs. However, it is necessary to also consider the amount of variation between replicates for each OM-MS combination. This can be plotted as medians and percentiles of replicates or all the replicates on one plot, a "worm" plot (e.g. Fig. 13), considered more useful if the lines could be displayed one at a time, e.g. as was done in D. Butterworth's introductory presentation, so that the variability between MS's could be observed. However, it was pointed out that this would require longer (less brief) presentations, which may not be desirable. Another suggestion was to look at development of biomass and catch trajectories simultaneously. Other questions focused on how realistic some projections were – whether catches at these levels would actually allow the stock to increase to the projected levels shown. Further discussion centered around error assumptions for catch at age; XSA assumes catch is known exactly, while other models such as statistical catch at age, allow error structure.

c. <u>Evaluation of Management Strategies</u>

Initial evaluations suggested that Constant Catch and F status quo were not acceptable strategies. Evaluation of deterministic runs for OM 1, 9, 17 (Fig. 6) showed that MS 2, 3, and 4 failed as Biomass in 2030 or before crashed at least once, and that MS 3 failed with regard to all 3 OM's. MS 1 produced large biomass increases, but also very large variations in F (catch constant at low level as Biomass increases). MS 6 looked best based in terms of catch variation, and it was difficult to choose among the other 3 MS's. Another MS useful for diagnostic purposes would be zero catch. This would bound the possibilities with regard to maximum rebuilding rate, and show if rebuilding targets were realistic.

There was some consideration of the 140,000 t target specified in the current FC Rebuilding Plan. It was observed that many OM/MS combinations produce biomass estimates much greater than the target level, and that the 140,000 t target could be regarded as a milestone rather than the ultimate target for rebuilding the stock. There is also the question of how the resource would be managed once the target has been reached, i.e. would a similar strategy still perform well on a recovered stock? Although this clearly would be a decision for NAFO FC, it is likely that in such a situation a different MS would be employed. The basis for a management strategy should be re-evaluated through MSE every 4-5 years.

In considering constant F strategies, it may be wise to limit catch at high biomass levels. This would help avoid reducing the stock too quickly. It was thought that identifying a target F to rebuild the stock to the target of 140,000 t, under the existing 15% rule, would be a useful approach. A management strategy could then be developed on the basis of a gradual reduction in F until the target F value is reached (always respecting the 15% maximum TAC change rebuilding plan rule). Alternatively, a target F value could be identified in the range of Fmsy and a similar management strategy based on gradual reduction in F developed. This idea was also mentioned earlier in the discussion of tuning the operating models and was also raised in discussion on the wiki prior to the SG meeting.

In response to some questions which had been posed prior to the meeting, the SG considered a suggestion for an interim rebuilding target, e.g. an increase in biomass of 25-50% over a 5 year period. Another related strategy was to consider harvesting a percentage of the potential biomass growth (e.g. 1/3), while leaving the remaining 2/3 for stock rebuilding. Additional points were suggested, such as limiting TAC increases to 1 in every 2 years, which was considered by some to be reasonable for a long-lived species such as Greenland halibut, as well as limiting TAC increases to the greater of 3,000 t or 20%.

For a rule such as one permitting a 15% decline in the resource before reducing the TAC (similar to MS 8), there should be continuity (e.g. allow some proportional change in TAC for decline <15%).

The SG concluded that it was not necessary to include additional categories of management strategies, as those chosen gave a wide spread of results. Further development of some approaches would be useful, such as the F strategy mentioned previously (gradual reduction until target is met). Another example: the parameters of the feedback control strategies (6-8) should be varied to improve performance in trial runs before being compared with other strategies in the MSE.

