Robustness testing of SCRL OMP-2014 and development of a metarule to be used in Exceptional Circumstances

S.J Johnston and D.S. Butterworth

MARAM

Department of Mathematics and Applied Mathematics

University of Cape Town

Summary

This document first conducts some robustness tests for SCRL OMP-2014 and then investigated a number of metarule candidates to be used in addition to the current OMP given Exceptional Circumstances. Metarule MR4 is recommended as the most appropriate option, although it is acknowledged that this metarule would apply for the relatively short term only, and that for 2025+ it would need to be improved to prevent possible unnecessary catch reductions.

Introduction

Johnston *et al.* (2014) describes the newly adopted OMP-2014 for the SCRL resource. The expected performance of this OMP was reported in detail (as variant 2 with median Bsp(25/06)=1.30) in Johnston and Butterworth (2014). Due to time constraints, robustness test results for the OMP selected were not reported by the deadline when adoption became necessary. Furthermore, a metarule to be used in Exceptional Circumstances had yet to be developed and simulated tested. This document serves to report on results from both these initiatives.

The development of a metarule should follow the following logical steps.

STEP1: Identify a set of plausible robustness tests that either examine alternate assumptions for underlying operating model of the resource, or model future possible (and plausible) "disasters".

STEP2: Evaluate the expected performance of each robustness test under OMP-2014 *without* any metarule.

STEP3: Identify problematic results.

STEP4: Develop a metarule that:

i) will not (or hardly) impact the RC predicted results; but

ii) will appreciably improve performance for the "problematic" robustness tests.

STEP1: Robustness tests

OMP 2014 was selected after considering the results of simulation testing using the baseline Reference Case (RC) model of the resource. The RC model is the one which is considered to be the most likely model of the underlying dynamics of the resource and its associated fishery. However, a number of assumptions are made in specifying the RC model. Here a set of robustness tests has been developed which examine the implications of alternative assumptions. This set was developed keeping in mind the plausibility of the alternative "factor" and the possible impact it could have on the results. Factors that were considered implausible or not likely to have much impact on the model results were not considered.

Robustness tests Rob1-Rob6 involve refitting of the operating model (OM) to the data.

ROB1: Natural mortality is decreased from 0.1 to 0.05 yr^{-1}.

ROB2: Natural mortality is increased from 0.1 to 0.20 yr^{-1}.

ROB3: The standard deviation of logged residuals about the stock recruit relationship is reduced from 0.8 to 0.4.

ROB4: The catch-at-length data are down-weighted by a factor of 0.5 in the likelihood function (compared to 1.0 for the RC).

ROB5: The steepness parameter "*h*" of the stock-recruit function is fixed at 0.6 (the RC model estimates this to be 0.99).

ROB6: The length range over which the area 2+3 selectivity is re-normalised is increased from 55mm-90mm to the range 50mm-120mm.

Table 1 compares these robustness model fits to data with those obtained from the RC. These models were also projected forwards deterministically under the assumption of a future fixed constant catch (CC) of 345 MT. Both the final (2025) exploitable and spawning biomass values for each test are reported in the last two rows of Table 1.

In order to test the effectiveness of the metarule, a further set of robustness trials has been developed which model possible negative impacts on the resource. These robustness tests do not involve refitting the OM, but model possible future "disasters" for the resource (and hence the fishery).

ROB7: There is an undetected 2% per annum increase in the CPUE catchability (from 2011 onwards).

ROB8a: There is a recruitment failure in the future – this is modelled by fixing recruitment to be at its lowest estimated value in the past for a period of **five** years (2004-2008), and then to revert to values determined by the S-R relationship thereafter.

ROB8b: There is a recruitment failure in the future – this is modelled by fixing recruitment to be at its lowest estimated value in the past for a period of **ten** years (2004-20**13**), and then to revert to values determined by the to S-R relationship thereafter.

ROB9: The carrying capacity drops by 50% over a 10 year period (starting in 2004). The summary statistics incorporating "*K*" use the "reduced" *K* value where applicable (i.e. post 2004).

ROB10: In 2014, 50% of all lobster >= 65mm CL die.

STEP2: Results of robustness tests without any metarule

Note that the operating model (OM) used for testing alternate metarules is the same OM that was used for developing OMP 2014, i.e. the most recent data have not been taken into account for comparability purposes.

Figure 1 compares various summary statistics for the RC model and robustness tests for OMP-2014 with **no metarule** in place.

Figure 2 compares the RC (M=0.1), ROB1 (M=0.05), ROB8b (recruitment failure), ROB9 (reduced carrying capacity) and ROB10 (50%v lobster deaths in 2014) model Bsp trajectories under a future CC=342 MT and deterministic future recruitment.

STEP3: Identify problem areas

Of the six robustness tests that test alternative underlying assumptions for the RC OM, only **ROB1** which sets natural mortality *M* to 0.05 (RC=0.1) has a substantial impact on future projections of the resource. In Table 1 the ($B_{sp}(2025)/K_{sp}$) under a CC of 342 MT is about half that predicted by the RC operating model.

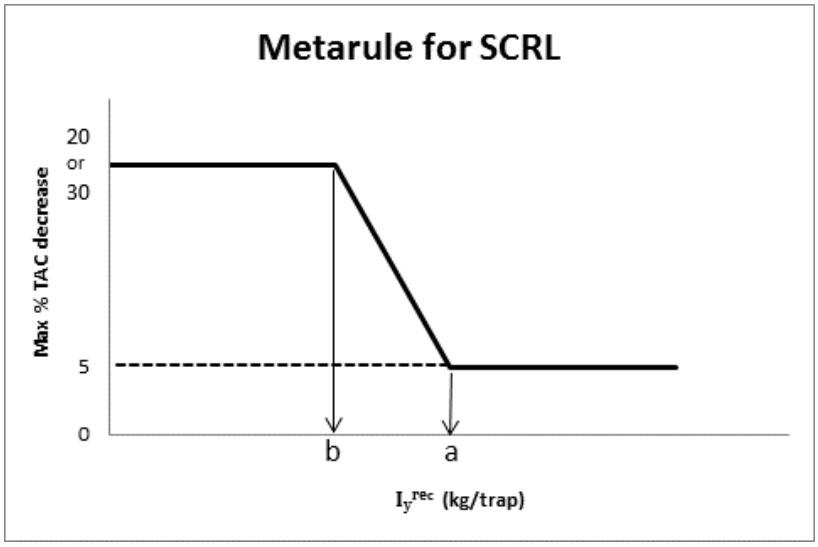
The other three robustness tests which predict more negative outcomes for the resource than the RC model when OMP-2014 is applied, are **ROB8b** (recruitment failure for ten years), **ROB9** (carrying capacity decreases in future) and **ROB10** (50% lobster deaths in 2014) - see Figures 1 and 2.

It was therefore decided that ROB1, ROB8b, ROB9 and ROB10 would be used to simulation test a range of alternate metarules (in conjunction with OMP-2014), with the aim of attempting to improve performance for these robustness tests, whilst at the same time not (or hardly) affecting the results for the RC OM.

STEP4: Metarule development

OMP-2014 needs to be developed further to include a "metarule" to be implemented under "Exceptional Circumstances" provisions. Here the metarule is triggered if the recent (three-year averaged) catch rate I_y^{rec} value drops below a threshold level "a". This metarule allows for the TAC to decrease further (up to 20% in the example below) than the usual maximum 5% TAC decrease, as shown in the figure below.

Thus if I_y^{rec} remains ≥ a, then the 5% maximum TAC reduction rule remains in place. If $I_y^{rec} \leq$ b then the maximum interannual TAC decrease increases to 20% (or 30%). For values of I_y^{rec} between a and b, a linear change in the maximum TAC decrease between 5% and 20% (or 30%) is applied.



A number of metarules have been investigated – tested on the RC (remember that ideally it is desirable not to change the RC case results to any substantial extent), and a number of the more severe robustness tests ROB1 (M=0.05), ROB8a (5 year recruitment failure), ROB8b (10 year recruitment failure), ROB9 (carrying capacity is reduced) and ROB10 (lobster deaths).

	a	**b**	Max inter-annual TAC decrease at **b**
MR1	0.9	0.4	20%
MR2	0.9	0.0	20%
MR3	0.9	0.0	30%
MR4	0.9	0.7	20%
MR5	0.9	0.7	30%

Note that the I_y^{rec} (the weighted average over the three areas and over 2010-2012) is 0.954 kg/trap and will be 1.084 kg/trap for the 2011-13 period. Thus none of these EC rules would have been invoked for the setting of the 2015 TAC.

