Risk evaluation for the current South African west coast rock lobster, hake and pelagic OMPs

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WEST COAST ROCK LOBSTER

1. The resource is managed using an OMP (Operational Management Procedure)

The choice of OMP involved an appropriate selection of the trade-offs between the conflicting objectives of greater catches, less TAC variability and lower risks.

2. Measures used to assess risk

The measures used of pertinence to risk were:

i) *B*75 (the exploitable biomass of lobsters above 75mm carapace length) – reported as a ratio of 2013:2003, i.e. the projected value of *B*(13/03)
ii) fishing effort (FE) – reported as a ratio of 2012:2003 (FE(12/03)), and
iii) fishing efficiency for both traps and hoopnets (E_{trap} and E_{hoop}), which is the ratio of the biomass >350g in 2012 relative to that ratio in 2003, e.g. E_{trap}(12/03).

The statistic *B*(13/03) was seen to evaluate biological risk. The industry were interested in assessing economic risk, and hence the use of the FE and E_{trap} and E_{hoop} statistics. The FE statistic was used as an indicator for future employment levels. In an economy were unemployment is a problem, options projecting a decrease in FE and hence employment were considered undesirable from a social/industrial perspective. Further, to limit instability to the industry as a result of large TAC changes, these were limited to maxima of 10% from one year to the next.

3. Key Uncertainties

A number of uncertainties existed with respect to resource dynamics. Two reference case models were developed to express these alternate interpretations of resource dynamics – called RC1 and RC2 and were given a relative probability weighting of 0.8:0.2. These two models differed mainly in the estimates of the current status of the resource, and hence the need for, and extent of, rebuilding required.

Other key uncertainties related to the future somatic growth rate and the future recruitment trends. For each of these two key uncertainties, three possible options for each were identified and assigned a relative plausibility weight. These are reported in Table 1 below. Note that what is reported reflects expectations – the OMP trials

allowed for variability about these expectations (quantified on the basis of past levels of variability), as well as observation error in the indices of abundance and somatic growth input to compute TAC recommendations.

This resulted in 2x3x3=18 scenarios. Projections were carried out integrating over these 18 scenarios, by giving each scenario a weight proportional to the product of the weights accorded each constituent factor.

4. Examples of risk-related output statistics

Table 2 reports the final table of the integrated-by-weights output statistics for the final six OMP variants that were considered. The "VAR5" OMP was the final selection. Note that the RC1 and RC2 results were eventually kept separate because some of the performance statistics lost meaning when their distributions were combined across this factor, and in fact the scientific working group considered only the RC1 results in the final deliberations.

5. Robustness tests

The three factors mentioned above (assessment, future somatic growth, and future recruitment), though regarded as the most important as well as the ones to which outputs were most sensitive, were not the only ones subject to uncertainty. Trials were also conducted to investigate robustness of performance to aspects such as alternate levels of natural survivorship and of discard mortality, and future "walkouts" (where low oxygen water causes lobsters trapped inshore to beach and die). Owing to time constraints, robustness trials were run deterministically (i.e. no stochastic variability in future projections) for the "central" scenario (future somatic growth remains low, future recruitment is average of the 75-90 period).

In interpreting the results of the robustness tests in context of meeting acceptable overall risk criteria, the results were treated to "tick" tests only, i.e. checks extended only so far as to confirm that anticipated performance under such scenarios did not differ substantially from that for the "central" scenario of which they were variants.

A. Category A type robustness tests (these test require the model to be re-fitted to the data)

1. alternative choice for the period over which fishing selectivity changes (F1)
2. alternative values for male survival rate (NS1, NS2)
3. female survival rate is constrained to be less than or equal to males (MCM1)
4. alternative levels of discard mortality (D2, D3)
5. alternative levels of historic somatic growth (SG1, SG2, SG3, SG4, NEWG2, NEWG3)
6. tests which simulate "walkouts" (and hence death) of lobsters (W1, W2)
7. CPUE for 1999-2001 are negatively biased (B4)

B. Category B type robustness tests

These tests examine the robustness to assumptions relating to the future of the resource. During the OMP testing, the OMP is not "aware" of these changes.

1. environmental "catastrophes" occur (E1, E3)
2. future levels of poaching are reduced (P1)
3. future trap:hoopnet ratio changes (TH1)
4. bias in future CPUE and somatic growth indices (B1, B2, B3)
5. missing input indices to the OMP (M1, M2)

Table 3 reports the results of these robustness tests which were run for the VAR5 OMP variant, in conjunction with RC1 and the scenario which assumes that future somatic growth remains low, and future recruitment is average of the 75-90 period (the "central" scenario).

HAKE – SPECIES AND COAST-COMBINED OMP

1. The resource is managed using an OMP

The choice of OMP (adopted in late 2006) involved an appropriate selection of the trade-offs between the objectives of increase catch rate (specifically that for offshore trawlers) in the short-medium term, getting M. paradoxus back to MSYl over 20 years and securing greater TAC stability over time.

2. Measures used to assess risk

The measures used of pertinence to risk were:

i) *AAV* – the expected Average Annual Variation in TAC from one year to the next, expressed as a proportion of the average annual catch;
ii) $CPUE_{2016}/CPUE_{2005}$ - the expected change in species-combined offshore trawl CPUE in 10-years time; and
iii) B^{sp}_{2027}/K^{sp} and $B^{sp}_{2027}/B^{sp}_{2007}$ - for each species, the expected spawning biomass at the end of the projection period, relative to pristine and to current level.

