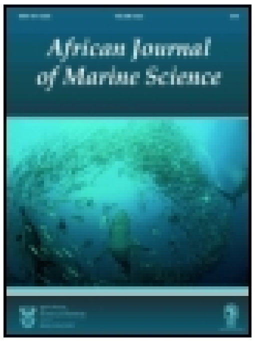

African Journal of Marine Science

ISSN: 1814-232X (Print) 1814-2338 (Online) Journal homepage: http://www.tandfonline.com/loi/tams20

A history of recent bases for management and the development of a species-combined Operational Management Procedure for the South African hake resource

RA Rademeyer , DS Butterworth & ÉE Plagányi

African Journal of Marine Science 2008, 30(2): 291–310
Printed in South Africa — All rights reserved

AFRICAN JOURNAL OF MARINE SCIENCE
ISSN 1814–232X EISSN 1814–2338
doi: 10.2989/AJMS.2008.30.2.8.558

A history of recent bases for management and the development of a species-combined Operational Management Procedure for the South African hake resource

RA Rademeyer*, DS Butterworth and ÉE Plagányi

MARAM (Marine Resource Assessment and Management Group), Department of Mathematics and Applied Mathematics, University of Cape Town, Rondebosch 7701, South Africa
** Corresponding author, e-mail: rebecca.rademeyer@uct.ac.za*

Manuscript received December 2007; accepted June 2008

The bases for historical catch limits placed on the hake fishery are reviewed in brief for earlier years and then in some depth over the period from 1991 when the Operational Management Procedure (OMP) approach was introduced for this fishery. The new OMP implemented from 2007 was the first to be based on the use of rigorous species-disaggregated assessments of the resource as Operating Models. The paper describes the Reference Set and range of robustness trials, together with the associated Operating Models, which were used for the simulation testing of the new OMP. Performance statistics for a number of candidate OMPs are compared, and the two key trade-off decisions in the selection process discussed (substantial *Merluccius paradoxus* and catch per unit effort [CPUE] recovery, and total allowable catch [TAC] stability constraints). Details of the OMP adopted and how its formulae depend on recent trends in CPUE and survey estimates of abundance are provided. OMP-2007, which is tuned to a median 20-year recovery target of 20% of pristine spawning biomass for *M. paradoxus* and a 50% increase in CPUE over the next 10 years, has been adopted for recommending hake TACs over the 2007–2010 period until the next scheduled major review. A set of general guidelines adopted for the process of possible overruling of recommendations from OMPs or bringing forward their reviews within an otherwise intended four-year cycle is detailed.

Keywords: hake, *Merluccius*, management, management procedure, OMP, South Africa

Introduction

The South African hake fishery is the country's most important fishery and comprises two species, the shallow-water Cape hake *Merluccius capensis* and the deep-water Cape hake *M. paradoxus*. The fishery has a long history and has been one of the first worldwide to move to a management system based on the implementation of an Operational Management Procedure (OMP)**.** Usually termed Management Procedures (MPs; Butterworth and Punt 1999), these and similar frameworks such as Management Strategy Evaluations (MSE; Smith *et al.* 1999) involve assessing the consequences over the medium term for both the resource(s) and associated fisheries of alternative options to determine management measures. The central idea is that simulation trials are used to ensure that the associated decision rules lead to performance that is robust to uncertainties about the dynamics of the resource being managed.

In the development of an OMP, these consequences are assessed by simulation over a range of plausible models for the dynamics of the resource being managed. This ensures that the chosen decision rules lead to performance that is robust to uncertainties about these dynamics. The simulation framework first requires the construction of a number of Operating Models (OMs) which reflect alternative possibilities for the underlying dynamics of the resource and fishery. Future resource monitoring data typical of what would become available in practice are then generated from these models. These data are used, either directly (in the case of an empirical MP) or through a two-stage assessment model and control rule (model-based MP) process, to provide total allowable catch (TAC) recommendations. In this way the biomass is projected forward for a defined period and the performance of each candidate MP is evaluated by considering the values of a set of performance statistics. Finally, the candidate MP which provides what are considered to be the best trade-offs between the various objectives for the fishery is selected. These steps are described below for the development and eventual selection of a species-combined OMP for the South African hake resource.