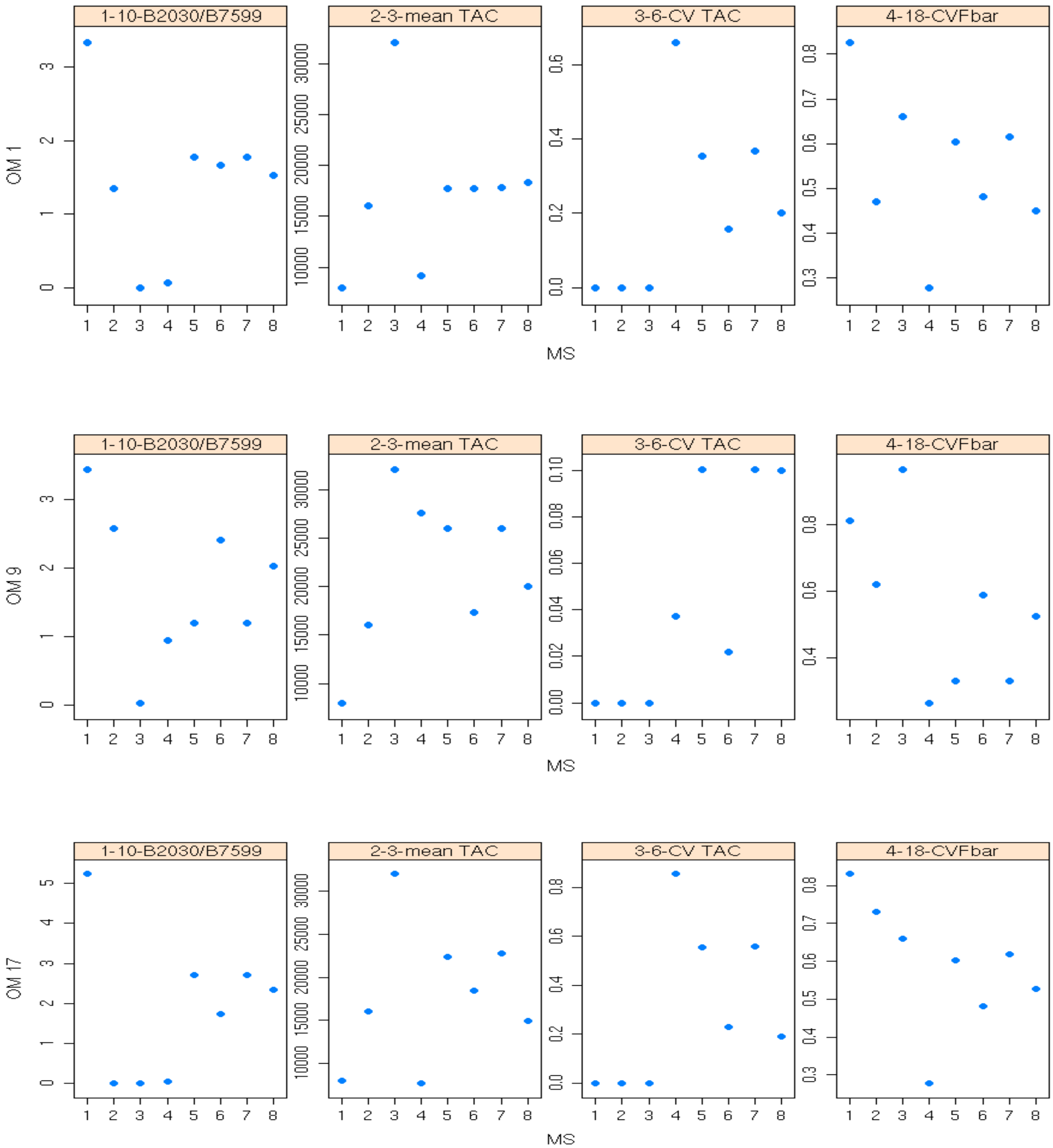

Fig 6. Results (to year 2030) of deterministic runs, for OM's 1, 9, and 17. All 8 management strategies (x-axis, refer to Table 2) are shown in each panel, with each column of 3 panels representing a common performance measure, and each row representing an operating model. The first numbers in each identifier above the plot are just reference numbers (e.g. 1-10, 2-3, etc.).

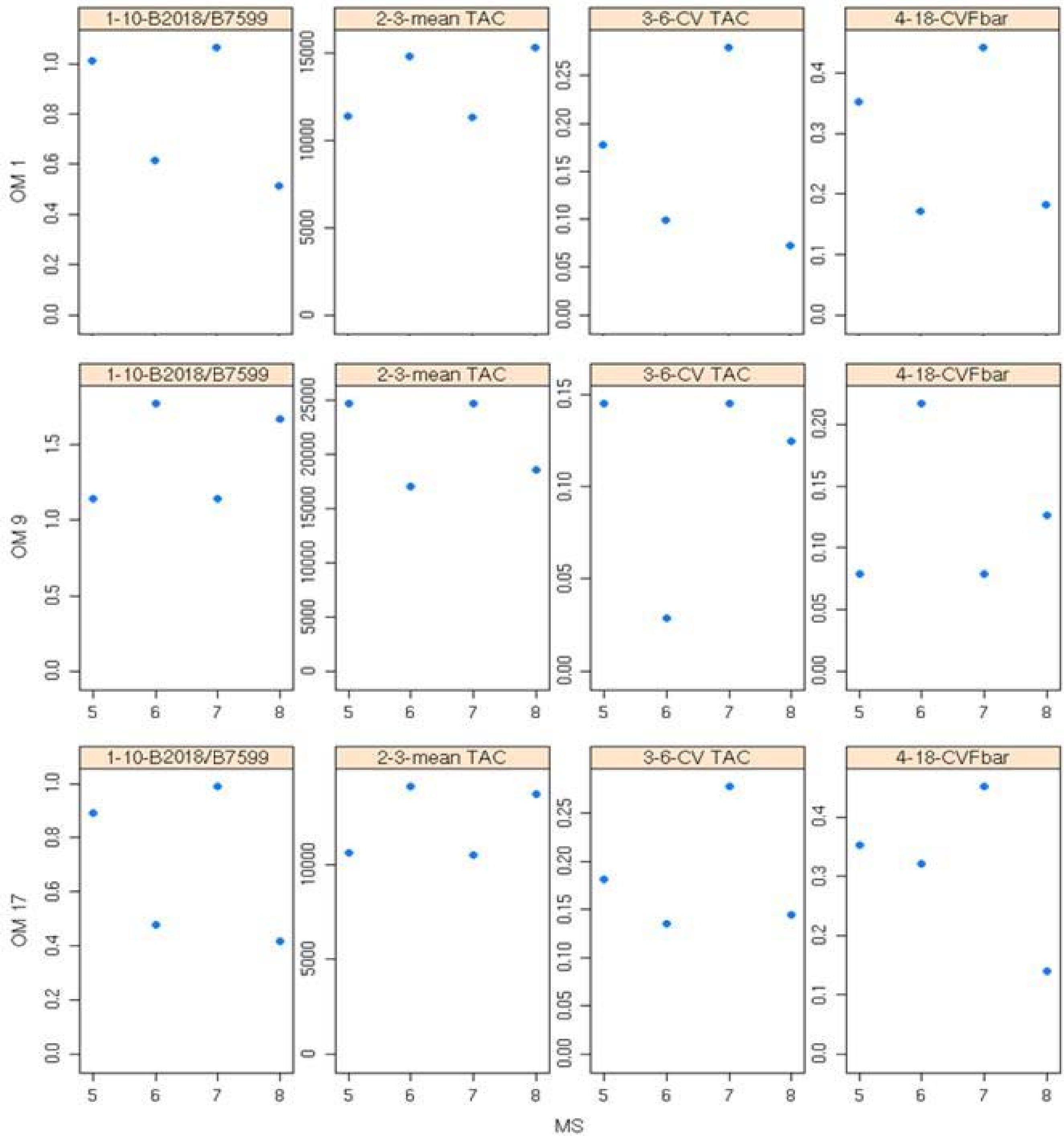

Fig 7. Results (to year 2018) of deterministic runs, for OM's 1, 9, and 17. Management strategies 5-8 (Table 2) are shown in each panel, with each column of 3 panels representing a performance measure, and each row representing an operating model. The first numbers in each identifier above the plot are just reference numbers (e.g. 1-10, 2-3, etc.).