New Summary statistics

Projections are extended to 2035 to allow better for the effects of transient effects on results to have dissipated. Three new summary statistics thus included in this report are:

- Cave(2026-2035)
- Bsp(2035/06)
- Bsp(2035/K)

Results

Tables 2a-f compare the results of five metarules for the RC, ROB1, ROB8a, ROB8b, ROB9 and ROB10 respectively. Results associated with OMP 2014 with NO metarule are also reported for each model.

Figures 3a-e compare summary statistics for the five metarules for the RC, ROB1, ROB8b, ROB9 and ROB10 models respectively. The medians and 5^{th} and 95^{th} percentiles from 1000 simulations are reported.

Figure 4 compares median Bsp/K, TAC and CPUE trajectories for the RC, ROB8b, ROB9 and ROB10 OMs between OMP 2014 with NO metarule (left hand plots) and OMP 2014 with metarule MR4 (right hand plots).

Figures 5a-c compare the Bsp/K, TAC and CPUE trajectories directly for the OMP 2014 with NO metarule and with MR4 for ROB8b (Figure 5a), ROB9 (Figure 5b) and ROB10 (Figure 5). These plots show clearly the impact MR4 would have on future TACs in response to drastically reduced CPUEs, and the positive effect this in turn has on the Bsp/K trajectories.

From these results, it would seem that:

- None of the metarules alter the RC model results to any substantial extent (which is as intended).
- OMP 2014 with NO metarule in place reacts fairly well over this set of robustness tests in that the future TAC is reduced in line with the negative signal received from the CPUE data. The rationale is that the addition of a metarule should result in a faster reaction to a reduced CPUE signal.
- The metarules reported here do show larger TAC reductions in reaction to reduced CPUEs – this is particularly so for ROB8b and ROB9 (see Figure 4).

Metarule recommendation

Metarule MR4 which allows for a TAC reduction of up to 20% would seem to be an appropriate choice. For robustness tests ROB8a (Table 2c), and ROB10 (Table 2f) MR4 results in the target Bsp(2025/06) of 1.30 being more nearly attained than if no metarule is in place. For ROB1 (Table 2b), ROB8b (Table 2d) and ROB9 (Table 2e) the benefit of MR4 comes later than 2025, with Bsp improving thereafter for the following decade. However these gains come at the expenses of large reductions in catch (see e.g. Figure 3c). Since Bsp(2035/06) values in these cases are much higher than the target value of 1.30, these levels of TAC reduction seem unnecessarily severe.

MR4 would come into play if the combined three year CPUE average drops below 0.90, and increase the annual TAC reduction from 5% to a maximum of 20% at a CPUE value of 0.70. Exceptional Circumstances would thus be defined as a three year combined CPUE average of 0.90 and below.

Conclusion

Metarule MR4 is the recommended metarule to be used (in conjunction with the current OMP) in Exceptional Circumstances. It is recognised that although this rule makes sense for the short term (up to say 2025), for the post 2025 period an improved metarule should be developed in time to prevent unintended or unnecessary catch declines in that period.

References

Johnston, S.J. and Butterworth, D.S. 2014. Final SCRL OMP candidates to be considered for OMP 2014. DAFF document, FISHERIES/2014/AUG/SWG_SCRL/06.

Johnston, S.J., Butterworth, D.S. and Glazer, J.P. 2014. South coast rock lobster OMP 2014: Initial specifications. DAFF document, FISHERIES/2014/SEP/SWG_SCRL/07.

Table 1: Estimated model parameters and –*ln*L values for the current RC and those six of the robustness tests which require the operating model (OM) to be refit.

	RC	**Rob1** ***M*=0.05**	**Rob2** ***M*=0.20**	**Rob3** σ_R**=0.4**	**Rob4 CAL WT=0.50**	**Rob5** ***h* = 0.6**	**Rob6 A23 norm 50-120**
	Scl.tpl/n5a.rep	M05.rep	M20.rep	Sigr04.rep	Calw05.rep	H06.rep	diffl.rep
-lnL Total	**-427.49**	**-414.98**	**-431.51**	**-421.90**	**-259.77**	**-423.11**	**-450.21**
-lnl CPUE	**-113.53**	**-110.25**	**-199.70**	**-110.92**	**-124.68**	**-112.26**	**-113.71**
-lnl CPUE A1E	-17.87	-18.07	-18.58	-17.78	-19.12	-17.82	-17.96
-lnl CPUE A1W	-50.42	-48.99	-52.44	-50.33	-53.78	-50.69	-49.79
-lnl CPUE A2+3	-45.23	-43.19	-48.67	-42.80	-51.79	-43.75	-45.96
-ln SCI CAL	**-361.31**	**-354.73**	**-361.62**	**-361.10**	**-300.03**	**-357.35**	**-403.45**
-ln SCI CAL A1E	-11.46	-10.93	-9.20	-8.97	-3.70	-11.22	-12.56
-ln SCI CAL A1W	-151.21	-149.06	-153.69	-149.72	-143.22	-151.37	-150.11
-ln SCI CAL A2+3	-198.65	-194.74	-198.73	-202.41	-153.11	-194.76	-240.78
K	4895	7315	4164	4344	5631	6525	4104
h	0.99	0.99	0.84	0.99	0.99	0.6 fixed	0.99
λ^{A1E}	0.153	0.147	0.256	0.168	0.170	0.135	0.161
λ^{A1W}	0.256	0.295	0.243	0.254	0.232	0.225	0.283
λ^{A2+3}	0.592	0.557	0.501	0.578	0.598	0.640	0.557
$B_{sp}(2011)$ ($B_{sp}(2011)/K_{sp}$)	1650 (0.34)	1698 (0.23)	2059 (0.49)	1422 (0.33)	2016 (0.36)	2170 (0.33)	1483 (0.36)
$B_{exp}(2011)$ ($B_{exp}(2011)/K_{exp}$) A1E	45 (0.16)	43 (0.15)	178 (0.40)	43 (0.15)	100 (0.27)	47 (0.18)	45 (0.160)
$B_{exp}(2011)$ ($B_{exp}(2011)/K_{exp}$) A1W	504 (0.58)	426 (0.55)	752 (0.71)	435 (0.53)	434 (0.53)	485 (0.58)	555 (0.588)
$B_{exp}(2011)$ ($B_{exp}(2011)/K_{exp}$) A2+3	959 (0.35)	699 (0.29)	1258 (0.40)	875 (0.33)	1217 (0.39)	1211 (0.35)	931 (0.346)
$B_{exp}(2025)$ under CC 342 MT	1374	669	2047	1465	1537	1137	1018
$B_{sp}(2025)$ ($B_{sp}(2025)/K_{sp}$) under CC 345 MT	1674 (0.34)	1261 (0.17)	1934 (0.46)	1655 (0.38)	1970 (0.35)	1648 (0.25)	1047 (0.26)

Table 2a: Metarule results for the **RC** model. Medians with the 5th and 95th percentiles shown in parentheses are reported.

MR	Bsp(2025/06)	Bsp(2025/*K*)	Bsp(2035/06)	Bsp(2035/*K*)	Cave (2014-2025)	Cave (2026-2035)
No MR	**1.30 (0.75; 2.79)**	**0.41 (0.24; 0.91)**	**1.26 (0.72; 2.47)**	**0.40 (0.23; 0.78)**	**409 (300; 427)**	**412 (208; 450)**
MR1	1.30 (0.75; 2.79)	0.41 (0.24; 0.91)	1.28 (0.73; 2.47)	0.41 (0.23; 0.78)	409 (296; 427)	412 (175; 450)
MR2	1.30 (0.75; 2.79)	0.41 (0.24; 0.91)	1.27 (0.73; 2.47)	0.41 (0.23; 0.78)	409 (299; 427)	412 (191; 450)
MR3	1.30 (0.75; 2.79)	0.41 (0.24; 0.91)	1.28 (0.73; 2.47)	0.41 (0.25; 0.77)	409 (296; 427)	412 (177; 450)
MR4	1.30 (0.76; 2.79)	0.42 (0.24; 0.91)	1.30 (0.74; 2.47)	0.42 (0.24; 0.78)	409 (294; 427)	409 (142; 450)
MR5	1.31 (0.77; 2.79)	0.42 (0.24; 0.91)	1.32 (0.74; 2.47)	0.42 (0.24; 0.79)	409 (294; 427)	407 (111; 450)

Table 2b: Metarule results for the **ROB1 robustness test (M=0.05)**. Medians with the 5th and 95th percentiles shown in parentheses are reported.

