Species-Disaggregated Candidate Management Procedures for the South African *Merluccius paradoxus* and *M. capensis* Resources

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INTRODUCTION

The performance of some initial Fox-model and empirical based candidate OMPs is compared in terms of expected catches, future CPUE trends and risk to the resource. The examples presented here should not be viewed as final candidates, but rather "intermediate" examples that are further guiding the OMP development process.

METHODS

The methods are as described in document WG/09/05/D:H:30, so that a brief summary only is presented here. Extensions to the methodology are described in full below.

Summary of simulation-testing framework

The operating model is applied to 64 Reference Case models (which are referred to in combination as the Reference Set (RS)). Three replicates of each of the 64 RS cases (i.e. a total of 192 simulations) have been projected over a 30-year period into the future. The "future data" utilised include species-disaggregated catch, species-disaggregated CPUE series (two per species) and survey indices of abundance (three per species).

The OMP is species disaggregated and hence may be used to compute appropriate TAC values for *M. paradoxus* and *M. capensis* separately, i.e. TACs based on the updated data in combination with an updated assessment of each species. Note, however, that the overall TAC species-split recommended by the OMP is not implemented by the operating model – rather the operating model uses the total TAC value (i.e. the sum of the values for the two species) and apportions this quantity between species by assuming a fixed *F* ratio (i.e. it assumes that the ratio of F_{para}/F_{cap} remains the same, and hence that the current pattern of fishing remains approximately constant over the projection period – though some robustness tests do explore sensitivity to this).

In the Fox-model based OMPs, a value of 10% is set as the baseline for limitations to the extent of TAC change from one year to the next, while in the empirical OMPs, values of 5% upwards and

10% downwards are set as the baselines. OMP candidates incorporate an immediate fixed phased reduction over the next two-years before a feedback-control rule kicks in. As an immediate example, the OMP candidates presented here include a 5000 ton reduction for the first two years (i.e. C_{2006} = 153 000 t; C_{2007} = 148 000 t) with feedback variations on this coming into play after this period.

A. Fox model-based OMPs

A range of Fox model-based OMPs linked to harvesting strategies ranging from $f_{0.1}$ to $f_{0.7}$ have been simulation tested.

The recommended TAC fed back to the operating model is computed as follows:

$$TAC_y = \Delta TAC_{y-1} + (1-\Delta) * \left(FOX^{para}{}_{y,f_{0.n}} + FOX^{cap}{}_{y,f_{0.n}} \right) \qquad (1)$$

where

$FOX^{sp}{}_{y,f_{0.n}}$ is the estimated catch of the species as indicated for year y (C_y^{sp}) corresponding to a Fox surplus production model-based $f_{0.n}$ harvesting strategy that may or may not be the same for each species.

For the results reported below, the value of Δ is always set to 0.5.

Extensions to the OMP

$$TAC_y = \Delta TAC_{y-1} + (1-\Delta) * \left(C_y^{para} + C_y^{cap} \right) \qquad (2)$$

where

$$C_y^{spp} = FOX^{spp}{}_{y,f_{0.n}} * \sqrt{h\left(Survey_y^{rat,spp}\right) h\left(CPUE_y^{rat,spp}\right)} * k\left(C_{ratio,y-1}^{spp}\right) \qquad (3)$$

with

$h\left(CPUE_y^{rat,spp}\right)$ is a function which adjusts the TAC depending on the ratio of the immediate CPUE for species *spp* (averaged over the past three years) compared to that over the period (5-year average) immediately preceding application of the MP,

$h\left(Survey_y^{rat,spp}\right)$ is a corresponding function adjusting the TAC depending on the ratio of the immediate surveys for species *spp* (averaged of the west coast summer and south coast autumn surveys – averaged over the past three years) compared to that over the period (5-year average) immediately preceding application of the MP, and

$k\left(C_{ratio,y-1}^{spp}\right)$ is a function which adjusts the *M. paradoxus* TAC in year y depending on the relation between the species ratio of the intended (TAC) and actual catch in year y-1.

The functions $h\left(CPUE_y^{rat,spp}\right)$ and $h\left(Survey_y^{rat,spp}\right)$ which control the TAC depending on the ratio of immediate CPUE (or Survey) value compared to that when the MP was first put into effect are:

$$CPUE_y^{rat,spp} = \left(\frac{\frac{1}{3}\sum_{y'=y-4}^{y-2} CPUE_{y'}^{spp}}{\frac{1}{5}\sum_{y=1999}^{2003} CPUE_y^{spp}} \right) \tag{4}$$

and

$$Survey_y^{rat,spp} = \left(\frac{\frac{1}{3}\sum_{y'=y-3}^{y-1} Survey_{y'}^{spp}}{\frac{1}{5}\sum_{y=2000}^{2004} Survey_y^{spp}} \right) \tag{5}$$

where

$$h\left(I_y^{rat}\right) = \begin{cases} 0 & \text{if } 0 < I_y^{rat} \leq 0.7 \\ \dfrac{1}{0.95-0.7}\left(I_y^{rat} - 0.7\right) & \text{if } 0.7 < I_y^{rat} \leq 0.95 \\ 1 & I_y^{rat} > 0.95 \end{cases} \tag{6}$$