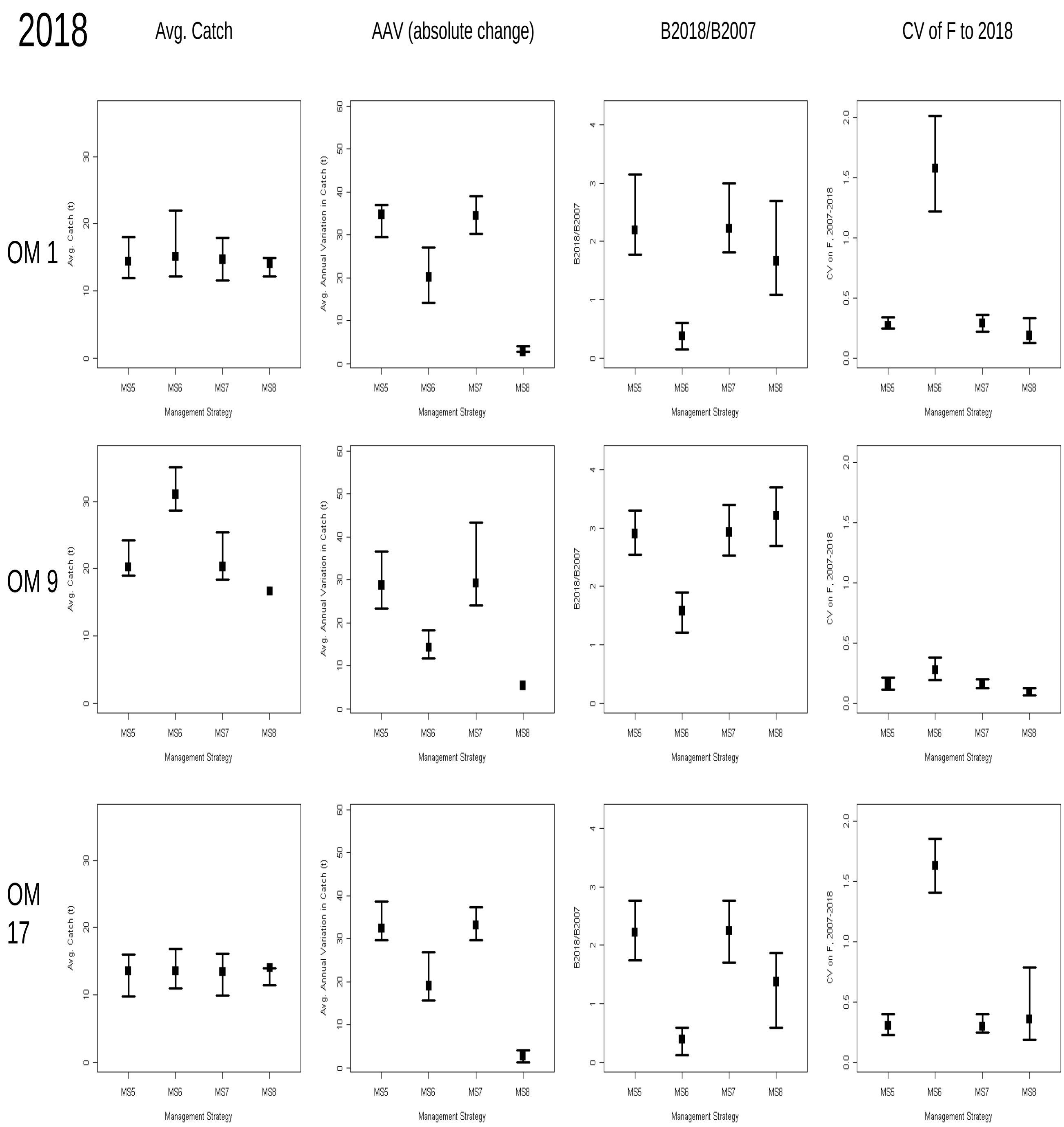

Fig. 8. Results (to year 2018) of stochastic runs, for OM's 1, 9, and 17. Management strategies 5-8 (Table 2) are shown in each panel, with each column of 3 panels representing a performance measure, and each row representing an operating model. AAV = Average Annual Variation in TAC