MR	Bsp(2025/06)	Bsp(2025/*K*)	Bsp(2035/06)	Bsp(2035/*K*)	Cave (2014-2025)	Cave (2026-2035)
RC No MR	1.30 (0.75; 2.79)	0.41 (0.24; 0.91)	1.26 (0.72; 2.47)	0.40 (0.23; 0.78)	409 (300; 427)	412 (208; 450)
No MR	**1.20 (0.76; 2.29)**	**0.28 (0.17; 0.54)**	**1.26 (0.76; 2.28)**	**0.29 (0.17; 0.52)**	**327 (268; 416)**	**268 (150; 449)**
MR1	1.20 (0.77; 2.28)	0.28 (0.18; 0.54)	1.30 (0.79; 2.32)	0.31 (0.18; 0.53)	326 (258; 416)	256 (113; 449)
MR2	1.20 (0.77; 2.28)	0.28 (0.17; 0.54)	1.28 (0.77; 2.30)	0.30 (0.18; 0.53)	326 (263; 416)	260 (127; 449)
MR3	1.20 (0.77; 2.86)	0.28 (0.18; 0.53)	1.30 (0.79; 2.31)	0.30 (0.18; 0.53)	326 (259; 416)	256 (114; 449)
MR4	1.21 (0.79; 2.28)	0.28 (0.18; 0.54)	1.34 (0.81; 2.35)	0.31 (0.18; 0.54)	324 (242; 416)	244 (78; 449)
MR5	1.22 (0.81; 2.29)	0.28 (0.18; 0.54)	1.38 (0.81; 2.38)	0.32 (0.19; 0.56)	323 (229; 416)	235 (49; 449)

Table 2c: Metarule results for the **ROB8a robustness test (recruitment failure for 5 years 2004-2008)**. Medians with the 5th and 95th percentiles shown in parentheses are reported.

MR	Bsp(2025/06)	Bsp(2025/*K*)	Bsp(2035/06)	Bsp(2035/*K*)	Cave (2014-2025)	Cave (2026-2035)
RC No MR	1.30 (0.75; 2.79)	0.41 (0.24; 0.91)	1.26 (0.72; 2.47)	0.40 (0.23; 0.78)	409 (300; 427)	412 (208; 450)
No MR	**1.24 (0.76; 2.70)**	**0.39 (0.24; 0.85)**	**1.50 (0.91; 2.62)**	**0.48 (0.29; 0.82)**	**283 (237; 358)**	**194 (134; 281)**
MR1	1.26 (0.79; 2.71)	0.40 (0.25; 0.85)	1.58 (0.93; 2.68)	0.50 (0.30; 0.84)	277 (219; 357)	269 (124; 445)
MR2	1.25 (0.78; 2.71)	0.40 (0.25; 0.85)	1.54 (0.92; 2.64)	0.49 (0.30; 0.83)	280 (228; 357)	275 (140; 446)
MR3	1.26 (0.79; 2.71)	0.40 (0.25; 0.85)	1.57 (0.93; 2.67)	0.50 (0.30; 0.84)	277 (221; 356)	270 (127; 445)
MR4	1.30 (0.82; 2.71)	0.41; 0.26; 0.85)	1.63 (0.97; 2.76)	0.52 (0.31; 0.87)	273 (200; 356)	247 (85; 445)
MR5	1.32 (0.85; 2.72)	0.42 (0.27; 0.96)	1.72 (0.98; 2.86)	0.55 (0.31; 2.86)	266 (177; 356)	227 (49; 445)

Table 2d: Metarule results for the **ROB8b robustness test (recruitment failure for 10 years 2004-2013)**. Medians with the 5th and 95th percentiles shown in parentheses are reported.

MR	Bsp(2025/06)	Bsp(2025/*K*)	Bsp(2035/06)	Bsp(2035/*K*)	Cave (2014-2025)	Cave (2026-2035)
RC No MR	1.30 (0.75; 2.79)	0.41 (0.24; 0.91)	1.26 (0.72; 2.47)	0.40 (0.23; 0.78)	409 (300; 427)	412 (208; 450)
No MR	**0.85 (0.60; 1.39)**	**0.27 (0.19; 0.43)**	**1.54 (1.04; 2.46)**	**0.49 (0.33; 0.78)**	**207 (166; 257)**	**194 (134; 282)**
MR1	0.88 (0.62; 1.45)	0.28 (0.20; 0.45)	1.80 (1.24; 2.73)	0.57 (0.40; 0.88)	189 (155; 239)	103 (57; 187)
MR2	0.87 (0.61; 1.42)	0.28 (0.20; 0.44)	1.70 (1.17; 2.64)	0.54 (0.37; 0.84)	196 (158; 247)	137 (86; 223)
MR3	0.88 (0.62; 1.44)	0.28 (0.20; 0.45)	1.79 (1.23; 2.71)	0.57 (0.40; 0.87)	190 (156; 240)	108 (61; 191)
MR4	0.91 (0.64; 1.47)	0.29 (0.21; 0.46)	1.92 (1.34; 2.88)	0.61 (0.43; 0.92)	178 (145; 229)	64 (32; 132)
MR5	0.93 (0.66; 1.51)	0.29 (0.21; 0.47)	2.05 (1.44; 3.02)	0.65 (0.47; 0.96)	167 (134; 217)	29 (10; 76)

Table 2e: Metarule results for the **ROB9 robustness test (*K* decreases in future).** Medians with the 5th and 95th percentiles shown in parentheses are reported.

MR	Bsp(2025/06)	Bsp(2025/*K*)	Bsp(2035/06)	Bsp(2035/*K*)	Cave (2014-2025)	Cave (2026-2035)
RC No MR	1.30 (0.75; 2.79)	0.41 (0.24; 0.91)	1.26 (0.72; 2.47)	0.40 (0.23; 0.78)	409 (300; 427)	412 (208; 450)
No MR	**0.79 (0.48; 1.70)**	**0.42 (0.25; 0.89)***	**0.80 (0.53; 1.30)**	**0.42 (0.28; 0.70)***	**362 (266; 425)**	**195 (98; 431)**
MR1	0.80 (0.49; 1.70)	0.42 (0.26; 0.89)*	0.86 (0.56; 1.40)	0.46 (0.30; 0.73)*	360 (258; 426)	162 (58; 430)
MR2	0.80 (0.48; 1.70)	0.42 (0.26; 0.89)*	0.84 (0.55; 1.38)	0.44 (0.29; 0.76)*	361 (261; 426)	175 (76; 430)
MR3	0.80 (0.49; 1.70)	0.42 (0.26; 0.89)*	0.86 (0.56; 1.40)	0.45 (0.30; 0.74)*	360 (259; 426)	164 (59; 430)
MR4	0.80 (0.50; 1.70)	0.43 (0.26; 0.89)*	0.91 (0.59; 1.48)	0.48 (0.31; 0.78)*	357 (252; 425)	137 (38; 429)
MR5	0.81 (0.51; 1.70)	0.43 (0.27; 0.89)*	0.96 (0.61; 1.58)	0.51 (0.32; 0.82)*	355 (244; 425)	112 (17; 430)

*here the *K* used is the "reduced *K*"

Table 2f: Metarule results for the **ROB10 robustness test (50% lobsters >=65mm CL die in 2014)**. Medians with the 5th and 95th percentiles shown in parentheses are reported.