The TAC reduction factor $k\left(C_{ratio,y-1}^{spp}\right)$ is only used in the computation of the *M. paradoxus* component of the TAC and is set to:

$$k\left(C_{ratio,y-1}^{para}\right) = \begin{cases} \left[1 - \alpha\left(C_{ratio,y-1}^{para} - 1\right)^{\kappa}\right] & \text{when } C_{ratio,y-1}^{para} > 1 \\ 1 & \text{when } C_{ratio,y-1}^{para} \leq 1 \end{cases} \tag{7}$$

where

α and κ are tuning parameters (here fixed to 6 and 2 respectively), and

$C_{ratio,y-1}^{para}$ is the ratio of actual over intended catch in year *y*-1 for *M. paradoxus.*

Furthermore, a penalty function is added to the negative log-likelihood so that $M\hat{S}YR_y$ - the estimated maximum sustainable yield rate – is kept within realistic values – fixed here between 0.03 and 0.075. Note that these estimated $M\hat{S}YR_y$ values – calculated as $\hat{r}_y / \ln \hat{K}_y$ for the Fox model – change with year *y* as more data become available.

B. Empirical-based OMPs

The formula for computing the TAC recommendation is as follows:

$$TAC_y = C_y^{para} + C_y^{cap} \tag{8}$$

with

$$C_y^{spp} = C_{y-1}^{spp}\left[1+\lambda_y\left(s_y^{spp} - \text{target}^{spp}\right)\right] \qquad (9)$$

where

TAC_y is the total TAC recommended in year *y*,

C_y^{spp} is the recommended species-disaggregated TAC in year *y*,

λ_y is a year-dependent tuning parameter,

target^{spp} is target rate of increase for species *spp*, set to 2% for *M. paradoxus* (i.e. the target is to achieve 2% recovery per year for this species) and to zero for *M. capensis* (i.e. the target is to keep this population – and CPUE – at the current level), and

s_y^{spp} is a measure of the immediate past trend in the abundance indices for species *spp* as available to use for calculations for year *y*.

This trend measure is computed as follows from the species-disaggregated GLM-CPUE ($I_y^{CPUE,spp}$), west coast summer survey data ($I_y^{surv1,spp}$) and south coast autumn survey data ($I_y^{surv2,spp}$):

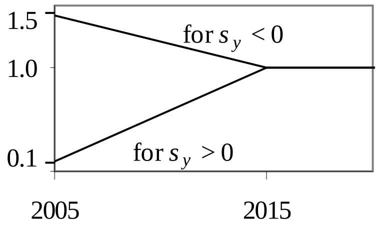
- linearly regress $\ln I_y^{CPUE,spp}$ vs year *y'* for $y' = y-p-2$ to $y' = y-2$, to yield a regression slope value $s_y^{CPUE,spp}$,
- linearly regress $\ln I_y^{surv1,spp}$ and $\ln I_y^{surv2,spp}$ vs year *y'* for $y' = y-p-1$ to $y' = y-1$, to yield two regression slope values $s_y^{surv1,spp}$ and $s_y^{surv2,spp}$,

where *p* is the length of the periods considered for these regressions, fixed here to 6 years. Note that the reason the trend for surveys is calculated for a period moved one year later than for CPUE is that by the time of year that the TAC recommendation was being computed for the following year, survey results for the current year would be known, but not CPUE as fishing for the year would not yet have been completed.

Then

$$s_y^{spp} = \left(\frac{s_y^{CPUE,spp}}{2} + \frac{s_y^{surv1,spp}}{4} + \frac{s_y^{surv2,spp}}{4}\right) \qquad (10)$$

The function for the year-dependent tuning parameter, λ_y, which is a measure of how responsive the candidate OMP is to change in trend, is shown below:



Furthermore, candidate OMPs (Fox-model and empirical based) differ depending on whether Options I, II or III additional rules/constraints are imposed (see Appendix).