The models and methods used to manage the hake fishery have necessarily evolved in parallel with the available data and understanding of the dynamics of the resource. Here, we provide a summary of the past management of the hake fishery, summarise previous OMPs applied, and describe the development of a new OMP that was first applied to provide recommendations for the 2007 TAC. This new OMP differs in a number of respects from previous hake OMPs, most notably in its treatment of the two species and the way in which it has attempted to encompass the major uncertainties.

Past management

Since its inception at the turn of the 19th century until 1977, although certain checks and restrictions were in place, the hake industry off South Africa operated largely as an open-access fishery. After South Africa declared a 200 nmi Exclusive Economic Zone (EEZ) in 1977, hake TACs were set by the South African authorities, at first taking account of recommendations made by the International Commission for South East Atlantic Fisheries (ICSEAF). Following the heavy exploitation of the late 1960s and early 1970s, a conservative stock rebuilding strategy was adopted. The recommended TACs were initially based on the use of steady-state surplus production models and later on dynamic surplus production models (Butterworth and Andrew 1984). In accordance with the accepted stock rebuilding strategy, a policy aimed at maintaining catches below annual sustainable yields was applied, in general by use of a $f_{0.1}$[1]-type strategy (Andrew and Butterworth 1987).

Since 1990, the South African hake fishery has been managed in terms of OMPs (except for some transitional periods while the OMP was revised). The annual TAC recommendations from 1991 to the present, the bases for these recommendations and the actual TAC adopted are detailed in Table 1. The *de facto* process followed at present is that the TAC recommendation is made by the South African Department of Environmental Affairs: branch Marine and Coastal Management (MCM) Scientific Working Group (SWG) and reviewed by the Chief Director: Resources Research, MCM, from whence it is passed on to the Chief Director: Resource Management, MCM, and eventually to the Minister of Environmental Affairs and Tourism for decision. Over the period covered in Table 1, the TAC implemented has hardly differed from the scientific recommendations. Further, except in a few years where delays in allocating rights led to some quota holders being allowed partial carry-overs to the next year, catches made have generally been very close to TACs allocated, so that implementation error in the management of the fishery is small.

Over the period 1990–1995, an OMP (referred to here as OMP-1991) was used to provide TAC recommendations for the years 1991–1996 for each of the West and South coasts, and was based on a species- and age-aggregated dynamic production model linked to a $f_{0.2}$ harvesting strategy. OMP-1991 incorporated a Schaefer production model using inputs comprising time-series of catches as well as catch per unit effort (CPUE) and survey abundance estimates (Punt 1992), though the OMs used for testing were age-structured and species-disaggregated.

OMP-1991 had been chosen following thorough prior simulation testing (Punt 1992, 1993), but by 1995 it had become apparent that it was in need of revision for two main reasons. First, the commercial CPUE on the West Coast had not increased as much as predicted five years earlier, suggesting some mis-specification in the base case operating model, which had been chosen in 1990 as the most appropriate representation of the hake resource dynamics (Geromont and Butterworth 1997). Changes in the fishing selectivity over time (probably as a result of the phasing out the illegal use of small-mesh netliners in the late 1980s) were brought to light and needed to be taken into account (Geromont and Butterworth 1998). These resulted in the CPUE series failing to provide a comparable index over the full 1978–1995 period for which detailed data had been collected from the local trawl fleet, and in the Schaefer model no longer providing adequate predictions of resource trends. Furthermore, general linear modelling (GLM) techniques applied to standardise the CPUE series suggested a lesser rate of recovery of the resource over recent decades than had the coarser standardisation methods used earlier.

For these reasons, the hake TAC was held fixed for the years 1997 and 1998, while a revised OMP was being developed. In August 1998, the Sea Fishery Advisory Council (SFAC — the primary body responsible for providing advice to the Minister at that time) adopted a revised OMP to provide recommendations for the West Coast component of the hake TAC (referred to here as WC-OMP-1999). This OMP was used until 2003. It was based on an $f_{0.075}$ harvesting strategy coupled to an age-aggregated Fox production model (Geromont and Glazer 1998). To avoid the problems associated with the non-comparability of the CPUE series over time, the OMP inputs omitted the period during which the fishing selectivity is believed to have changed (i.e. over which netliners were phased out) and used only the pre-1984 and post-1991 CPUE data, treating them as independent series.