The B^{sp}_{2027}/K^{sp} and $B^{sp}_{2027}/B^{sp}_{2007}$ statistics were seen to evaluate biological risk. The industry were interested in assessing economic risk, and hence the use of the *AAV* (which gives an indication of the extent of industrial stability) and $CPUE_{2016}/CPUE_{2005}$. In addition, the OMP placed constraints on the maximum extent of the inter-annual TAC change.

3. Key Uncertainties

Three key aspects of the assessment account for most of the uncertainty regarding resource status and productivity (recall the resource consists of two species: shallow-water hake, *Merluccius capensis*, and deep-water hake, *M. paradoxus*). A Reference

Set (RS) consisting of 24 equally-weighted scenarios was constructed for OMP trial purposes by incorporating variations around these three aspects:

a. two (age-dependent) upper bounds for natural mortality;
b. three assumptions about the species split in the pre-1978 catches (surveys provide information on species composition thereafter); and
c. four upper bounds for the steepness parameter of the two stock-recruitment functions.

4. Examples of risk-related output statistics

Table 4 and Fig. 1 reports key comparative results for the RS for four candidate OMPs, each tuned to three different median recovery level for M. paradoxus (15%, 20% and 25%) of K after 20 years. OMP120% was the candidate finally selected.

5. Robustness tests

To take account of further uncertainty than that included in the RS, trials were also conducted to investigate robustness of performance to aspects such as different assumptions about discards, catch series, and biological information as well as changes in factors such as availability of research surveys and fishing selectivity in the future. In the initial phase of OMP evaluation, close to 30 robustness trials were suggested by the MCM Demersal Working Group; however, in the final stage six tests were selected as being either ones of immediate interest related to OMP selection, or which had indicated appreciable sensitivity in earlier tests. These were:

1) "**SR1"**: The assumed variance σ_R of residuals about the ln *R* vs *S* relationship was fixed to 0.25 throughout (i.e. the estimates of recruitment strength for more recent cohorts were not shrunk further towards the stock-recruitment function expectation) in the assessment scenarios considered for the RS.

2) "**Decr in *K***": In the RS, poorer estimated recruitment for *M. capensis* throughout most of the 1990s and the early 2000s suggested a possible systematic deviation below the stock-recruitment model. To better reflect this poorer *M. capensis* recruitment (and continue this into the future), the carrying capacity for *M. capensis* was reduced by 20% from 1992 onwards.

3) "**A1b – disc1**": Discarding is considered to occur for the offshore and inshore trawlers only. Discarding for both fleets is modelled as an increase in commercial selectivity of 0.2 for ages 1 and 2 for catches of both *M. capensis* and *M. paradoxus*. Thus the amount of catch discarded is not an input, but computed within the assessment from the fishing mortality estimated for the offshore and inshore trawlers to take their recorded landings. The loss of fish from longlines is also included by doubling the fishing mortality from this fleet. This discarding is assumed to occur from the beginning of the fishery to the present but is **not** carried through to the projections.

4) "**A7b –Ricker forced**": Instead of the Beverton-Holt stock-recruit relationship used in the RS, the stock-recruit relationship in this robustness test is of the Ricker form: $R = \alpha B_{sp} e^{-\beta B_{sp}}$. Furthermore, the stock-recruit curve for each species is constrained so that maximum recruitment occurs when the spawning biomass is at 45% of pristine level.

5) "**B7 – fut σ_R=0.4**": In conjunction with increased variability for the stock-recruitment fluctuations in the past, future variability is also increased (to σ_R=0.4, compared to 0.25 for the RS).

6) "**B8 – decr *K* in future**": The carrying capacity *K* for both species is assumed to decrease linearly by 30%, starting in 2005, to reach the reduced level in 2009.

Because of time constraints, only four of the 24 Reference Set scenarios were refitted for those tests which involved changes to assumptions for the data. However for B8 for which only future projections are affected, the full 24 scenarios were run.

Table 5 compares performance statistics across the various robustness tests for $OMP1_{20\%}$, the OMP finally selected, with a corresponding graphical presentation in Fig. 2.

Results for these robustness tests were considered only insofar as to check that they showed insubstantial deterioration in performance compared to the corresponding Reference Set.

PELAGICS – ANCHOVY AND SARDINE

1. The resource is managed using an OMP

The choice of OMP involved an appropriate selection of trade-offs between the conflicting objectives of greater catches, less TAC variability and lower risks. Given the joint nature of this OMP a further trade-off selection between the average directed sardine TAC and the average anchovy TAC (with associated juvenile sardine bycatch) was necessary. The current OMP is known as OMP-04, reflecting its adoption in 2004, when it replaced OMP-02.

2. Measures used to assess risk

The measures of pertinence to risk used in selecting OMP-04 were:
i) $risk_S$ - the probability that adult sardine biomass falls below the average adult sardine biomass between November 1991 and November 1994 at least once during the 20-year projection period.

ii) $risk_A$ - the probability that adult anchovy biomass falls below 10% of the average adult anchovy biomass between November 1984 and November 1999 at least once during the 20-year projection period.