RESULTS

The simulation-testing framework described above was used to compare the performance of a large number of alternative OMPs, and the results of a selected few examples are presented here. Results are given for the Reference Set ("RS") and a sensitivity ("low F") (one of the robustness trials) in which the F_{ratio} ($F_{ratio} = F_{para} / F_{cap}$) used to disaggregated future catches by species is decreased by 30% to model a greater fraction of *M. capensis* in the catches. The basis for this sensitivity is evident from Fig. 1, which shows the F_{ratio} estimated for previous years for two key cases within the RS. The RS projections set F_{ratio} to its average value over 2002 to 2004, which is rather higher than during the 1990's. The sensitivity bases catches in projections on a value for the ratio which is closer to that for these earlier catches. This particular sensitivity has been singled out because (as will be evident from the results that follow) a particular difficulty in keeping future catches on the higher side in the future is the depletion of *M. paradoxus* that results because the RS F_{ratio} specification frequently leads to higher actual catches of *M. paradoxus* (and correspondingly lower catches of *M. capensis*) than candidate OMPs intend in terms of the species-specific TACs that they compute. Results for the four candidate OMPs are presented, each applied both to the RS and the low F sensitivity operating models, where option III (which bases any restriction on inter-annual TAC change upon the TAC for both species combined) applies throughout:

1) "Empirical, RS": Empirical based OMP: maximum increase=5%/yr, maximum decrease=10%/yr; applied to the RS.
2) "Empirical, lowF": As 1), but applied to Low F.
3) "f0604, RS": Fox-model based OMP: $f_{0.6}$ for *M. paradoxus*, $f_{0.4}$ for *M. capensis*, $h\left(I_y^{rat,spp}\right)$ used, maximum increase=10%/yr, maximum decrease=10%/yr; applied to the RS.
4) "f0604, lowF": Applied to Low F – otherwise as 3).
5) "f0603, RS": As 3) but, $f_{0.6}$ for *M. paradoxus*, $f_{0.3}$ for *M. capensis*.
6) "f0603, lowF": Applied to Low F – otherwise as 5).
7) "f0603, RS, Cratio rule": As 5) but including the TAC reduction factor $i\left(C_{ratio,y}^{para}\right)$.
8) "f0603, lowF, Cratio rule": Applied to Low F – otherwise as 7).

A summary of performance statistics for each of these candidate OMP/operating model combinations is given in Table 1 and Fig. 2.

Trajectories of resource abundance and catch are plotted for four combinations that involve the RS: (1), (3), (5) and (7) (Figs 3-6). Results are shown both for the two species combined, and for *M. paradoxus* and *M. capensis* on their own. For each plot, the median is indicated by a thick dotted line, the 90th percentiles are shaded, and the same ten (randomly selected) individual biomass and catch realisations are plotted.

DISCUSSION

The empirical based candidate OMP achieves relatively good average catch and resource recovery for *M. paradoxus* (Fig. 3), but this is achieved by keeping the catch relatively steady over the first 10-years or so, followed by a sharp drop, i.e. in the short term, it borrows from the future to keep immediate catches higher.

The catch trajectories for the Fox-model based candidate OMPs (Figs 4, 5 and 6) show a decrease in the short term followed by a steady increase. Note that here, in contrast to the empirical candidate OMP, in nearly all cases the maximum 10% TAC reduction constraint is invoked in the first year that the feedback component of the candidate OMP comes into play, i.e. two years of a fixed TAC reduction each of 5000 tons are followed by a third of almost 15000 tons (an unsatisfactory feature that will require refinement of these candidates to avoid.) Good recovery for *M. paradoxus* in terms of the RS is shown under the "f0604" candidate OMP (Fig. 4), but there are longer term problems under the "f0603" candidate for which there is a >5% probability of extirpating the *M. paradoxus* resource within 20 years (see Fig. 5).

As expected, the "low F" sensitivity generally results in a slightly better resource status for *M. paradoxus*. In particular, the lower 5%-ile of the depletion for *M. paradoxus* under the "f0603" procedure is increased somewhat to an arguably acceptable level (see Table 1).

Throughout, results reflect a drop over time in the utilisation of the *M. capensis* resource – a characteristic whose desirability might be questionable, but which is difficult to avoid without exposing the *M. paradoxus* resource to greater risk.

Ideally one would wish for a candidate that gave adequate performance in terms of risk to the *M. paradoxus* resource, as in the case of the "f0604" candidate for the RS, but yielded higher catches (medians of averages over the next 20 years closer to 140 than to 130 thousand tons) if the low F sensitivity better reflected reality, as achieved in the case of the "f0603" candidate. The reason underlying the problem in reducing risk for the RS scenarios appears to be that while a candidate OMP advocates decreasing the *M. paradoxus* catch, this is not achieved in reality, as the F_{ratio} prescription sees a larger component of *M. paradoxus* in the total catch duly achieved than was intended. The idea underlying the Cratio rule variant is for the "f0603" candidate to penalise future TACs in instances where the *M. paradoxus* component of the catch exceeds the proportion intended by the OMP by means of the $k\left(C^{spp}_{ratio,y-1}\right)$ factor, thereby rendering this more risk averse for the RS. Results shown in Table 1 and Fig. 6 show that this intent is indeed achieved for the RS, but noise effects see it also degrading catch performance when this candidate is applied to the low F case; furthermore inter-annual catch variability is increased appreciably.