The three main objectives considered in selecting WC-OMP-1999 were: (a) a high probability for the resource to recover to the Maximum Sustainable Yield Level (MSYL), expressed in terms of spawning biomass (MSYL = B^{sp}_{MSY}/K^{sp}) within the next 10 years, (b) a low probability of a net decline in the spawning biomass over this 10-year period and (c) a low probability of a decrease in TAC early in the 10-year period.

The need for a revised OMP for hake on the South Coast arose following the development, in this region in particular, of a longline fishery for hake[2]. Previously, the OMP for hake on the South Coast was based upon aggregating over the two hake species (as for on the West Coast), with the justification for this aggregation based upon simulations for the West Coast fishery that assumed that the species and

[1] If C is the equilibrium catch for effort E, the $f_{0.n}$ strategy is defined as the effort level $E_{0.n}$ satisfying the equation $\left.\frac{dC}{dE}\right|_{E=E_{0.n}} = 0.n \left.\frac{dC}{dE}\right|_{E=0}$, i.e. the marginal return (at equilibrium) for additional effort has fallen to a fraction 0.*n* of its value for the pristine fishery

[2] The current hake fishery has four sectors: the offshore and longline fleets operate both on the South and West coasts, and the inshore and handline fleets operate on the South Coast exclusively. The inshore and line fleets catch *M. capensis* mainly as they operate in relatively shallow water

Table 1: TAC recommendations and basis for advice from 1991 to 2007

	Component of the resource	Basis for management recommendation (t)	Comments	Scientific TAC recommendation (t)	Minister's TAC decision (t)	Actual catch (t)	Reference
1991	WC — both species SC — both species	OMP-1991: 102 000 OMP-1991: 43 000		145 000	141 000	141 000	MCM (1991)
1992	WC — both species SC — both species	OMP-1991: 100 600 OMP-1991: 43 300		144 000	145 000	141 600	MCM (1992)
1993	WC — both species SC — both species	OMP-1991: 101 300 OMP-1991: 45 000		146 000	147 000	141 473	MCM (1993)
1994	WC — both species SC — both species	OMP-1991: 100 000 OMP-1991: 51 000		148 000	148 000	147 177	MCM (1994)
1995	WC — both species SC — both species	OMP-1991: 100 000 OMP-1991: 51 000		151 000	151 000	141 040	MCM (1995)
1996	WC — both species SC — both species	OMP-1991: 98 900 OMP-1991: 51 700		151 000	151 000	159 263	MCM (1996)
1997		Fixed	TAC fixed while revising OMP because of concern regarding: (1) CPUE time-series comparability over time, (2) model mis-specification and (3) standardisation of CPUE data	151 000	151 000	147 680	MCM (1997a)
1998		Fixed		151 000	151 000	154 222	MCM (1997b)
1999	WC — both species SC — both species	WC-OMP-1999: 100 000 *Ad hoc*: 51 000	On SC, five-year catch averages of 23 000 t for *M. capensis* and 28 000 t for *M. paradoxus*	151 000	151 000	137 399	MCM (1998)
2000	WC — both species SC — both species	WC-OMP-1999: 103 000 *Ad hoc*: 52 500	*Ad hoc* assumption for SC: same proportional change as indicated by WC-OMP-1999 (i.e. +3%)	155 500	155 500	154 651	MCM (1999)
2001	WC — both species SC — *M. capensis* SC — *M. paradoxus*	WC-OMP-1999: 107 000 SCcapensis-OMP-2001: 25 000 *Ad hoc*: 34 000	*Ad hoc* proportional addition to WC-OMP-1999 output, based on the average ratio between the catch of the SC *M. paradoxus* component to the catch of both species on the WC over the period 1995–1999	166 000	166 000	158 567	MCM (2000)
2002	WC — both species SC — *M. capensis* SC — *M. paradoxus*	WC-OMP-1999: 110 000 SCcapensis-OMP-2001: 25 000 *Ad hoc*: 25 000–35 000	WC-OMP-1999 recommended 3 000 t increase, but because of concern on *ad hoc M. paradoxus* SC adjustment, total TAC kept fixed	166 000	166 000	147 358	MCM (2001)
2003	WC — both species SC — *M. capensis* SC — *M. paradoxus*	WC-OMP-1999: 108 000 SCcapensis-OMP-2001: 25 000 RY difference: 20 000–28 000	SC *M. paradoxus* component computed to be between 20 000 t and 28 000 t based on the difference in sustainable yield between a WC only and WC+SC age-structured model for *M. paradoxus* only. It was decided to phase down over three years to the total of 158 000 t, given global TAC recommendations from the OMPs were expected to be stable over the next three years	163 000	164 000	154 838	MCM (2002)
2004	SC — *M. capensis* WC — both species SC — *M. paradoxus*	SCcapensis-OMP-2001: 24 000 RY: 98 000 RY difference: 31 000	WC-OMP-1998 overridden as new data indicated that the then current status of resource was appreciably below that implied by the 1997 assessment. 20-year RY for SC and WC *M. paradoxus* together with SCcapensis-OMP-2000 output suggested 10 000 t decrease needed to stabilise abundance. However, projections indicated that reduction of planned 3 000 t would not result in undue harm	161 000	161 000	154 403	MCM (2003)