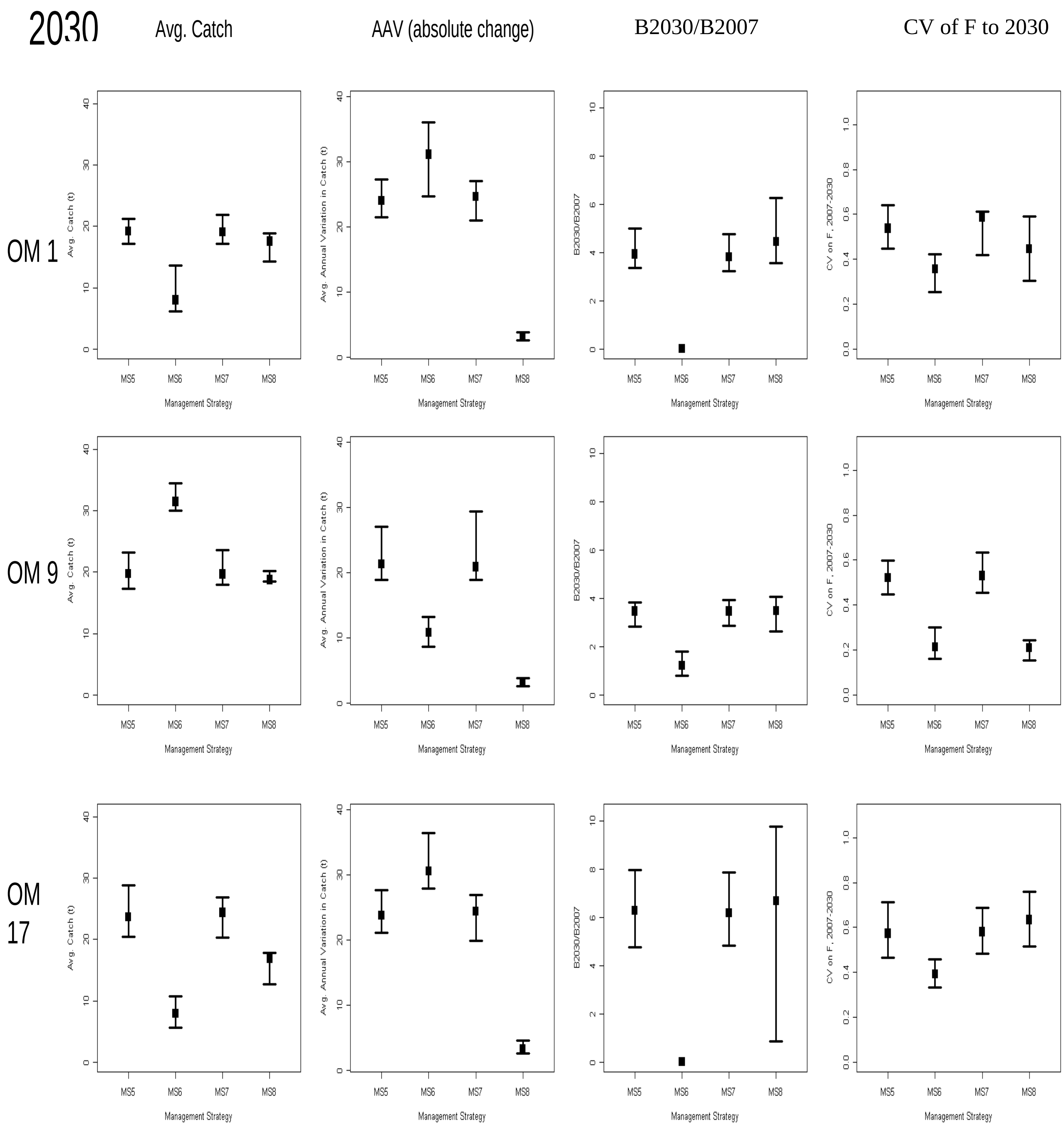

Fig. 9. Results (to year 2030) of stochastic runs, for OM's 1, 9, and 17. Management strategies 5-8 (Table 2) are shown in each panel, with each column of 3 panels representing a performance measure, and each row representing an operating model. AAV = Average Annual Variation in TAC

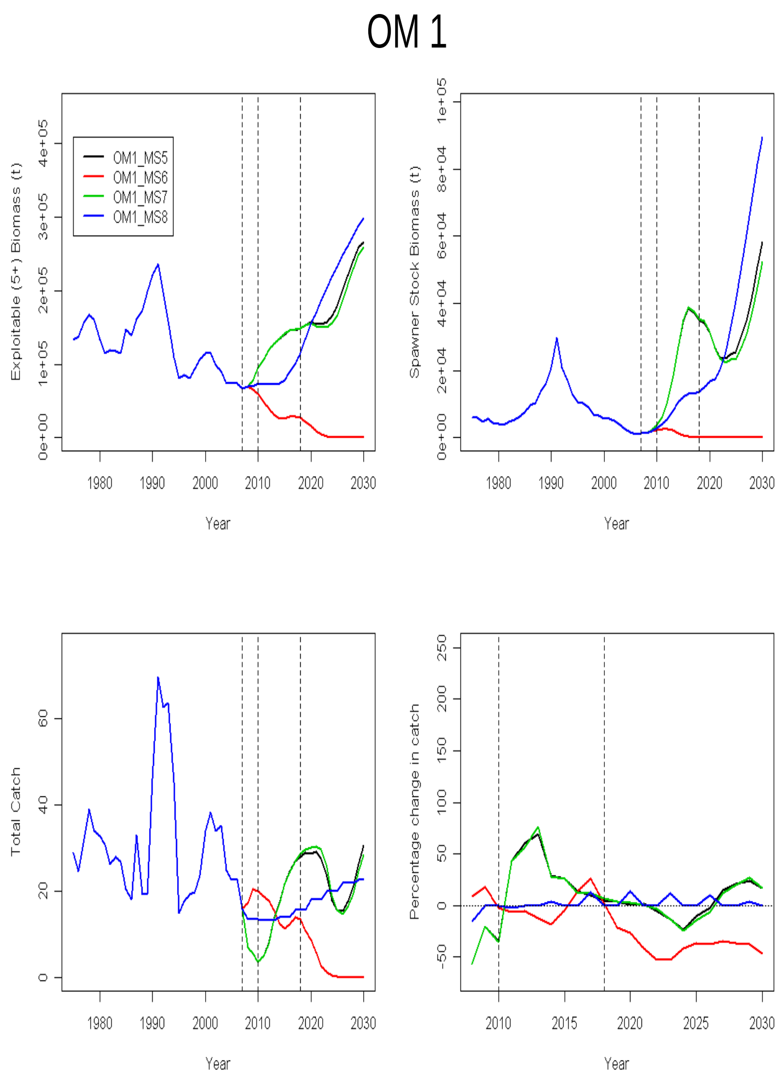

Fig 10. Results (to year 2030) of stochastic runs, for OM 1. Results for management strategies 5-8 (Table 2) are shown in each panel, with each panel representing a different performance measure.