FUTURE PLANS

The first priority is to continue attempts to achieve better catch performance for the low F operating model for the Fox model based candidate OMPs, while still controlling the risk of *M. paradoxus* depletion for the RS, through use of information on the species ratio for the catch achieved. Furthermore, since Figs 4-6 indicated that this risk becomes a concern only some 10-15 years in the future, attempts will be made to see whether, say, a relaxation of the restriction on the extent of downward TAC adjustment at about that time could prevent such undesirable behaviour. Similar initiatives for the empirical candidate OMP may also be pursued, though as a lower priority.

Once the best possible performance (within time constraints) has been achieved on that front (and the candidate(s) tested also against the other robustness tests), performance trade-offs will be computed for the following variations of what have been taken above as fixed components of the candidate OMPs considered:

i) the length of the initial period of pre-set reductions (2 years above);

ii) the extent of such initial pre-set reductions (5000 tons p.a. above); and

iii) the extent of limitations to annual TAC changes under the feedback component of the OMP (5/10% up and 10% down above).

This exercise may require some iteration, as modifications under i) – iii) may necessitate concomitant changes to the feedback component of the candidate OMP to preserve some aspect of longer term performance.

LITERATURE CITED

Plaganyi, E.E., Rademeyer, R.A. and D.S. Butterworth. 2005. Preliminary Development of a Species-Disaggregated Management Procedure for the South African *Merluccius paradoxus* and *M. capensis* Resources. DWG/09/05/DH: 30.

Appendix 1. Constraint Options

Option I:

The TAC recommendation per species is constrained to vary by no more than α% from year to year, i.e.

$$\text{If}\quad \begin{array}{l} C_y^{para} > (1+\alpha) * C_{y-1}^{para} \quad then \quad C_y^{para} = (1+\alpha) * C_{y-1}^{para} \\ C_y^{para} < (1-\alpha) * C_{y-1}^{para} \quad then \quad C_y^{para} = (1-\alpha) * C_{y-1}^{para} \\ C_y^{cap} > (1+\alpha) * C_{y-1}^{cap} \quad then \quad C_y^{cap} = (1+\alpha) * C_{y-1}^{cap} \\ C_y^{cap} < (1-\alpha) * C_{y-1}^{cap} \quad then \quad C_y^{cap} = (1-\alpha) * C_{y-1}^{cap} \end{array}$$

where α = 0.05 is the baseline.

Option II:

As above, except that if the *M. paradoxus* TAC is reduced, the recommended *M. capensis* TAC is also reduced by the same proportion (unless the OMP-recommended *M. capensis* reduction is greater than this), i.e.

$$If \quad C_y^{para} < C_{y-1}^{para} \quad then \quad C_y^{cap} = \beta * C_{y-1}^{cap}$$

$$where$$

$$\beta = C_y^{para} / C_{y-1}^{para}$$

Option III:

The TAC recommendation when summed over the two species is constrained to vary by no more than α% from year to year, i.e.

$$If \quad TAC_y > (1+\alpha) * TAC_{y-1} \quad then \quad TAC_y = (1+\alpha) * TAC_{y-1}$$

$$If \quad TAC_y < (1-\alpha) * TAC_{y-1} \quad then \quad TAC_y = (1-\alpha) * TAC_{y-1}$$

where α = 0.05 is the default.

Table 1: Summary of performance statistics for 20-year projections for the four candidate OMPs each applied to the RS and low F operating models (see text for details).