MR	Bsp(2025/06)	Bsp(2025/*K*)	Bsp(2035/06)	Bsp(2035/*K*)	Cave (2014-2025)	Cave (2026-2035)
RC No MR	1.30 (0.75; 2.79)	0.41 (0.24; 0.91)	1.26 (0.72; 2.47)	0.40 (0.23; 0.78)	409 (300; 427)	412 (208; 450)
No MR	**1.20 (0.74; 2.61)**	**0.38 (0.24; 0.81)**	**1.42 (0.85; 2.51)**	**0.45 (0.27; 0.80)**	**311 (228; 415)**	**314 (172; 450)**
MR1	1.23 (0.78; 2.61)	0.39 (0.25; 0.82)	1.54 (0.89; 2.63)	0.49 (0.28; 0.82)	298 (203; 415)	285 (120; 450)
MR2	1.22 (0.76; 2.61)	0.39 (0.25; 0.81)	1.48 (0.87; 2.58)	0.48 (0.28; 0.81)	304 (212; 415)	297 (142; 450)
MR3	1.23 (0.78; 2.61)	0.39 (0.25; 0.82)	1.53 (0.89; 2.60)	0.49 (0.28; 0.81)	299 (205; 415)	287 (124; 450)
MR4	1.27 (0.82; 2.64)	0.40 (0.26; 0.82)	1.65 (0.94; 2.79)	0.52 (0.30; 0.87)	285 (183; 415)	247 (82; 450)
MR5	1.32 (0.86; 2.66)	0.42 (0.27; 0.83)	1.74 (0.95; 2.89)	0.55 (0.31; 0.92)	271 (163; 415)	215 (43; 450)

Figure 1: Comparison of summary statistics of the RC model and all the initial robustness tests, for OMP-2014 with **no metarule** in place. Medians and 5th and 95th percentiles are shown.

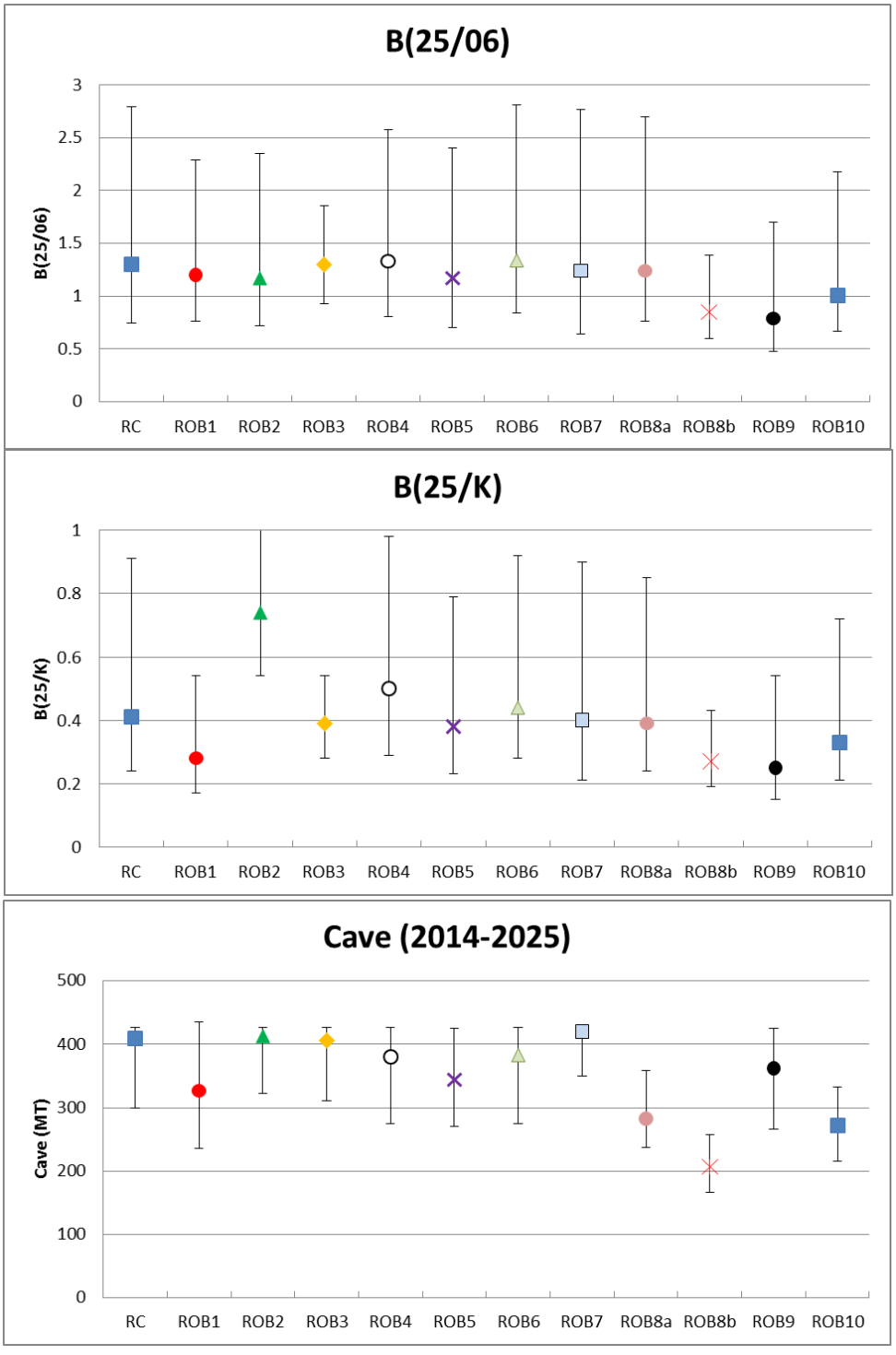


Figure 2: Comparative median Bsp and Bsp/K trajectories under a future constant catch (CC) of 342 MT for the RC, ROB1 (M=0.05), ROB8b (Recruitment failure for 10 year 2004-2013), ROB9 (K drops 50% for 10 years) and ROB10 (50% of lobsters >=65mm CL die in 2014) models. Note that if K changes over time, Bsp/K is calculated in terms of the value of *K* for the year concerned.

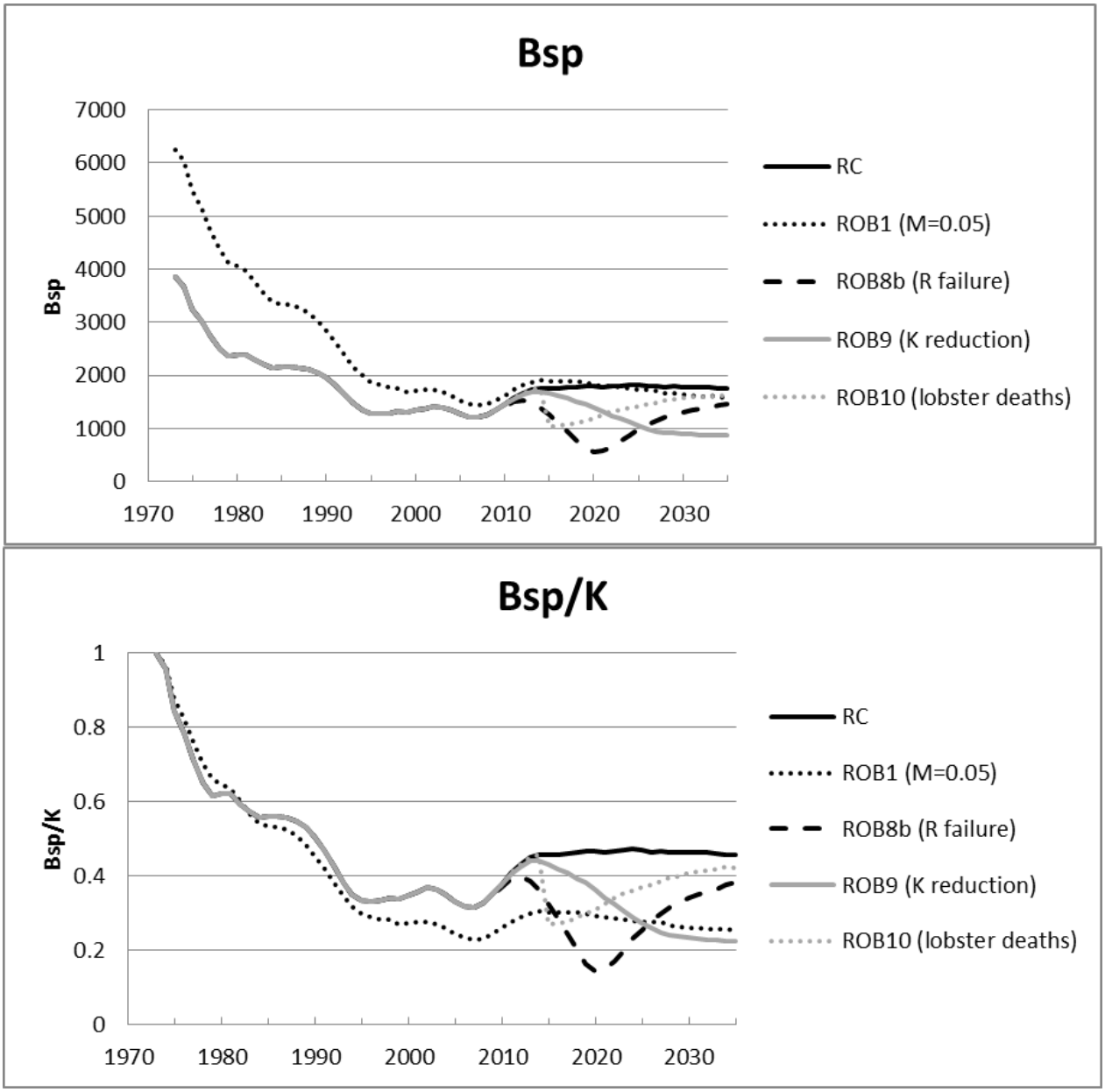


Figure 3a: Comparison of various summary statistics for the **RC** model for OMP-2014 with **four different metarules** in place. Medians and 5th and 95th percentiles are shown.