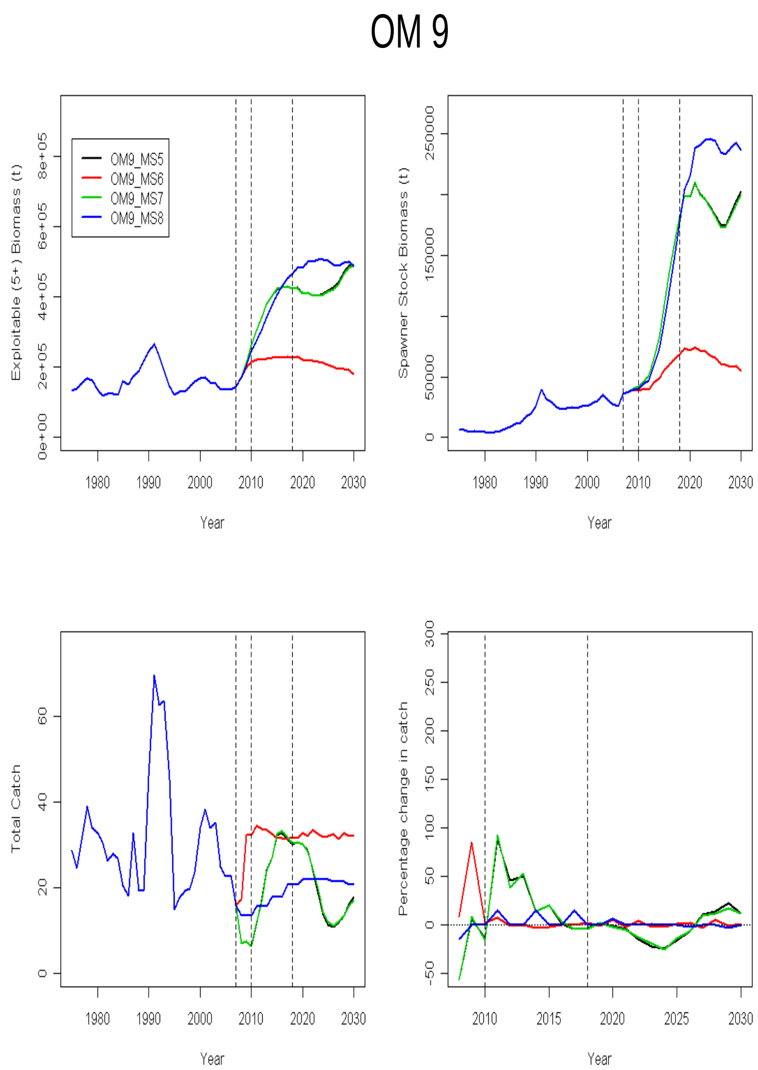

Fig 11. Results (to year 2030) of stochastic runs, for OM 9. Results for management strategies 5-8 (Table 2) are shown in each panel, with panel representing a different performance measure.

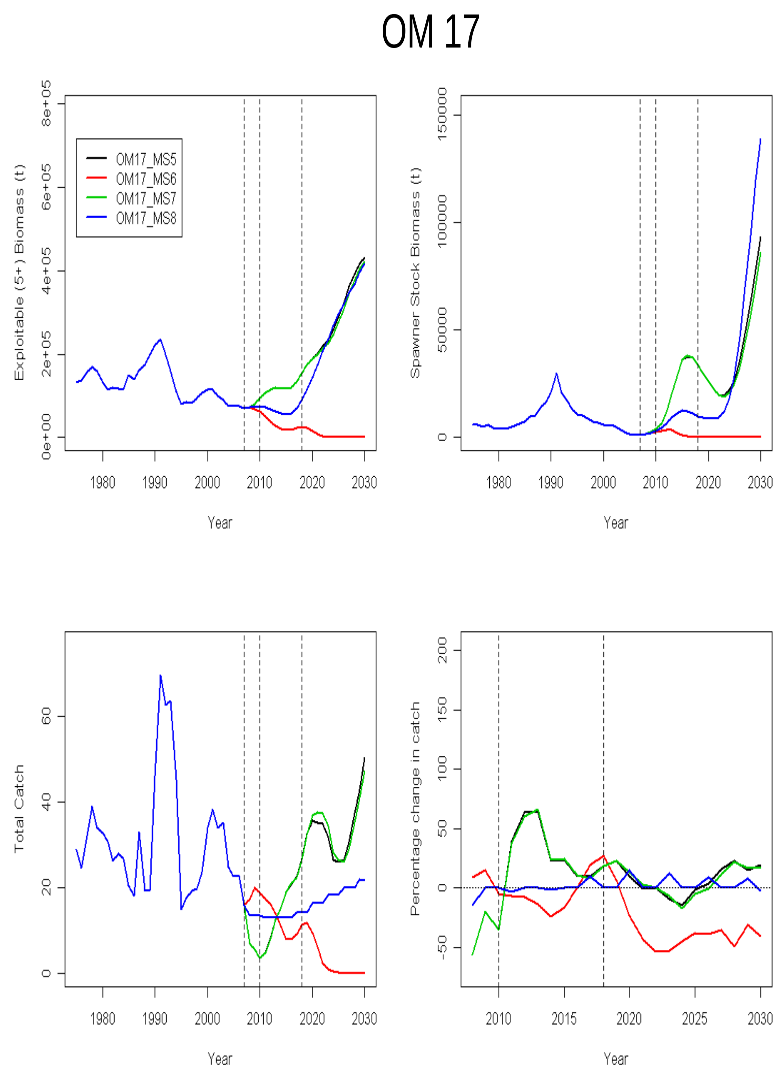

Fig 12. Results (to year 2030) of stochastic runs, for OM 17. Results for management strategies 5-8 (Table 2) are shown in each panel, with each panel representing a different performance measure.