Table 1: (cont.)

	Component of the resource	Basis for management recommendation (t)	Comments	Scientific TAC recommendation (t)	Minister's TAC decision (t)	Actual catch (t)	Reference
2005	Both coasts and species	Coast-combined, species disaggregated model	Runs of coast-combined, species disaggregated models for both *M. capensis* and *M. paradoxus* indicated that the 'default option' of continuation of the planned 8 000 t phase-down would not lead to undue immediate risk	158 000	158 000	143 613	MCM (2004)
2006	Both coasts and species	Coast-combined, species disaggregated model with illustrative control rule	An illustrative control rule was developed to set TACs in simulations after an initial two-year period of pre-fixed TAC reductions (of 5 000 t, 8 000 t or 10 000 t). This suggested that an 8 000 t reduction for 2006 was appropriate	150 000	150 000	149 999	MCM (2005)
2007	Both coasts and species	OMP-2007		135 000	135 000	141 281	MCM (2006)

WC = West Coast
SC = South Coast
RY = Replacement Yield

age-selectivity of the fishery remained unchanged (Punt 1992). These assumptions became invalidated on the South Coast as the hake longline fishery targets mainly older *M. capensis*.

The revised OMP for the South Coast *M. capensis* component of the hake resource was adopted in June 2000 (referred to here as SCcapensis-OMP-2001). It was of the same form as the one used for the West Coast, based on a Fox-form age-aggregated production model but incorporating a $f_{0.3}$ harvesting strategy (Geromont and Butterworth 2000).

The objectives of the OMP for the South Coast *M. capensis* resource were somewhat different than for the West Coast hake resource. This is because the South Coast shallow-water Cape hake population was estimated to be in a healthy state, well above MSYL, and a resource strategy of 'rebuilding to MSYL' strategy was not required for this component of the overall hake resource. Therefore, the choice of a candidate OMP involved a trade-off between catch and catch rate, rather than a trade-off between the average annual catch and the extent of resource recovery, as had been the case for the WC-OMP-1999. Thus, the main consideration in selecting an OMP for the South Coast *M. capensis* resource became trying to keep catch rates relatively stable in the short to medium term. The $f_{0.3}$ harvesting strategy option was chosen as it projected roughly steady levels of both catch and catch rate over the next few years.