The evaluation of earlier OMPs had been based on risk measures relating the adult sardine and anchovy biomass to a percentage of carrying capacity *K*. In OMP-02 the risk for anchovy was limited to a 30% probability of dropping below 0.15*K* at least once during the 20-year projection period, while the risk for sardine was limited to a 10% probability of dropping below 0.2*K* at least once during the 20-year projection period. The specified levels of risk differed between the resources as anchovy is a shorter-lived species and subject to higher levels of recruitment variability and is therefore more likely to be more resilient to depletion to a particular level. In addition the survey results for anchovy were considered to be more reliable than those for sardine because of lesser target identification problems.

The value of *K* is highly dependent on what stock recruitment relationship was assumed. In addition, the estimated residual variance around the stock recruitment relationship affects perceptions of perceived risk: the higher the estimated variance, the more likely that the resource is resilient to fluctuations to low levels and so the greater the probability that dropping below a specified fraction of the threshold that can be tolerated. These variances change as assessments are updated. In revising OMP-02 it became clear because of the foregoing that a more robust approach to specifying thresholds was required - hence the change to $risk_S$ and $risk_A$ as defined above for OMP-04. Note that the choice of the period of 1991-1994 used to define $risk_S$ was chosen to reflect a level at which the recovery of sardine abundance from preceding low levels appeared well established, even in the presence of limited fishing. The thresholds for acceptable risk remained the same for OMP-04 as for OMP-02 (i.e. $risk_S < 0.1$ and $risk_A < 0.3$).

Further to limit instability to the industry as with rock lobster, the OMP places limits on the extent to which TACs could change from one year to the next.

3. Key uncertainties

Key uncertainties relating to the future dynamics of sardine and anchovy were future recruitment trends and a potential change in the sardine growth rate. However, in contrast to the reference set used for west coast rock lobster and hake, the current pelagic OMP (OMP-04) was tuned using one base case Bayesian assessment model for each of sardine and anchovy. Risk and other performance statistics under alternative robustness tests were also considered (see 5. below).

4. Examples of risk-related output statistics

Table 6 reports the final table of output statistics for OMP-04. Variants of this OMP were considered earlier in the OMP development process, using the statistics in Table 6 to distinguish between options. The OMP equations contain control parameters that are tuned during the OMP testing process such that the OMP satisfies the two risk criteria defined above (i.e. $risk_S < 0.1$ and $risk_A < 0.3$).

5. Robustness tests

A number of robustness tests for sardine and anchovy were considered to account for uncertainty in natural mortality, the assumed stock-recruitment relationship, the calculation of the proportion of anchovy 1-year-olds in the November spawner biomass survey, bias in the anchovy egg surveys and in the sardine spawner biomass surveys, the growth rate of sardine since the turn of the century (for which no ageing information was available) and alternative options of fixing or estimating some additional variance model parameters.

Summary statistics for OMP-04 were considered for all robustness tests using results from the posterior mode only (i.e. deterministic robustness test model runs in the interests of meeting deadlines). The OMP was then tested under the robustness tests for which the risk was found to be greater when using only the deterministic model. Although the risk to the resource was greater for the deterministic alternative sardine

stock-recruitment relationships, Bayesian analyses were not performed for these robustness tests due to the poor fit to the data at the posterior mode. The robustness tests for which OMP-04 was tested using Bayesian results were:

i) A_0 – base case anchovy assessment
ii) A_{M1} – adult and juvenile natural mortality of 0.6 year^{-1} (base case 0.9 year^{-1})
iii) A_{M2} – adult and juvenile natural mortality of 1.2 year^{-1}
iv) A_{HS} – hockey stick stock-recruitment curve with the inflection point estimated (inflection point equal to 20% of K in base case)
v) A_{BH} – Beverton Holt stock-recruitment curve
vi) A_R – Ricker stock-recruitment curve
vii) A_{kegg2} – positively biased egg surveys, i.e., $k_g^A = 1.25$ (base case $k_g^A = 1$)
viii) S_0 – base case sardine assessment
ix) S_{kN1} – unbiased November spawner biomass surveys, i.e., $k_N^S = 1$ (base case had $k_N^S = 0.720$)

Table 7 reports the output statistics for OMP-04 under these robustness tests. In interpreting the results of the robustness tests in context of meeting acceptable overall risk criteria, the results were treated to "tick" tests only, i.e. checks extended only so far as to confirm that anticipated performance under such scenarios did not differ substantially from that for the "central" scenario of which they were variants.

Table 1: Three representative scenarios for each of future somatic growth rate and future recruitment considered by the rock lobster scientific working group in 2003, with the associated "relative plausibility" weights accorded to each.

	Option	**Weighting**
Future somatic growth rate	Low (1989-2001 average)	0.50
	Increase to 1968-2001 average over the next 10 years	0.35
	Increase to 1968-2001 average over the next 3 years	0.15
Future recruitment	Lowest value over 1975-95 period	0.10
	Average value over 1975-90 period	0.60
	Highest value over the 1975-95 period	0.30

Table 2: Integrated-by-weights output statistics for six west coast rock lobster OMP variants. Medians and 80% probability intervals are shown.