		1	2	3	4	5	6	7	8
		Empirical RS	Empirical lowF	f0604 RS	f0604 lowF	f0603 RS	f0603 lowF	f0603 RS Cratio rule	f0603 lowF Cratio rule
	AvTAC								
	Median	136.0	138.0	133.9	132.4	144.2	143.5	134.2	131.8
	5%-ile	118.8	122.3	94.4	98.7	107.3	110.6	101.7	102.4
	95%-ile	156.3	160.6	152.7	146.1	169.2	166.7	151.3	145.6
	AAV								
	Median	3.4	3.3	3.1	2.9	3.0	2.9	8.3	8.3
	5%-ile	2.3	2.2	1.5	1.5	1.4	1.5	6.9	7.4
	95%-ile	5.1	4.6	5.2	5.1	5.4	5.2	8.7	8.7
M. paradoxus	B^{sp}_{2025}/K^{sp}								
	Median	0.28	0.30	0.30	0.33	0.18	0.23	0.28	0.34
	5%-ile	0.14	0.14	0.07	0.13	0.01	0.04	0.06	0.14
	95%-ile	0.50	0.49	0.67	0.68	0.55	0.58	0.62	0.65
	B^{sp}_{2025}/B_{2005}								
	Median	2.08	2.19	2.32	2.61	1.26	1.72	2.18	2.63
	5%-ile	1.14	1.13	0.43	0.67	0.04	0.24	0.37	0.72
	95%-ile	4.00	3.96	6.64	6.81	5.98	5.77	6.82	7.04
M. capensis	B^{sp}_{2025}/K^{sp}								
	Median	0.85	0.84	0.85	0.85	0.82	0.82	0.85	0.85
	5%-ile	0.67	0.65	0.75	0.74	0.69	0.68	0.74	0.73
	95%-ile	0.96	0.94	0.97	0.96	0.94	0.93	0.96	0.95
	B^{sp}_{2025}/B_{2005}								
	Median	1.27	1.25	1.28	1.27	1.23	1.23	1.27	1.27
	5%-ile	1.09	1.08	1.07	1.06	1.00	1.02	1.02	1.06
	95%-ile	1.63	1.54	1.79	1.82	1.71	1.68	1.82	1.84

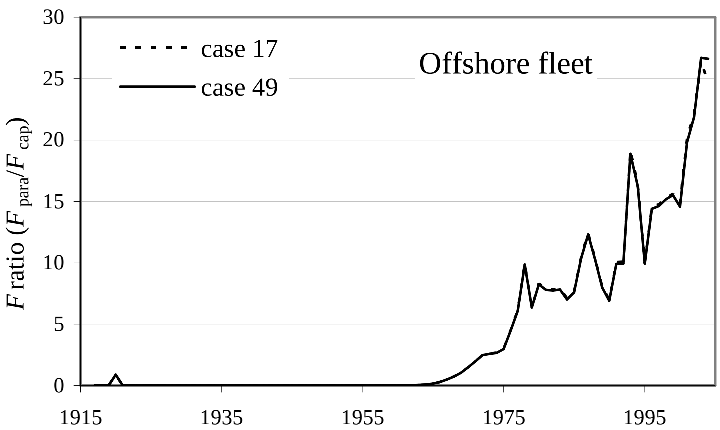


Fig. 1: Trends in past F_{ratio} (=F_{para}/F_{cap}) for the offshore fleet for case 17 (M4-C1-H1-SR1) and case 49 (M4-C1-H1-SR2) of the RS.