Unlike the situation for *M. capensis*, an attempted separate assessment for *M. paradoxus* on the South Coast did not yield sensible results, probably because the *M. paradoxus* found on the South Coast is a component of the West Coast *M. paradoxus* stock (Geromont and Butterworth 1999). In the absence of an OMP for this component of the resource, the TAC contribution for South Coast *M. paradoxus* for 2001 was computed as an *ad hoc* proportional addition to the West Coast OMP output; this assumes that changes in the South Coast *M. paradoxus* allowable catch should match trends in West Coast hake abundance. The following year (2002), concerns first developed that stock performance as indicated by an updated assessment fell outside (and below) the range covered in the WC-OMP-1999 trials. This is evident from the plots of probability intervals for projections of the reference case assessment at the time (1998) of the WC-OMP-1999 testing, which assume future catches equal to those subsequently made (Figure 1). These are compared with the intervals that follow if identical assessment methodology is applied taking account of the further monitoring data that became available since 1998. For this reason, the TAC was first held fixed for a year, and then phased down over a period of three years (later this phase-down was extended to a fourth year). Although the OMP would have reacted in time, given its feedback nature, and in due course provided a recommendation of a (fairly substantial) TAC reduction, this option was considered inferior to a smoother phased decrease in the TAC. This was an interim arrangement pending agreement on a fully species-disaggregated assessment to serve as a basis for a revised OMP that fully distinguished the two hake species; in the meantime, the extent of phase-down was determined by a 20-year average Replacement Yield (RY) computation (i.e. the fixed catch which would result in a biomass in 20 years time equal to that at present) using the best

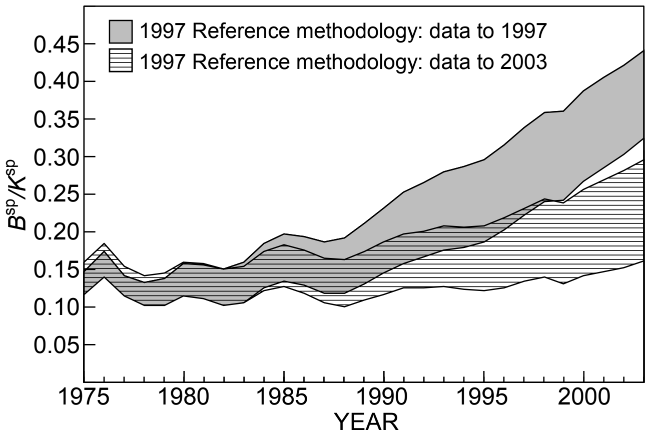

Figure 1: 95% probability intervals for the estimated spawning biomass (expressed as a proportion of the pre-exploitation level) for West Coast hake for the 1997 reference case assessment method applied: (i) to the data available at the time of WC-OMP-1999 testing in 1998 and (ii) to the data available in 2003. The projections beyond 1997 for (i) assume the subsequent catches actually made

assessment model available at that time. Towards the end of this period, given increasingly pessimistic assessments as a consequence of downward trends in resource abundance indices, there was recognition that further reductions would likely be necessary under the revised OMP once it was finalised and adopted.

In November 2006, a new coast- and species-combined OMP (referred to here as OMP-2007) was adopted as the default basis for TAC recommendations for the next four years, starting in 2007. It has as its primary objectives to recover *M. paradoxus* to MSYL over 20 years, given the poor status of this component of the resource that is indicated by the new species-disaggregated assessments (Rademeyer *et al*. 2008), and to increase the CPUE of the offshore trawl fleet by 50% over the next 10 years to enhance the economic viability of the fishery. The development of this OMP is described in detail below.

The Species-combined OMP-2007

The Operating Model/s

Given key uncertainties regarding major considerations of resource status and productivity, a Reference Set (RS) of 24 Operating Models (OMs) spanning these uncertainties, rather than a single OM, was constructed for the South African hake resource. The model structure and results for this RS are described in detail in Rademeyer *et al.* (2008). Essentially, the model is for both the West and South coasts combined (now considered to better correspond to the underlying stock structure) and the two hake species are assessed separately, although within the same model to be able to take account of data (such as commercial catches-at-age), which do not distinguish the two species. The *M. paradoxus* resource is estimated to be currently well below its MSYL, at <10% of its pristine spawning biomass level. The *M. capensis* resource on the other hand is estimated to be above its MSYL, around 50% of pristine. Both resources show a declining trend over the past decade, due principally to poor recruitment over that period.