	VAR1	VAR2	VAR3	VAR4	VAR5	VAR6
	RC1	**RC1**	**RC1**	**RC1**	**RC1**	**RC1**
***B*(13/03)**	1.30 [0.78, 2.68]	1.17 [0.69, 2.54]	1.03 [0.58, 2.48]	1.27 [0.78,2.58]	1.15 [0.67, 2.50]	1.03 [0.58, 2.43]
C_{ave}**(10)**	3019 [2240, 4348]	3626 [2590, 4800]	4441 [3213, 5110]	3181 [2242, 4946]	3754 [2651, 5100]	4497 [3210, 5110]
C_{ave}**(5)**	2965 [2620, 3465]	3376 [2876, 3694]	3862 [3399, 3915]	3134 [2614, 3880]	3666 [2999, 3915]	3915 [3449, 3915]
***V*(10)**	6.91 [5.29, 8.46]	7.60 [5.81, 9.34]	9.19 [7.21, 10.0]	8.82 [7.48, 9.95]	9.36 [7.89,10.0]	9.72 [8.46, 10.0]
***V*(5)**	4.81 [2.73, 7.25]	6.07 [3.63, 8.76]	9.64 [6.19, 10.0]	8.66 [6.41, 9.98]	9.41 [7.22, 10.0]	10.0 [8.36, 10.0]
***FE*(12/03)**	0.78 [0.44, 1.44]	1.07 [0.58, 1.87]	1.44 [0.81, 2.63]	0.77 [0.41, 1.56]	1.10 [0.56, 2.02]	1.46 [0.80, 2.63]
E_{trap}**(12/03)**	1.28 [1.09, 1.43]	1.26 [1.04, 1.41]	1.22 [1.00, 1.38]	1.27 [1.07, 1.42]	1.25 [1.03, 1.40]	1.22 [0.99, 1.38]
E_{hoop}**(12/03)**	1.33 [1.11, 1.48]	1.31 [1.07, 1.45]	1.27 [1.02, 1.43]	1.32 [1.10, 1.48]	1.29 [1.05, 1.46]	1.27 [1.01, 1.43]
TAC(2003)	2930 [2919, 2945]	3021 [3004, 3043]	3197 [3168, 3206]	3162 [3046, 3207]	3206 [3206, 3206]	3206 [3206, 3206]
	RC2	**RC2**	**RC2**	**RC2**	**RC2**	**RC2**
***B*(13/03)**	1.10 [0.66, 2.02]	1.00 [0.61, 1.99]	0.88 [0.54, 1.90]	1.06 [0.66, 1.98]	0.97 [0.59, 1.94]	0.87 [0.63, 1.92]
C_{ave}**(10)**	2901 [2223, 4282]	3482 [2563, 4777]	4195 [3154,5096]	3100 [2205, 4787]	3662 [2599, 5110]	4320 [3156, 5110]
C_{ave}**(5)**	2954 [2616, 3451]	3349 [2872, 3685]	3847 [3360,3915]	3083 [2604, 3814]	3657 [2981, 3915]	3915 [3450, 3915]
***V*(10)**	6.91 [5.33, 8.36]	7.54 [5.96, 9.32]	9.08 [7.13, 10.0]	8.72 [7.40, 9.84]	9.29 [7.96, 10.0]	9.73 [8.41, 10.0]
***V*(5)**	4.69 [2.60, 7.23]	5.91 [3.66, 8.71]	9.48 [5.96, 10.0]	8.43 [6.37, 9.92]	9.20 [7.02, 10.0]	10.0 [8.27, 10.0]
***FE*(12/03)**	1.00 [0.53, 1.78]	1.31 [0.71, 2.41]	1.83 [0.93, 3.46]	0.98 [0.51, 1.89]	1.33 [0.68, 2.62]	1.82 [0.92, 3.46]
E_{trap}**(12/03)**	1.25 [1.01, 1.45]	1.21 [0.97, 1.42]	1.14 [0.91, 1.35]	1.24 [1.00, 1.44]	1.19 [0.95, 1.40]	1.28 [0.90, 1.35]
E_{hoop}**(12/03)**	1.40 [1.09, 1.67]	1.35 [1.02, 1.63]	1.27 [0.94, 1.55]	1.38 [1.07, 1.67]	1.32 [0.99, 1.62]	1.27 [0.93, 1.54]
TAC(2003)	2927 [2915, 2944]	3017 [2997, 3043]	3190 [3157, 3207]	3136 [3001, 3207]	3206 [3206, 3206]	3206 [3206, 3206]

B(13/03) = biomass above 75mm at start of 2013 relative to that at the start of 2003
C_{ave} (10), C_{ave} (5) = average catch over next 10 (or 5) years
V(10), *V*(5) = average inter-annual catch variation over the next 10 (or 5) years expressed as a percentage
FE(12/03) = fishing effort in 2012 relative to that in 2003
E_{trap}(12/03), E_{hoops}(12/03) = ratio of the biomass above 350g in 2012 relative to that ratio in 2003 for lobsters caught by traps (or hoops)

Table 3: Results of the robustness trials for west coast rock lobster run for the deterministic middle option VAR5 (in conjunction with RC1 scenario 2 assumptions regarding future somatic growth and recruitment – the "central" scenario.)