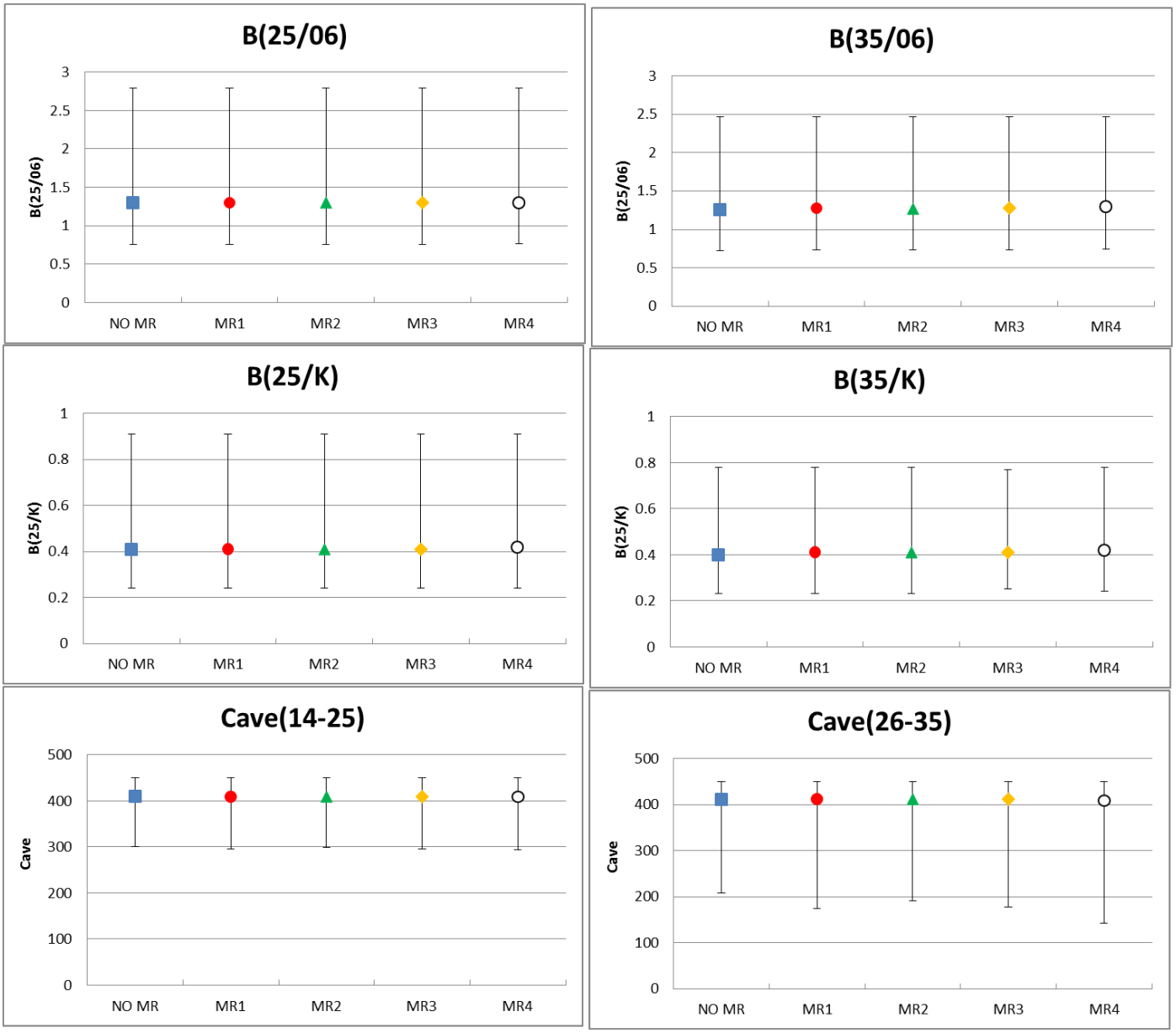


Figure 3b: Comparison of various summary statistics for robustness test **ROB1** (M=0.05) for OMP-2014 with **four different metarules** in place. Medians and 5th and 95th percentiles are shown.

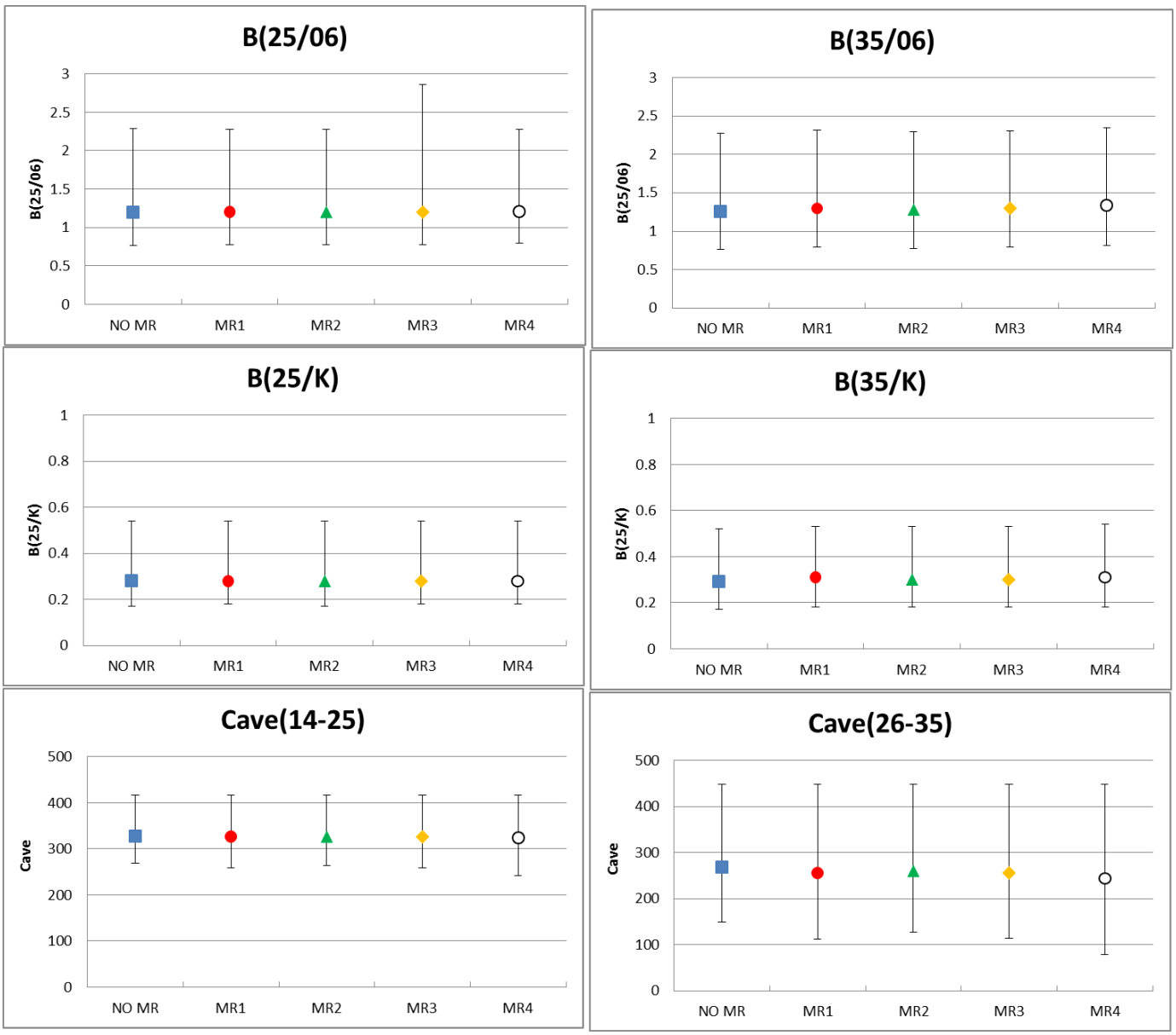


Figure 3c: Comparison of various summary statistics for robustness test **ROB8b** (recruitment failure) for OMP-2014 with **four different metarules** in place. Medians and 5th and 95th percentiles are shown.