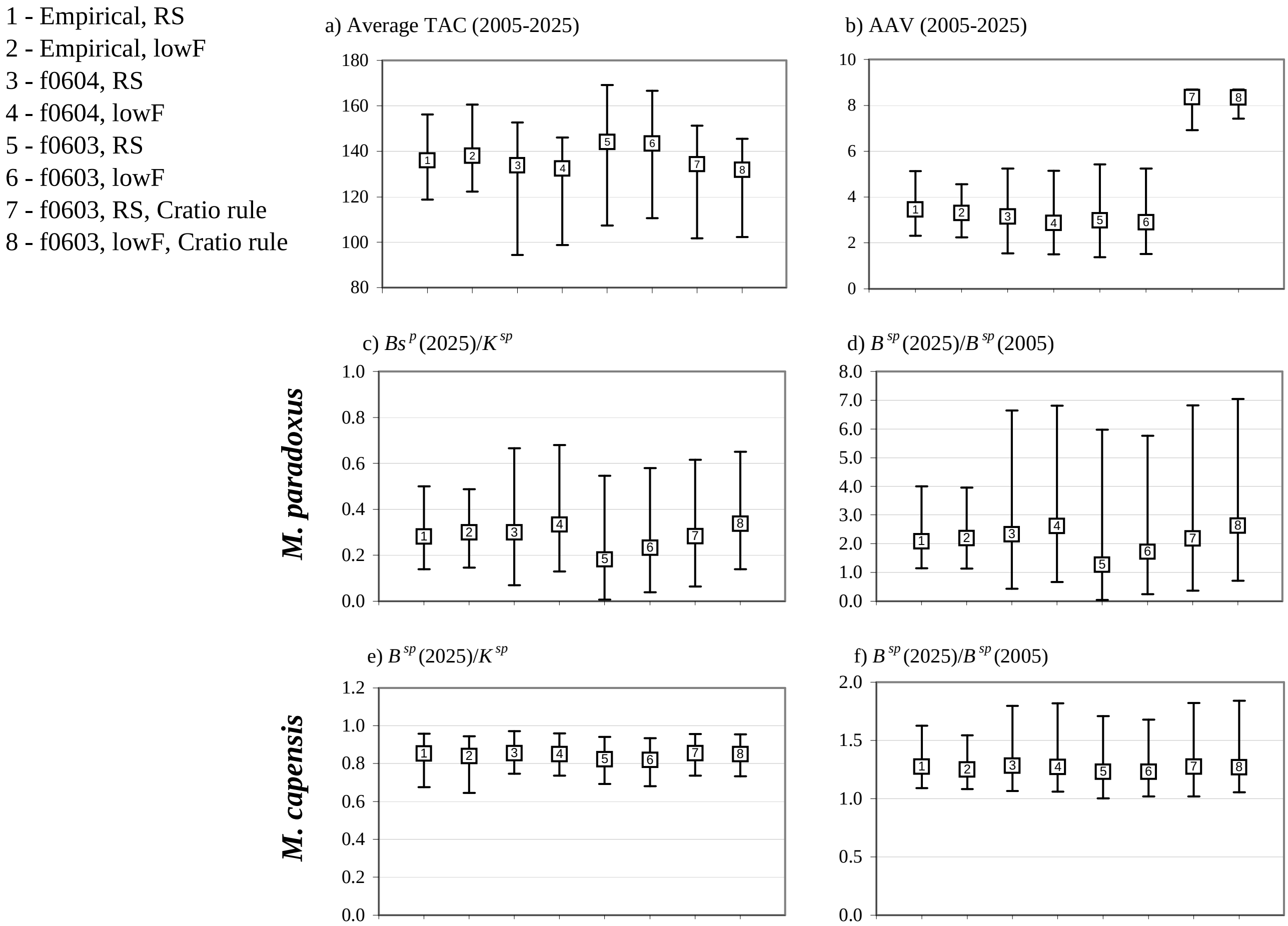


Fig. 2: Graphical summary of performance statistics for the eight candidate OMP/operating model combinations considered (see text for details). Each panel shows medians together with 90%-iles.

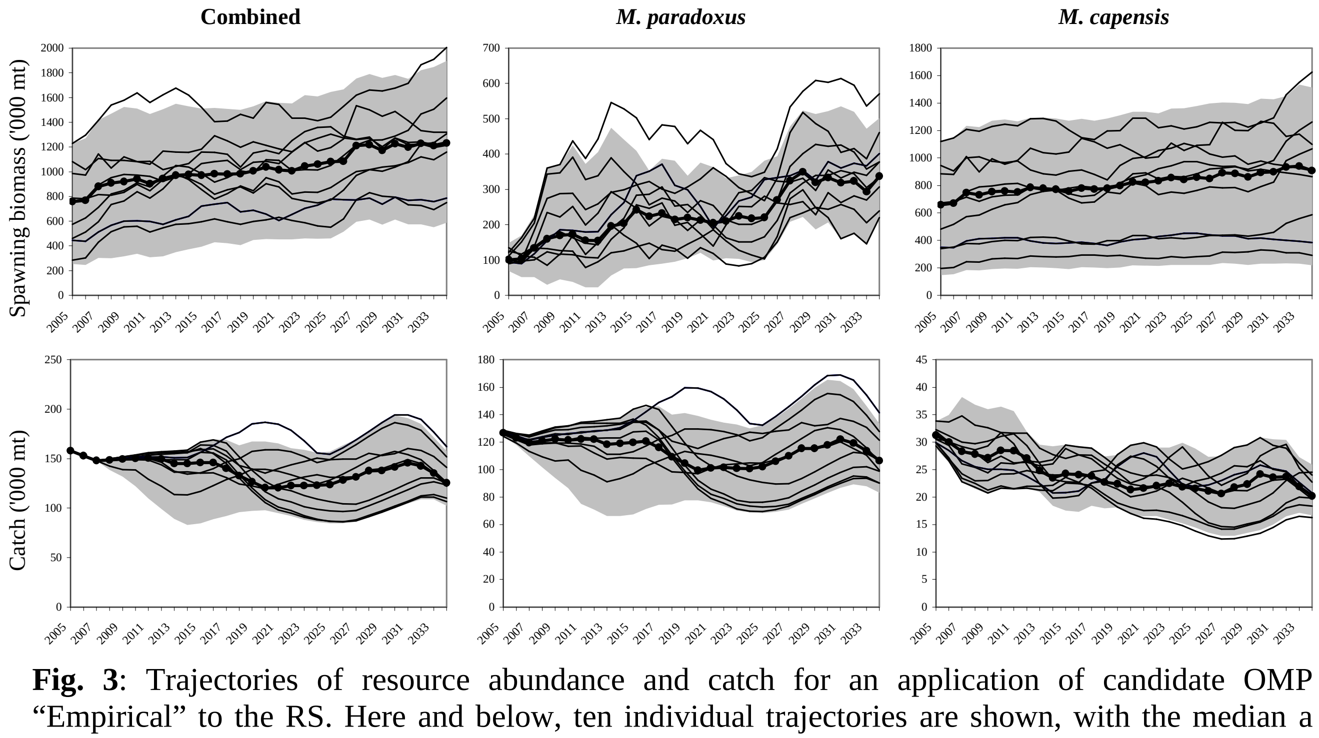


Fig. 3: Trajectories of resource abundance and catch for an application of candidate OMP "Empirical" to the RS. Here and below, ten individual trajectories are shown, with the median a dark dotted line; the shaded areas show 90%probability envelopes