Test	Description	*B*(13/03)	C_{ave}(10)	*V*(10)	FE(12/03)	TAC(03)	TAC(04)	TAC(05)
RC	Reference Case	1.00	2864	5.28	0.74	3206	3527	3221
F1	Change fishing selectivity	1.02	2555	7.86	0.56	3206	3527	3174
NS1	Male s = 0.88	0.93	2395	8.53	0.48	3206	3351	3016
NS2	Male s = 0.92	1.06	2493	7.33	0.56	3606	3343	3009
D2	Disc mort d = 0.2	1.00	2439	7.99	0.55	3206	3509	3158
D3	D decr. 5 yrs prior 1992							
SG1	Adult sg 0.5mm more	1.08	2377	7.82	0.46	3206	3296	2966
SG2	1870-1967 sg = 68-88 ave							
SG3	Pre-1990 sg = 1990+ level	0.98	3409	2.86	0.91	3206	3527	3512
SG4	1990+ sg = pre-1990 level	0.66	5043	9.03	2.92	3206	3527	3880
W1	1990+ 225 MT walkout, 112 MT for 2003+	1.01	2492	7.42	0.57	3206	3360	3024
W2	Same as W1, but also 1870-1990 500 MT walkout each decade							
B4	Hoop and trap CPUE 1999-2001 negatively biased by a factor of 1.3	0.98	3230	4.10	0.85	3206	3527	3580
E1	In 2000 R drops 50% for 3 yrs	0.87	2560	9.49	0.48	3206	3527	3221
E3	In 2007 25% all lobsters die	0.72	2576	9.36	0.61	3206	3527	3221
P1	Poaching reduced to 200 MT over next 5 yrs	1.04	2897	5.46	0.75	3206	3527	3221
TH1	Use 60:40 trap:hoop ratio	1.00	2864	5.29	0.74	3206	3527	3221
B1	CPUE 2003+ stays constant	0.96	2898	5.09	1.01	3206	3527	3185
B2	Future adult sg is 0.5mm more than thought	1.28	3146	5.24	0.78	3206	3527	3248
B3	Future adult sg is 0.5mm less than thought	0.84	2611	7.33	0.66	3206	3527	3174
M1	2005 FIMS missing – use 2004	1.00	2870	5.32	0.74	3206	3527	3221
M2	2005 sg missing – use 2004	1.00	2864	5.28	0.74	3206	3527	3221

Table 4: Summary of performance statistics for the full combination of four candidate hake OMPs and three median recovery tuning for *M. paradoxus*, for the Reference Set. For each statistic, the median and 90% PIs are shown.

		OMP1			OMP5			OMP7			OMP11		
		15%	20%	25%	15%	20%	25%	15%	20%	25%	15%	20%	25%
Species combined	avTAC	129.52	125.19	120.78	129.85	125.77	122.11	128.09	123.89	119.63	130.10	126.34	121.81
		113.22	108.82	104.80	109.76	106.15	102.28	102.14	98.43	94.83	114.59	110.26	105.66
		144.51	139.43	134.32	145.18	140.55	136.02	143.55	139.80	134.61	146.34	141.28	135.21
	AAV	5.10	5.03	4.92	5.37	5.29	5.21	4.09	4.10	4.04	5.47	5.31	5.29
		3.35	3.45	3.31	3.54	3.76	3.49	3.19	3.23	3.12	3.87	4.01	3.65
		7.01	6.85	6.73	7.55	7.44	7.50	5.85	5.95	6.11	7.19	7.12	7.07
	$CPUE_{2016}/CPUE_{2005}$	1.53	1.57	1.60	1.55	1.60	1.64	1.47	1.50	1.53	1.55	1.61	1.67
		1.24	1.26	1.30	1.25	1.30	1.34	1.17	1.21	1.24	1.29	1.33	1.36
		1.91	1.95	1.99	1.99	2.05	2.10	1.87	1.91	1.94	1.95	1.99	2.05
	C_{2007}	135.00	135.00	135.00	134.97	134.97	134.97	138.75	138.75	138.75	130.00	130.00	130.00
		-	-	-	-	-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-	-	-	-	-
	C_{2008}	121.50	121.50	121.50	121.47	121.47	121.47	128.34	128.34	128.34	117.00	117.00	117.00
		121.50	121.50	121.50	118.94	118.54	118.54	128.34	128.34	128.34	117.00	117.00	117.00
		130.86	129.99	128.88	131.47	129.11	127.75	128.34	128.34	128.34	127.39	124.82	123.29
	C_{2009}	112.31	111.02	109.88	109.33	109.33	109.21	118.72	118.72	118.72	106.61	105.30	105.30
		109.35	109.35	109.35	102.64	102.20	102.20	118.72	118.72	118.72	105.30	105.30	105.30
		128.66	127.86	126.98	128.22	126.84	125.88	118.72	118.72	118.72	125.22	122.50	121.47
M. paradoxus	B_{2027}/K	**0.150**	**0.200**	**0.250**	**0.150**	**0.200**	**0.250**	**0.150**	**0.200**	**0.250**	**0.150**	**0.200**	**0.250**
		0.069	0.121	0.167	0.059	0.109	0.165	0.061	0.111	0.167	0.050	0.111	0.160
		0.259	0.313	0.372	0.283	0.334	0.389	0.353	0.396	0.420	0.250	0.305	0.364
	B_{2027}/B_{2007}	2.13	2.88	3.79	2.11	2.91	3.65	2.18	3.05	3.82	2.07	2.86	3.65
		1.21	1.96	2.54	1.07	1.81	2.43	1.19	1.82	2.42	0.98	1.88	2.51
		3.82	4.86	5.98	4.05	5.03	6.16	5.90	6.68	7.87	3.76	4.79	6.02
M. capensis	B_{2027}/K	0.67	0.70	0.72	0.67	0.70	0.72	0.69	0.72	0.73	0.67	0.70	0.72
		0.56	0.59	0.61	0.55	0.58	0.60	0.56	0.59	0.61	0.55	0.58	0.61
		0.82	0.85	0.87	0.82	0.84	0.87	0.84	0.86	0.88	0.81	0.84	0.87
	B_{2027}/B_{2007}	1.42	1.49	1.54	1.43	1.49	1.54	1.45	1.51	1.56	1.42	1.48	1.53
		1.17	1.22	1.26	1.16	1.21	1.26	1.20	1.24	1.29	1.16	1.20	1.25
		1.70	1.78	1.84	1.72	1.79	1.84	1.75	1.81	1.86	1.70	1.77	1.83