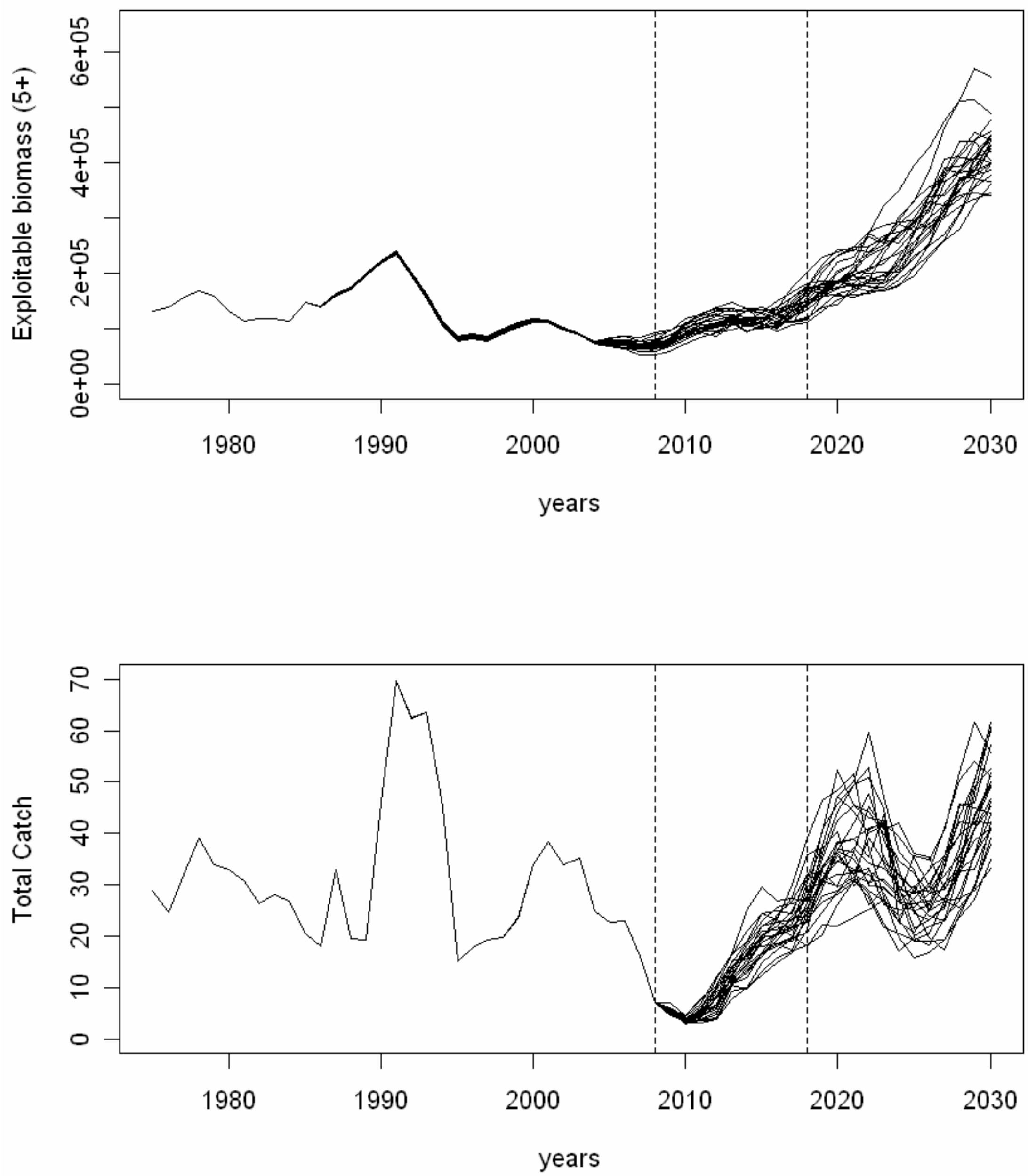

Fig 13. “Worm” plots of each replicate of the stochastic run for OM 17, MS 7. The first vertical line represents the start of the MSE simulation period and the second vertical line represents the end of the rebuilding plan (2018). Variation in exploitable biomass pre-2006 comes from the bootstrapping of residuals for the XSA of each replicate. There is no variation around total catch pre-2006 because catch is treated as exactly known.

5. Conclusions

a. Review of progress against Terms of Reference:

1. Develop a full reference set of operating models for SA 2 + Div. 3KLMNO Greenland halibut conditioned on the most recent stock assessment and other available information.

The SG made good progress, with development of OM's well underway.

2. Give consideration to appropriate levels of process error (P), observation error (O) and model error (M) following the ICES COMFIE report "POM" approach (ICES 1997. Report of the Comprehensive Fishery Evaluation Working Group (COMFIE). ICES CM 1997/Assess: 15). Also give consideration to implementation error.

Completed. All combinations of OM's, MS's and performance measures were run, and a subset of the results were examined by the SG. Deterministic and stochastic results were presented. Implementation error was not included in the analyses at this time, but was considered by the SG and some alternative approaches were proposed.

3. Develop an appropriate suite of performance statistics that cover sustainability, Precautionary Approach and industry objectives.

This was addressed fully. As the operating models are fine tuned, so too can the performance measures, including how they are presented.