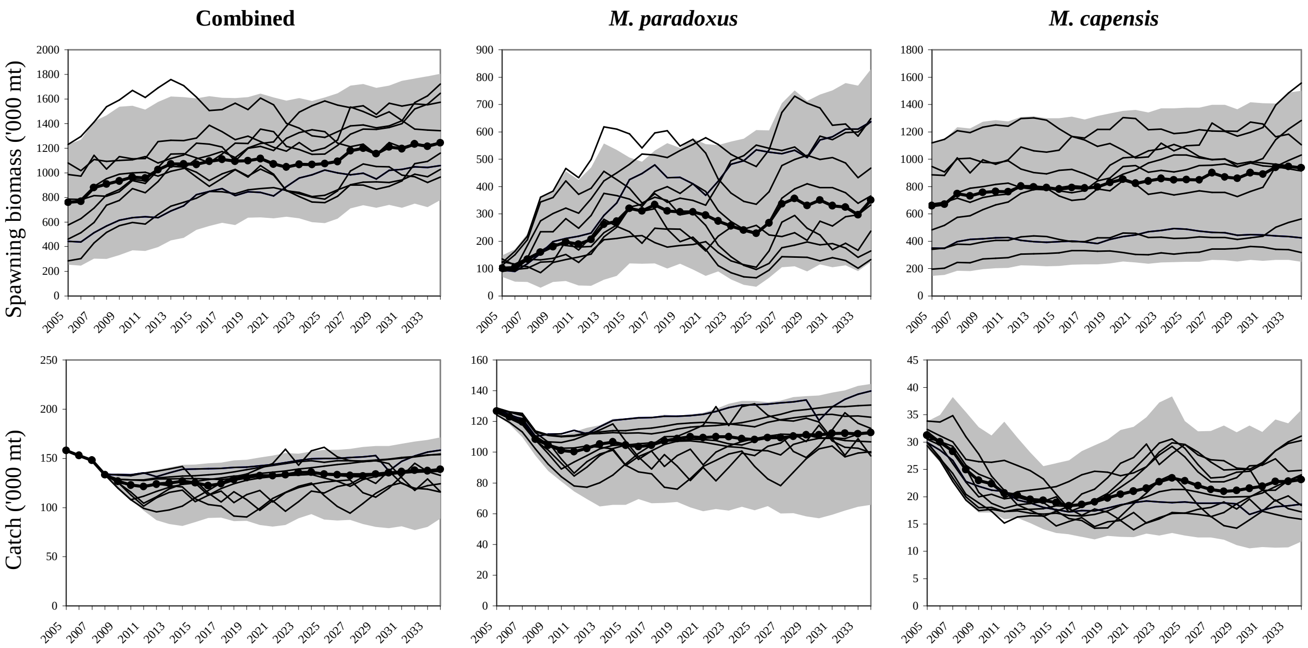


Fig. 4: Trajectories of resource abundance and catch for an application of candidate OMP “f0604” to the RS.