Generating future data

'Future data' in the form of species-disaggregated CPUE series (one per species) and survey indices of abundance (two per species) are required by the Harvest Control Rule (HCR) to compute a TAC for each of the years in the projection period for the set of candidate OMPs eventually evaluated. These abundance indices (CPUE and surveys) are generated from the OM, assuming the same error structures as in the past, as follows:

(a) Coast-combined species-disaggregated CPUE series are generated from model estimates for mid-year exploitable biomass and catchability coefficients, with multiplicative lognormal errors incorporated where the associated variance is estimated within the OM concerned from past data. When computing the TAC for year y+1, such data are available to year y–1.

(b) Species-disaggregated biomass estimates from the West Coast summer and South Coast autumn surveys are generated from model estimates of mid-year survey biomass. Because the research survey vessel, the RV *Africana*, changed gear in 2003/2004, estimates from that date are adjusted by a multiplicative bias (Rademeyer *et al*. 2008). Lognormal error variance includes the survey sampling variance with the CV set equal to the average historical value, plus survey additional variance (the variability that is not accounted for by sampling variability), estimated within the OM concerned from past data. For the TAC for year y+1, such data are available for year y.

The reason for this difference in periods for which data are available is that recommendations for a TAC, which applies over a calendar year (y+1), are required by October of the preceding year (y). By that time the results of the surveys conducted during year y will be available, but not for CPUE which pertains to the full calendar year y. Thus, care is taken in developing and testing the OMP that only data that would actually be available at the time a TAC recommendation is required are used.

Furthermore, in order to project the resource biomass trajectory forward, the TAC needs to be disaggregated by species and by fleet. The OMP is species-disaggregated and hence may compute appropriate TAC values for *M. paradoxus* and *M. capensis* separately. However, given the difficulties that would be encountered in trying to set species-specific hake TACs (fish processed on board for example cannot be easily identified by species), the TAC recommended by the OMP is an overall figure for the two species combined. The OM uses this total TAC value (i.e. the sum of the values for the two species) and re-apportions it between species when projecting forward by assuming a fixed fishing mortality (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 — although some robustness tests do explore sensitivity to this). This fixed ratio is computed as the average over the last three years (2004–2006). Although this

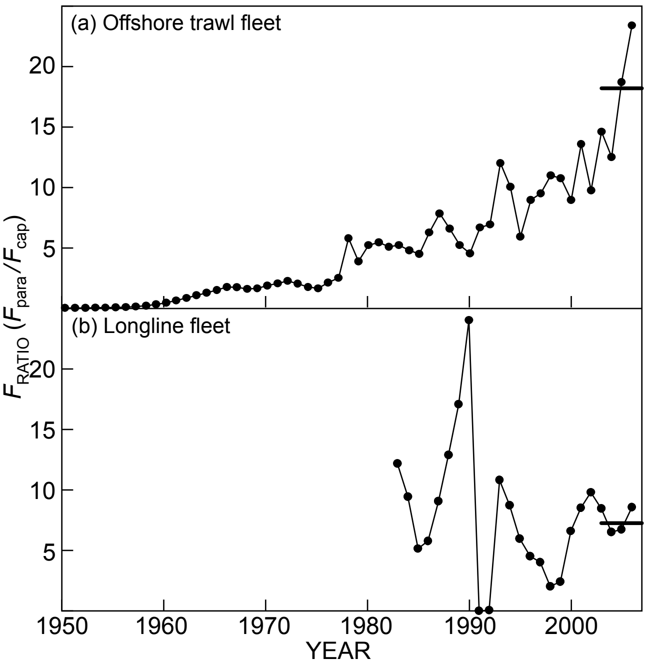

Figure 2: Trends in past F_{ratio} (F_{para}/F_{cap}) for the (a) offshore trawl and (b) longline fleet for the baseline assessment, from Rademeyer *et al*. (2008). The average over the period 2004–2006 is also shown