Table 5: Summary of performance statistics for hake candidate **OMP1**, tuned for the 20% median recovery for *M. paradoxus*, for the RS and a series of robustness tests. For each statistic, the median and 90% PIs are shown. The ratios associated with the estimates of K^{sp} are for the present K^{sp}, i.e. in the case of the "Decr in *K*" test including the 20% decrease, and in the case of test B8 before the future decrease in carrying capacity.

		RS	SR1	Decr in K	A1b	A7b	B7	RS	B8
		(4 scenarios only)						(24 scenarios)	
Species combined	avTAC	120.15	132.02	117.89	134.71	122.98	118.94	125.05	100.98
		105.85	117.13	102.76	116.81	107.27	94.34	108.76	90.16
		133.20	144.69	132.30	149.53	138.06	138.20	139.27	112.89
	AAV	4.81	5.01	4.89	5.52	4.54	5.49	4.99	5.30
		3.37	3.42	3.48	3.82	3.21	3.86	3.45	3.83
		6.55	6.40	6.72	7.03	6.01	7.47	6.82	6.80
	$CPUE_{2016}/CPUE_{2005}$	1.64	1.55	1.61	2.06	1.50	1.75	1.57	1.31
		1.37	1.31	1.26	1.63	1.32	1.18	1.27	1.08
		2.09	1.95	2.11	2.58	1.76	2.44	1.96	1.61
	C_{2007}	135.00	135.00	135.00	135.00	135.00	135.00	135.00	135.00
		-	-	-	-	-	-	-	-
		-	-	-	-	-	-	-	-
	C_{2008}	121.50	126.35	121.50	121.50	121.51	121.50	121.50	121.50
		121.50	121.50	121.50	121.50	121.50	121.50	121.50	121.50
		127.56	134.69	126.81	124.78	132.23	127.30	130.02	128.88
	C_{2009}	110.39	125.21	109.55	109.35	113.97	109.35	111.00	109.88
		109.35	109.76	109.35	109.35	109.35	109.35	109.35	109.35
		122.56	139.55	121.56	116.91	132.62	122.23	128.16	126.98
M. paradoxus	B_{2027}/K	0.247	0.258	0.256	0.320	0.537	0.259	0.200	0.172
		0.157	0.170	0.167	0.220	0.429	0.143	0.121	0.104
		0.375	0.365	0.391	0.444	0.728	0.425	0.312	0.255
	B_{2027}/B_{2007}	3.85	3.46	4.03	5.07	3.33	4.23	2.91	2.55
		2.71	2.56	2.82	3.14	2.46	2.31	1.98	1.70
		5.97	5.29	6.14	8.14	3.99	7.28	4.91	4.11
M. capensis	B_{2027}/K	0.69	0.69	0.50	0.69	0.81	0.65	0.70	0.52
		0.59	0.59	0.43	0.58	0.73	0.52	0.59	0.44
		0.87	0.84	0.63	0.88	0.96	0.90	0.85	0.63
	B_{2027}/B_{2007}	1.56	1.54	1.44	1.66	1.21	1.66	1.49	1.11
		1.28	1.28	1.24	1.38	1.08	1.32	1.22	0.88
		1.85	1.84	1.74	2.06	1.45	2.17	1.78	1.31

Table 6: Output statistics for the chosen pelagic OMP-04 trade-off point (wrt the sardine:anchovy average catches).

Sardine		Anchovy	
$\overline{C}^{S}$	365.9	$\overline{C}^{A}$	300.2
AAV^{S}	0.197	AAV^{A}	0.330
$\overline{B^{S}_{2023}/K^{S}}$	0.728	$\overline{B^{A}_{2023}/K^{A}}$	0.671
$\overline{B^{S}_{2023}/Risk^{S}}$	4.012	$\overline{B^{A}_{2023}/Risk^{A}}$	1.465
$\overline{B^{S}_{\min}/K^{S}}$	0.451	$\overline{B^{A}_{\min}/K^{A}}$	0.131
$\overline{B^{S}_{\min}/Risk^{S}}$	2.445	$\overline{B^{A}_{\min}/Risk^{A}}$	0.273

$\overline{C}^{S/A}$ - average directed catch (000t),

$AAV^{S/A}$ - average proportional annual change in directed catch,

$\overline{B^{S/A}_{2023}/K^{S/A}}$ - average biomass at the end of the projection period as a proportion of carrying capacity,

$\overline{B^{S/A}_{2023}/Risk^{S/A}}$ -average biomass at the end of the projection period as a proportion of the risk threshold,

$\overline{B^{S/A}_{\min}/K^{S/A}}$ - average minimum biomass over the projection period as a proportion of carrying capacity, and

$\overline{B^{S/A}_{\min}/Risk^{S/A}}$ - average minimum biomass over the projection period as a proportion of the risk threshold.