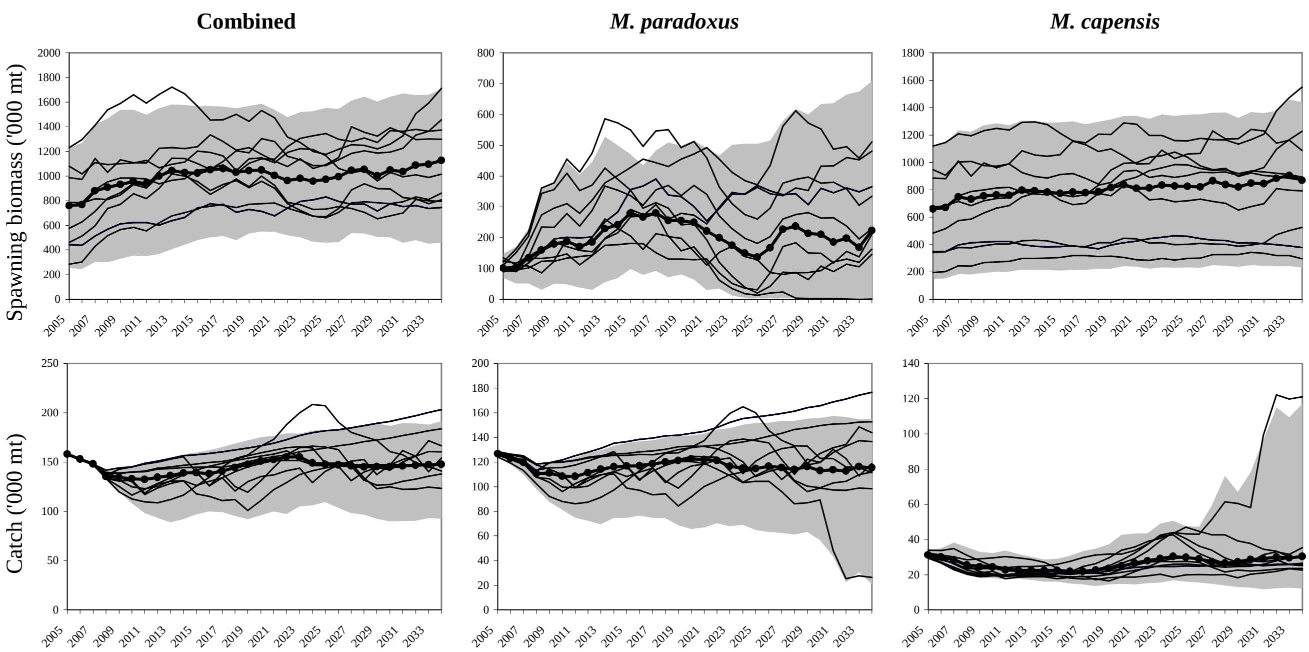


Fig. 5: Trajectories of resource abundance and catch for an application of candidate OMP “f0603” to the RS.

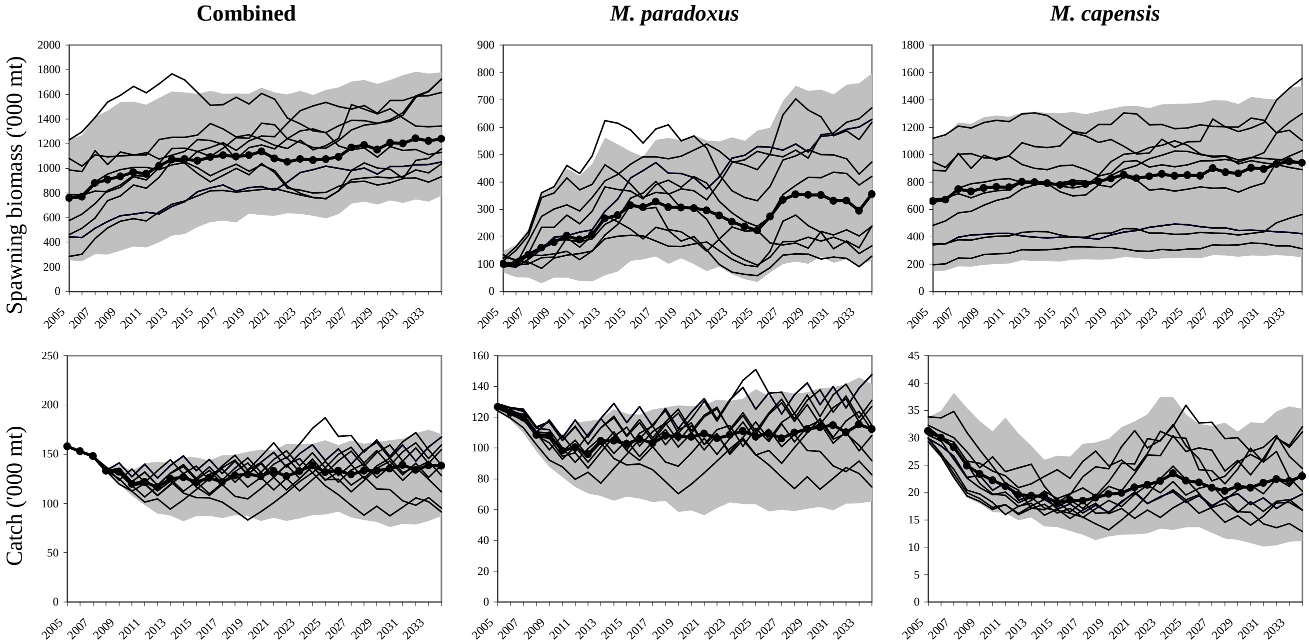


Fig. 6: Trajectories of resource abundance and catch for an application of candidate OMP "f0603,Cratio rule" to the RS.