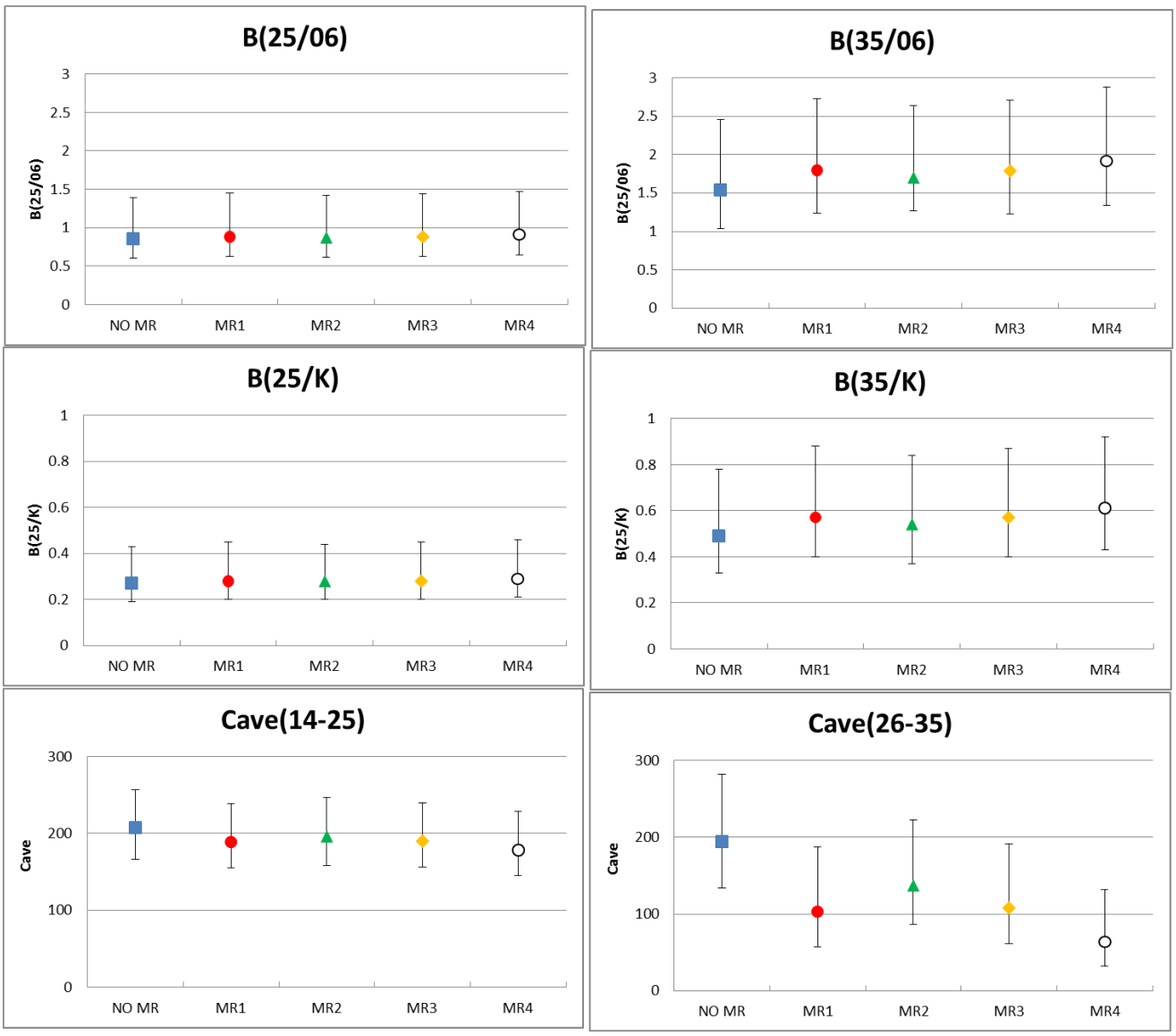


Figure 3d: Comparison of various summary statistics for robustness test **ROB9** (carrying capacity decrease), for OMP-2014 with **four different metarules** in place. Medians and 5th and 95th percentiles are shown. Note that if *K* changes over time, Bsp/K is calculated in terms of the value of K for the year concerned.

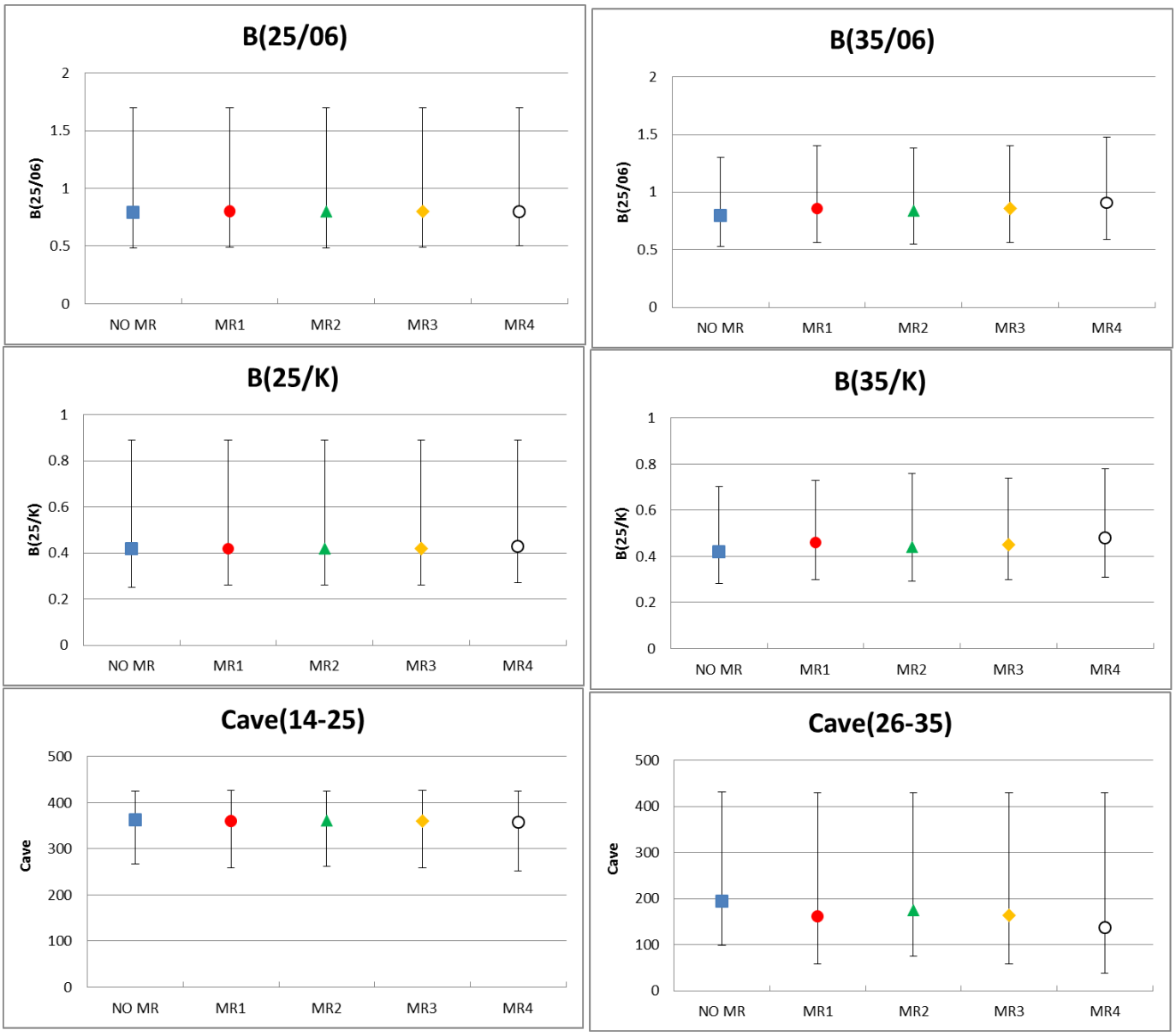


Figure 3e: Comparison of various summary statistics for robustness test **ROB10** (lobsters die in 2014) for OMP-2014 with **four different metarules** in place. Medians and 5th and 95th percentiles are shown.