Table 7a: Summary statistics resulting from running the pelagic OMP-04 under some anchovy robustness tests, using results from the posterior distributions obtained using MCMC. (The slight difference between the A_0 results here and those in Table 1 are due to OMP-04 originally been accepted subject to finalisation of the exceptional circumstances provisions. Table 1 reports the summary stats for anchovy prior to finalisation of these exceptional circumstances rules, while this table reports the summary stats after finalisation of the rules.)

	A_0	A_{M1}	A_{M2}	A_{HS}	A_{BH}	A_R	A_{kegg2}
$Risk^A$	0.238	0.228	0.212	0.408	0.316	0.474	0.238
$\overline{C}^A$	303.1	284.9	311.3	251.2	268.1	245.6	301.0
AAV^A	0.337	0.342	0.318	0.367	0.348	0.368	0.337
$\overline{B^A_{2023}/K^A}$	0.695	0.596	0.765	0.332	0.382	0.285	0.624
$\overline{B^A_{2023}/Risk^A}$	1.521	1.465	1.664	0.996	1.000	0.889	1.433
$\overline{B^A_{2023}/B^A_{2004}}$	0.002	0.891	0.002	0.587	0.001	0.528	0.002
$\overline{B^A_{\min}/K^A}$	0.137	0.127	0.144	0.091	0.090	0.067	0.123
$\overline{B^A_{\min}/Risk^A}$	0.286	0.302	0.288	0.271	0.241	0.207	0.271

Table 7b: Summary statistics resulting from running the pelagic OMP-04 under some sardine robustness tests, using results from the posterior distributions obtained using MCMC.

	S_0	S_{kN1}
$Risk^S$	0.096	0.368
$\overline{C}^S$	365.9	331.1
AAV^S	0.197	0.168
$\overline{B^S_{2023}/K^S}$	0.728	0.747
$\overline{B^S_{2023}/Risk^S}$	4.009	4.744
$\overline{B^S_{2023}/B^S_{2004}}$	0.643	0.519
$\overline{B^S_{\min}/K^S}$	0.451	0.440
$\overline{B^S_{\min}/Risk^S}$	2.445	2.688