4. Evaluate a suite of management strategies that allow for both rebuilding of the stock to the target level and for sustainability thereafter.

Addressed, but more analysis needs to be carried out undertaken before recommendations are made as to the best, or optimal, management strategies.

5. Evaluate the performance statistics for each of the management strategies and rank the strategies on this basis.

This was not fully completed, as it was decided during the meeting that additional work on the MSE was required before rankings should be considered undertaken. However, performance measures were considered in detail, and an example of a proposed ranking process was discussed by the SG. Choosing a winner based on a single mean weighted performance measure for each strategy was not considered as an advisable way to proceed.

6. Advise on applicability of this approach, in general, for possible use in developing rebuilding plans for other NAFO stocks.

The SG though that the MSE process was applicable to other stocks, but emphasized that it requires considerable work over a period of 2-3 years to develop. It is likely that availability of skilled people to work on this approach will determine its use initially. The SG did note that MSE does not have to be restricted to stocks with rebuilding plans. The SG did not know how well MSE would work in a multispecies or ecosystem level approach although application in these areas has been suggested by others.

b. Conclusions

1) *Management strategy evaluation for the Greenland halibut stock in SA 2 + Div. 3KLMNO is a useful exercise and should be continued to completion. It would be premature to make recommendations based on the incomplete MSE for this stock at this time.*

2) Further investigation of operating models is required – a 14-point list is provided for guidance (Table 4).

3) Some management strategies investigated were generally acceptable – some minor modifications could be explored. Those involving constant catch or status quo F were rejected.

4) Performance statistics evaluated were acceptable – could be slightly refined to obtain the best variants, as operating models and management strategies evolve.

5) Examples decided on and shown in the report are illustrative only and not intended to represent the best or final choices of operating models, management strategies or performance measures.

6) The Study Group format (scientists, managers, industry) was successful, and involvement of all parties in the ongoing development of MSE is important. To further this collaboration, exploratory or sentinel surveys (joint industry – science) could be investigated to determine their potential to provide additional information on the stock. Inclusion of ENGO's in future meetings on Greenland halibut MSE should be considered.

c. Recommendations

1) The Study Group should be continued, but only if appropriate expertise is available. The work on G. halibut MSE could be regarded as a 3-year project, currently nearing the end of year 1.

2) Funding to continue the G. halibut MSE work should be pursued by Contracting Parties of NAFO. Ideally, the project could be housed at a host institute, where 2 dedicated persons could be funded to complete the study, although other options are possible.

3) Although Scientific Council has considered CPUE previously, this issue should be re-examined with respect to the Greenland halibut stock, and should be clarified whether an useable index of abundance can be derived from catch rate data.

4) The wiki site used by the Study Group in advance of the Vigo meeting should be maintained if possible to document further development work on Greenland halibut. Wiki software is open-source code; thus, the feasibility of using a NAFO-based server should be investigated.

6. Report of Study Group

The SG agreed on the main points to form a basis of the eventual report to Scientific Council. A draft report will be circulated for approval, via e-mail to SG members, as soon as possible following the meeting. Following approval by the SG, the final report will be presented to SC in June 2008 by the SG Chair. A multi-authored NAFO Scientific Council Research Document will also be prepared (lead author David Miller) for presentation of the Greenland halibut MSE study details, also for June 2008.

7. Next steps

The work examined thus far represents a first step in the process, although it is not yet at the stage where advice to Fisheries Commission can be provided on the management of Greenland halibut. If substantial progress is to be made, then dedicated expertise will be required over the next 2 years, such as that provided by D. Miller thus far. The SG discussed a number of options, but agreed that dedicated resources were necessary, preferably developed by NAFO SC participants. Support from industry and fisheries managers was considered to be crucial, as was dialogue with Fisheries Commission.

8. Closing

The Chair thanked all the participants for their work, both before and during the meeting. The contributions of the invited experts, and the support of NAFO, were also acknowledged. The Chair thanked the hosts for the meeting facilities and arrangements, and for the excellent hospitality extended to participants during the meeting. The Chair also expressed his gratitude to P. Shelton for chairing the morning session on Day 2. The meeting closed at 1730.

9. References

Butterworth, D.S. and Geromont, H.F. 2001. Evaluation of a class of possible Interim Management Procedures for the Namibian hake fishery. In: A decade of Namibian Fisheries Science. Payne A.I.L., Pillar S.C. and Crawford R.J.M.(Eds). South African Journal of Marine Science, 23: 357-374.

Butterworth D.S., Punt AE. 1999. Experiences in the evaluation and implementation of management procedures. ICES J. Mar. Sci. 1999; **56**: 985–998.

Rademeyer R.A., Plagányi É.E., Butterworth D.S. 2007. Tips and tricks in designing management procedures. ICES J. Mar. Sci. 2007; **64**: 618–625.

Appendix I : Study Group Attendees

NAFO Scientific Council Study Group
on Rebuilding Strategies for Greenland halibut

Instituto Español de Oceanografía/ Centro Oceanográfico de Vigo
Vigo, Spain - February 21-23, 2008

Ricardo Alpoim, EU-Portugal
James Baird, Canada
Bill Brodie, Canada (SG Chair)
Doug Butterworth*, South Africa
Enrique de Cardenas, EU-Spain
Bruce Chapman, Canada
Carmen Fernandez, EU-Spain
Diana Gonzalez-Troncoso, EU-Spain
Fernando Gonzalez-Costas, EU-Spain
Brian Healey, Canada
James Ianelli*, USA
Kiyoshi Katsuyama, Japan
Jean-Claude Mahe, EU-France
David Miller, Canada
Iago Mosqueira, EU-Spain
Rob Scott*, EU-UK
Peter Shelton, Canada
Bob Steinbock, Canada
Leo Strowbridge, Canada
José A. Suárez-Llanos, EU-Spain
Noriaki Takagi, Japan
Antonio Vazquez, EU-Spain