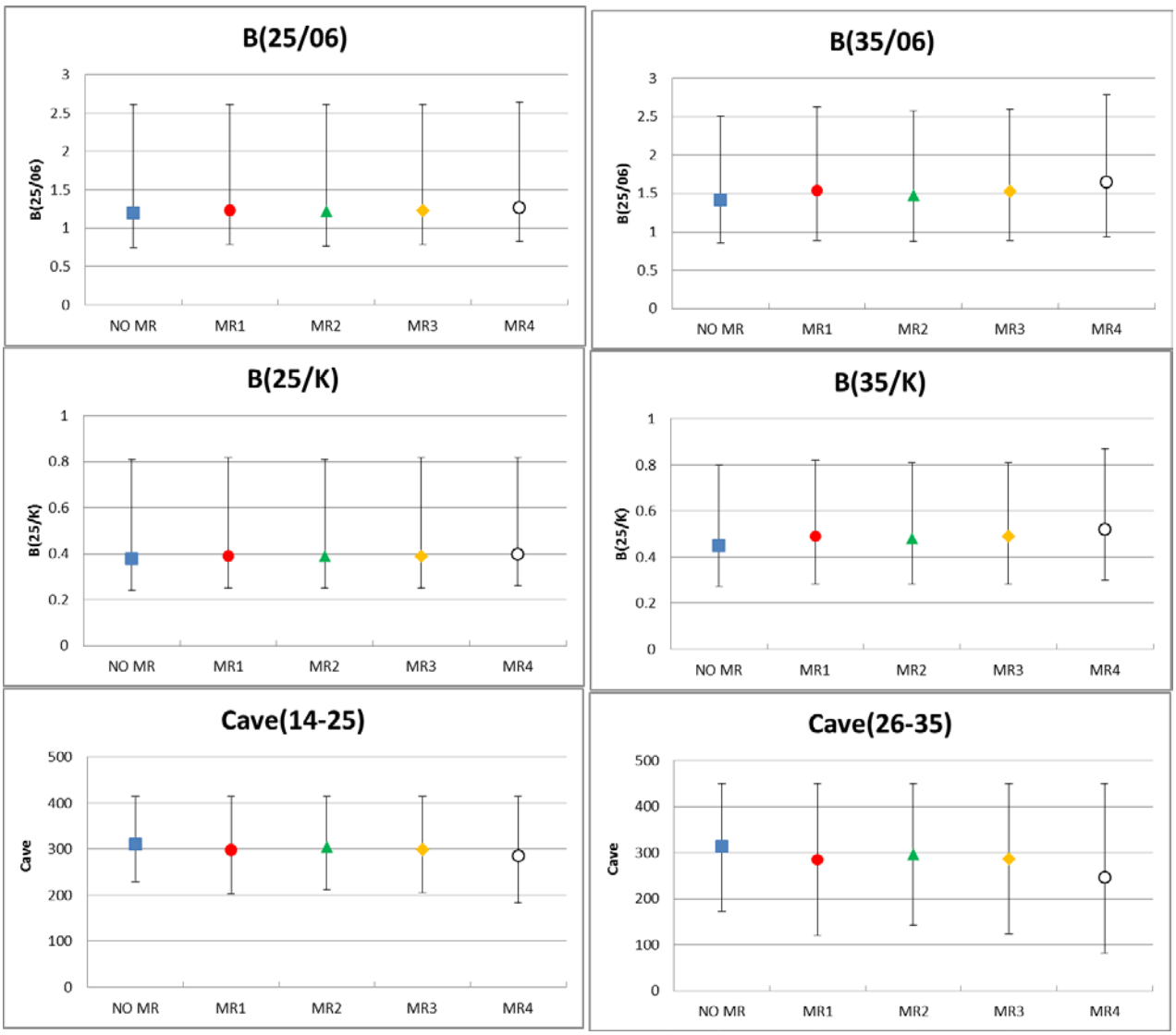


Figure 4: Comparions between OMP-2014 with NO EC rule (LHS) and with MR4 (RHS) for the RC and three robustness tests.

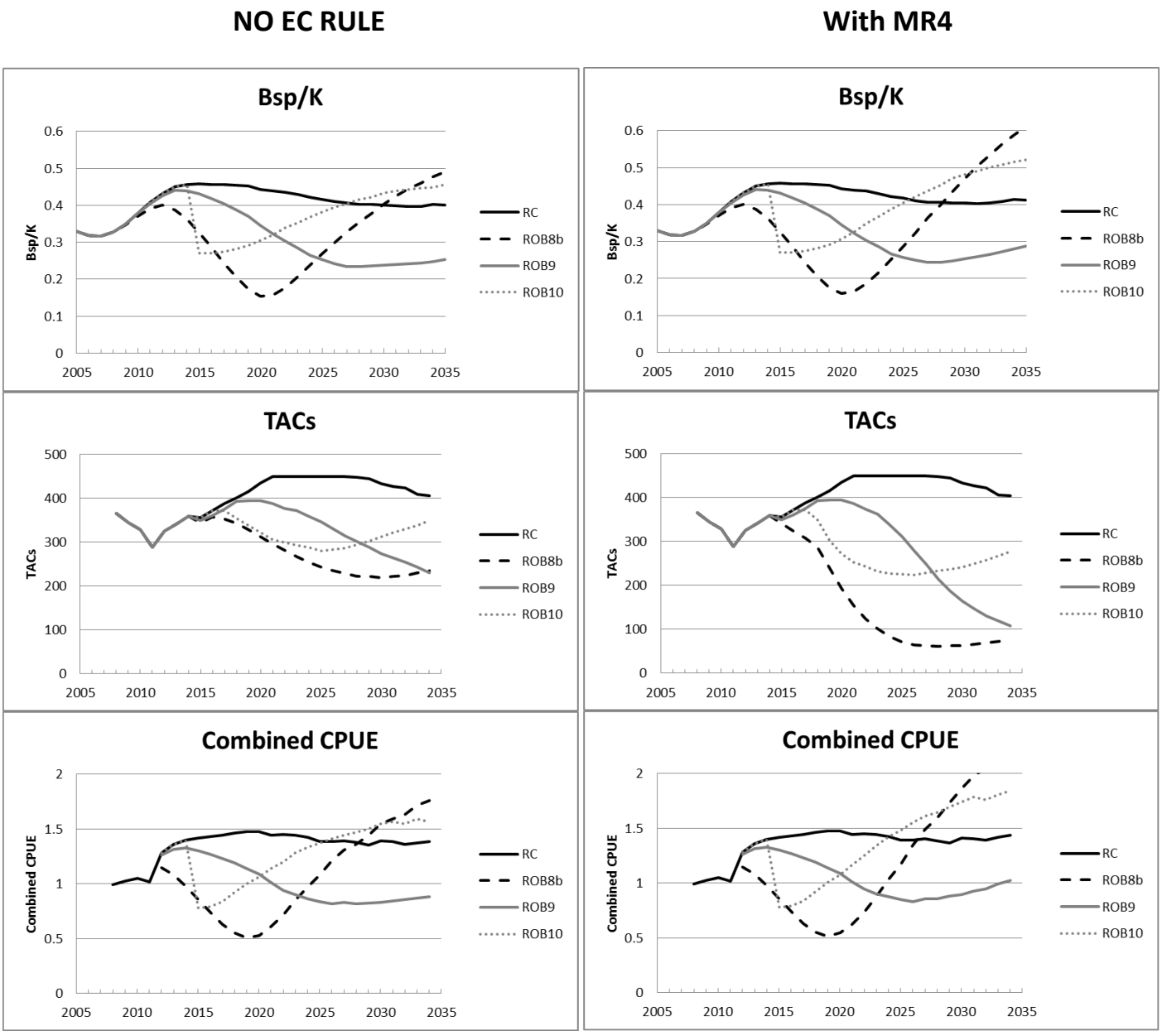


Figure 5a: Comparisons between OMP-2014 with NO EC rule and when combined with MR4 for the robustness test **ROB8b** (recruitment failure).