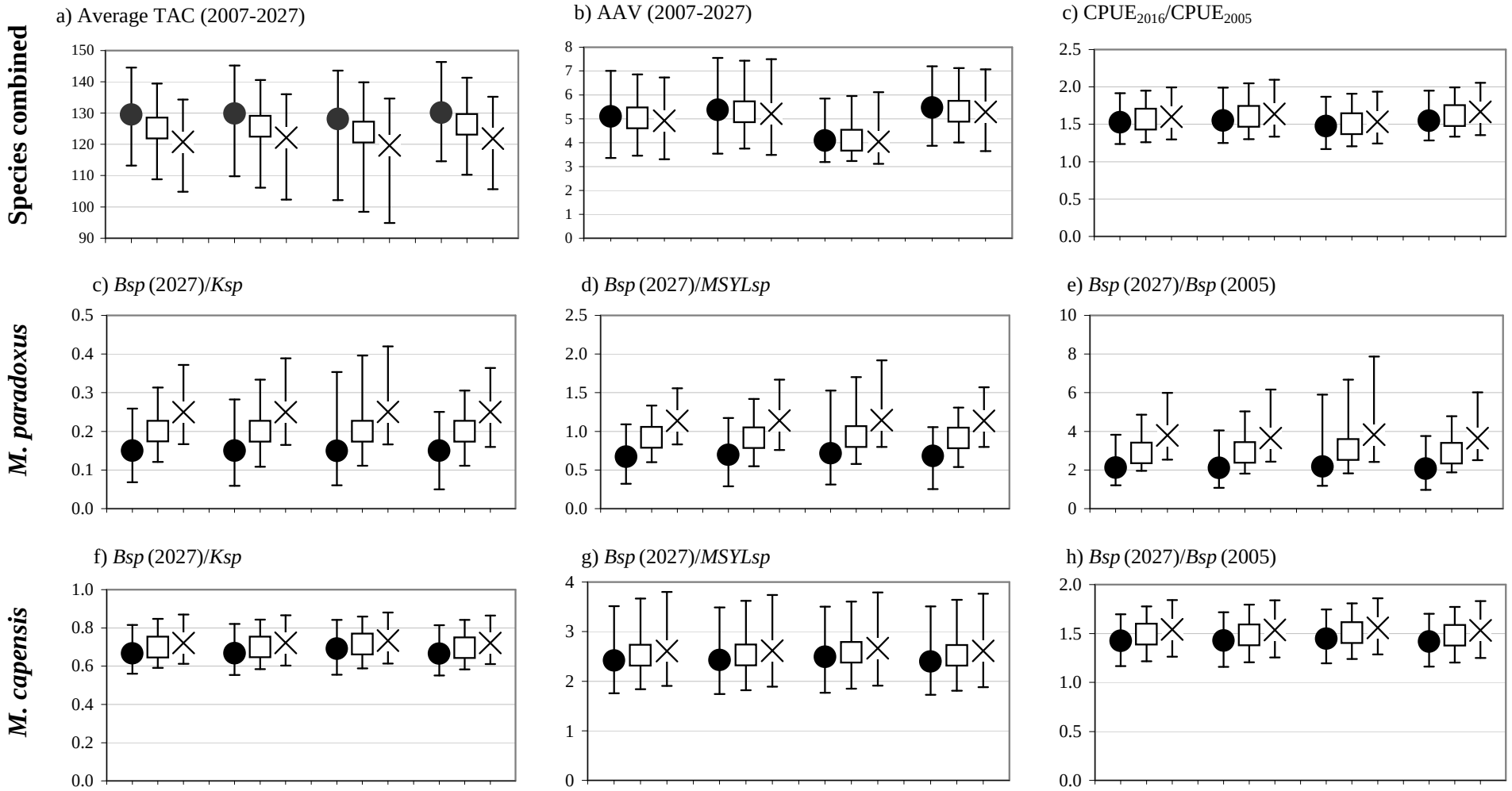
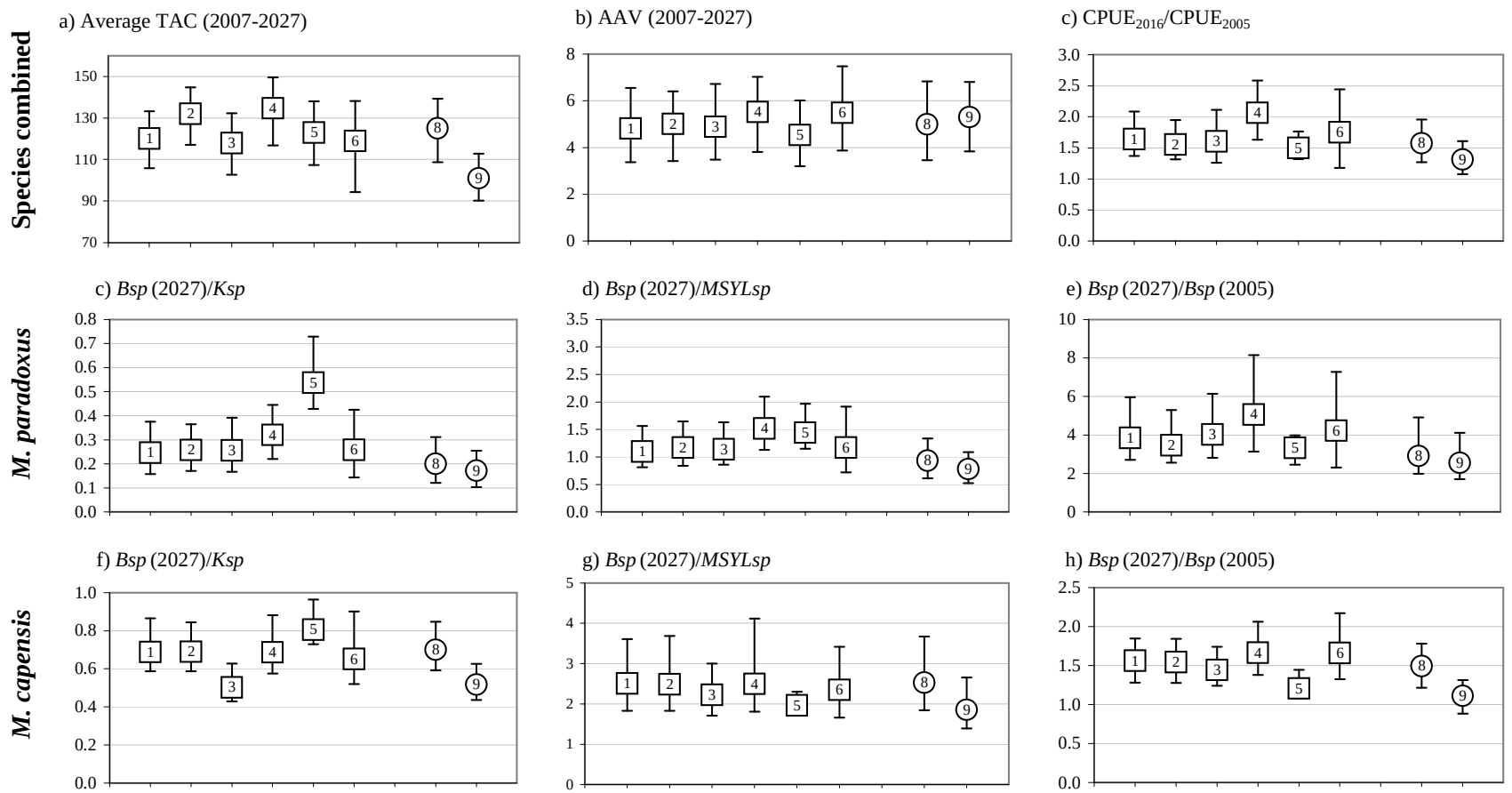


Fig. 1: Graphical summary of performance statistics for the full combination of four candidate hake OMPs (OMP1, OMP5, OMP7 and OMP11 from left to right) and three **median** recovery tunings (15%, 20% and 25% of *K* from left to right) for *M. paradoxus* for the **Reference Set**. Each panel shows medians together with 90% PIs.



Four scenarios only (open squares):

1 – Reference Set
2 – SR1
3 – Decr in *K*
4 – A1b – with discards
5 – A7b – Ricker SR curve
6 – B7 – σ_R=0.4

All 24 scenarios (open circles):

8 – Reference Set
9 – B8 – decr in *K* in the future

Fig. 2: Graphical summary of performance statistics for hake OMP1, tuned to the 20% median recovery level for *M. paradoxus* for the RS and a series of robustness tests.. Each panel shows medians together with 90% PIs. The ratios associated with the estimates of K^{sp} are for the present K^{sp}, i.e. in the case of the "Decr in *K*" test including the 20% decrease, and in the case of test B8 before the future decrease in carrying capacity.