* Indicates Invited Expert

Appendix II : Agenda

1. Opening - Introductions, meeting arrangements

2. Background, Terms of Reference (Chair)

3. Introductory presentations
    a. Overview of Management Strategy Evaluation (D. Butterworth)
    b. FLR methodology (R. Scott)
    c. Overview of the Ghal MSE (D. Miller)
    d. Operating model structure (B. Healey)
    e. Management strategies considered (P. Shelton)
    f. Performance measures proposed (W. Brodie)

4. Presentation and discussion of results
    a. Discussion of performance measures
    b. Discussion of operating models
    c. Evaluation of Management Strategies

5. Conclusions

6. Report of Study Group. Agree on main points to form basis of eventual report to Scientific Council. Draft report will be circulated for approval, via e-mail, as soon as possible following the meeting. Final report will be presented to SC in June 2008 by the SG Chair.

7. Next steps

Appendix III : Terms of Reference

1. Develop a full reference set of operating models for SA 2 + Div. 3KLMNO Greenland halibut conditioned on the most recent stock assessment and other available information.

2. Give consideration to appropriate levels of process error (P), observation error (O) and model error (M) following the ICES COMFIE report "POM" approach (ICES 1997. Report of the Comprehensive Fishery Evaluation Working Group (COMFIE). ICES CM 1997/Assess: 15). Also give consideration to implementation error.

3. Develop an appropriate suite of performance statistics that cover sustainability, Precautionary Approach and industry objectives.

4. Evaluate a suite of management strategies that allow for both rebuilding of the stock to the target level and for sustainability thereafter.

5. Evaluate the performance statistics for each of the management strategies and rank the strategies on this basis.

6. Advise on applicability of this approach, in general, for possible use in developing rebuilding plans for other NAFO stocks.

Appendix IV : Fisheries Commission Rebuilding Plan

NOT TO BE CITED WITHOUT PRIOR
REFERENCE TO THE SECRETARIAT

Northwest Atlantic Fisheries Organization

Serial No. N4904 NAFO/FC Doc. 03/13

25TH ANNUAL MEETING – SEPTEMBER 2003

NAFO REBUILDING PLAN FOR THE STOCK OF GREENLAND HALIBUT IN SUBAREA 2 AND DIVISIONS 3KLMNO (New Article 7 of the CEM)

THE FISHERIES COMMISSION

- Noting with great concern the advice of the Scientific Council on the Greenland Halibut Stock in Subarea 2 and Divisions 3KLMNO for 2004,

- Noting that such advice has indicated:
    - that the exploitable biomass of the Greenland halibut stock has been declining in recent years and is presently estimated to be at its lowest level;
    - that the recent recruitment has been poor, and
    - that if catches continue at recent levels the stock will decline further;

- Conscious of the need, in light of this advice, to take effective measures to arrest the decline in the exploitable biomass and to ensure the rebuilding of this biomass to reach a level that allows a stable yield of the Greenland halibut fishery over the long term;

- Conscious also of the fact that the rebuilding of the stock is the only means to provide a future for the interested fisheries industry sector,

- Noting that it is necessary to implement a monitoring programme to ensure that the stock is achieving the rebuilding objective in future years,

HAS AGREED AS FOLLOWS

1. Contracting Parties shall implement a fifteen-year rebuilding programme for the Greenland halibut stock in Subarea 2 and Divisions 3KLMNO.

2. The objective of this programme shall be to attain a level of exploitable biomass 5+ of 140,000 tonnes on average, allowing a stable yield over the long term in the Greenland halibut fishery.

3. For this purpose, a total allowable catch for the following years is established as follows:

    2004: 20,000 tonnes
    2005: 19,000 tonnes
    2006: 18,500 tonnes
    2007: 16,000 tonnes

The total allowable catch for subsequent years shall be established taking into account the progress made in the rebuilding of the stock.

4. The Scientific Council shall monitor and review the progress of the programme and submit each year an assessment thereon to the Fisheries Commission.

5. The total allowable catch from 2008 onwards may be adjusted by the Scientific Council advice. However, the total allowable catch shall not be set at levels beyond 15% less or greater than the total allowable catch of the preceding year.

6. The following specific measures shall be applicable with regard to the Greenland halibut fishery in Subarea 2 and Divisions 3KLMNO in respect of vessels 24 meters in length or greater:

a) Contracting Parties shall issue specific authorisations to vessels fishing for Greenland halibut (hereafter referred to as 'authorised vessels') and shall transmit the list of such vessels to the NAFO Secretariat.

b) Each Contracting Party shall allocate its quota for Greenland halibut among its authorised vessels.

c) Authorised vessels may only land Greenland halibut catch in ports designated by NAFO Contracting Parties. Landings in ports of non-Contracting Parties shall be prohibited.
Each landing shall be submitted to inspection in port. The corresponding port inspection report shall be transmitted to the NAFO Secretariat within 7 working days from the date at which the inspection was completed.

d) Contracting Parties shall implement a catch reporting regime that ensures effective monitoring of the utilisation of each vessel's quota.

7. Each Contracting Party shall adjust fishing effort commensurate with the available fishing opportunities.

8. In reviewing the implementation of this rebuilding plan, the Fisheries Commission may decide on additional measures to ensure the effective attainment of its objective.

9. Contracting Parties shall prohibit landings from non-Contracting Party vessels that have engaged in fishing activities in the Regulatory Area.

10. Contracting Parties fishing on the Others quota shall be subject to the notification and reporting requirements pursuant to Article 3, paragraph 3 and Article 19, paragraph 3 of the Conservation and Enforcement Measures