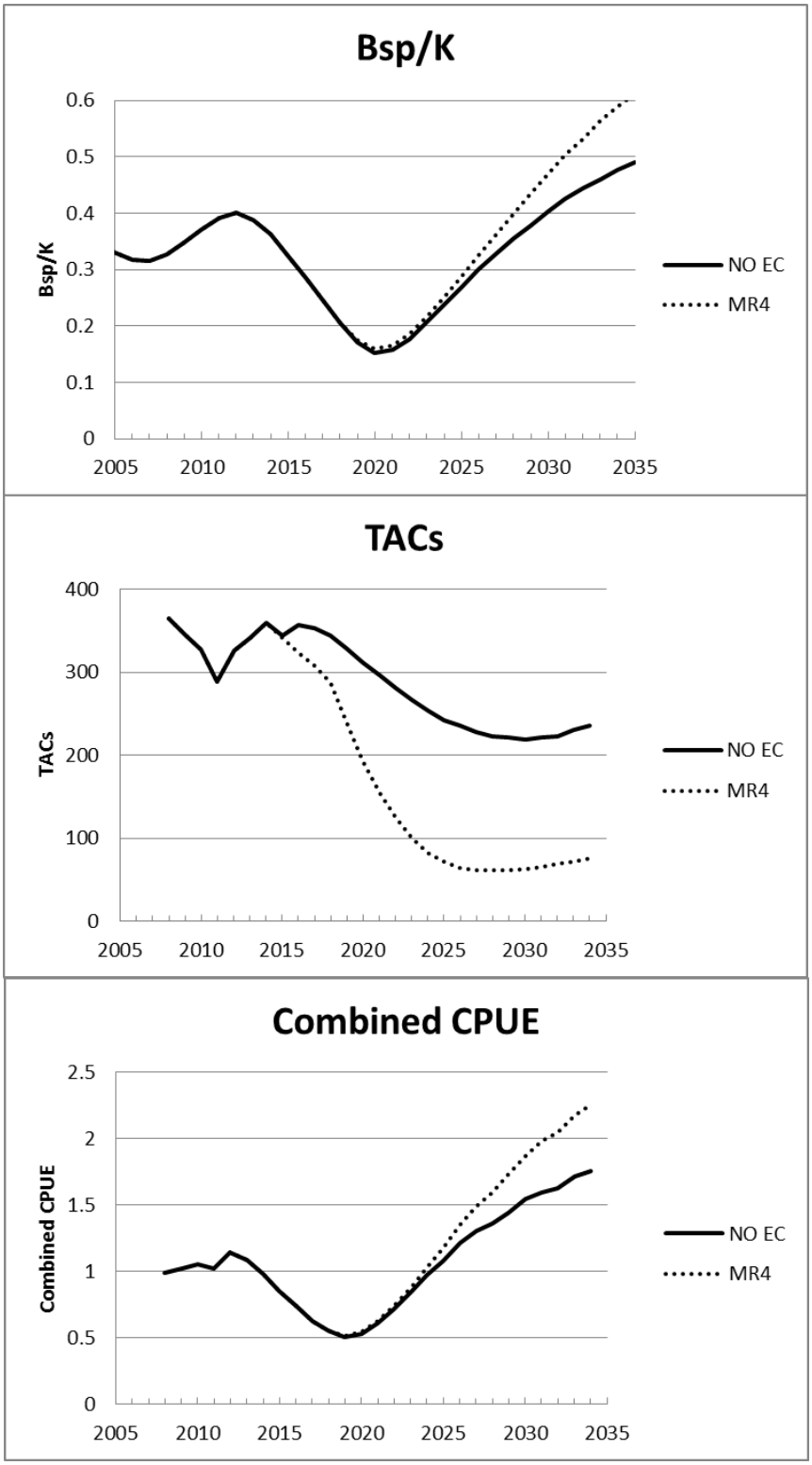


Figure 5b: Comparisons between OMP-2014 with NO EC rule and when combined with MR4 for the robustness test **ROB9** (carrying capacity decrease).

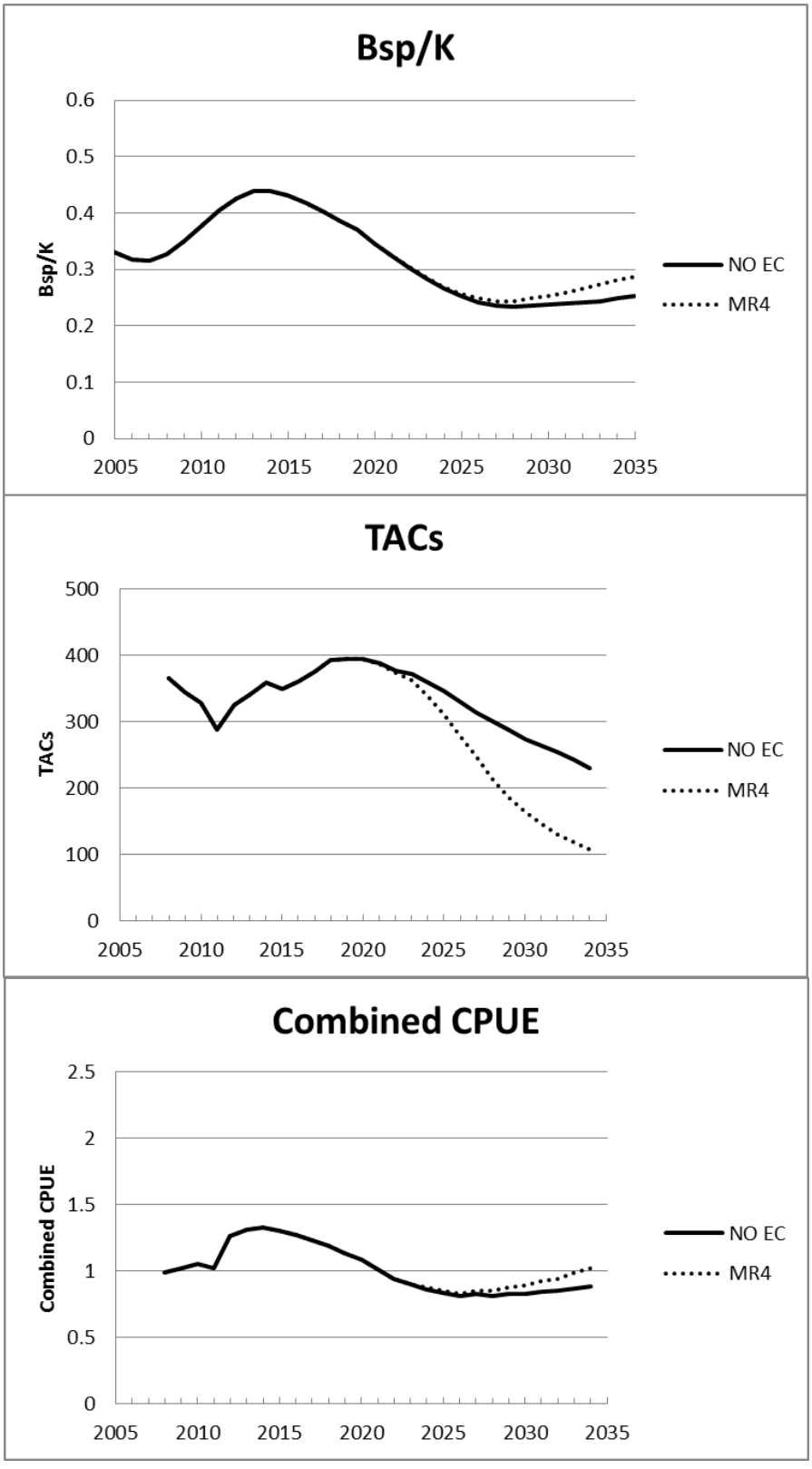


Figure 5c: Comparisons between OMP-2014 with NO EC rule and when combined with MR4 for the robustness test **ROB10** (50% lobsters >= 65mm CL die in 2014).