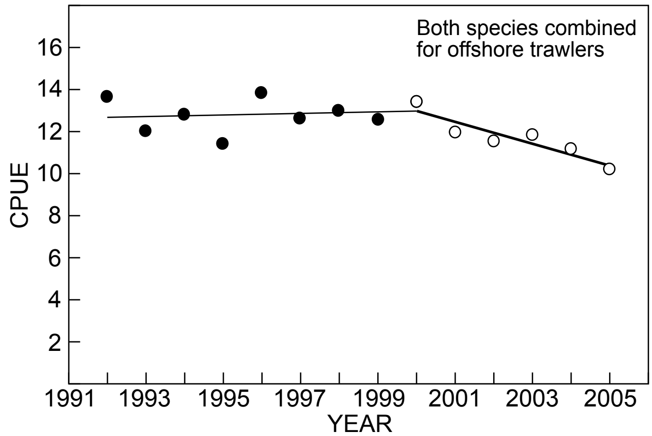

Figure 3: Species-combined GLM-standardised CPUE for offshore trawlers. The lines show two linear regressions: 1992–1999 and 2000–2005

ratio has been very variable (Figure 2), this was nonetheless considered the most realistic way to proceed.

Also, the total TAC recommended by the candidate MP is divided in fixed proportions among the various fleets, with the following values used for the sector allocations in a recent rights re-allocation process for the fishery: offshore trawl — 84%, inshore trawl — 6%, longline — 7% and handline — 3%.

The testing framework applied assumed that the split of the catches by species and fleet is known without error. Although this assumption is not exact in practice, particularly for the handline fishery, it is considered to be reasonably accurate.

Candidate management procedures considered

It was decided to focus on empirical approaches for the reasons elaborated in the Discussion. The candidate OMPs presented here and the OMP eventually selected are therefore model-free, increasing or decreasing the TAC in response to the magnitude of recent trends in CPUE and survey estimates for both species. Furthermore, because of concerns related to the current low level estimated for the *M. paradoxus* biomass, a minimum estimated rate of increase is required for this species before its contribution to the TAC might increase. The details of the associated computations are set out in Appendix 1. The OMP includes a number of free 'control' parameters, the values of which can be adjusted to tune the performance of the OMP to achieve the desired balance in terms of the projected risks and rewards.

Objectives for the fishery

The objectives that were identified for this fishery are essentially threefold:

(1) Improve catch rates quickly in the short-to-medium term: standardised catch rates for offshore trawlers have decreased appreciably since the turn of the century (Figure 3). Given an increasing fuel price, it would become increasingly difficult for this fishery to operate profitably unless catch rates improve substantially.
(2) Increase the *M. paradoxus* biomass level back to the MSYL over 20 years: this component of the hake resource is currently estimated to be at an unacceptably low level, so that both to reduce biological risk and taking cognisance of international norms it needs to achieve substantial recovery in the medium to long term.
(3) After likely large initial cuts to achieve (1), secure greater TAC stability over time.

Performance statistics

The following performance statistics, related to the objectives above, were computed for the candidate MP tested. Projections were conducted over 20 years.

Utilisation-related
- Average catch: $\frac{1}{20}\Sigma C_y$ over 2007–2026 (for both species combined and also for each species separately).
- Annual species-combined catch: C_{2007}, C_{2008}, C_{2009} (note that C_{2006} was fixed by the TAC decision already made in 2005, and simulations assumed that this catch would be landed).

Resource status-related
- 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;
- $CPUE_{2016}/CPUE_{2003–2005}$: the expected change in species-combined offshore trawl CPUE in 10 years' time compared with the average over the recent three years data for the offshore trawl fleet. (An average was used because of suspicions that low values in 2005 might to some extent reflect an appreciable downward fluctuation in catchability more than abundance.)

TAC variability

- The average annual variation (AAV) in catch:

$$AAV = \frac{1}{21}\sum_{y=2007}^{2027}\left|C_y - C_{y-1}\right| / C_{y-1}$$

In addition, time trajectories (both worm plots and probability envelopes) were plotted for certain outputs from the projections, such as C_y and B_y^{sp}.

Robustness tests

The RS of OMs for the South African *M. paradoxus* and *M. capensis* resources (Rademeyer *et al*. 2008) is considered to reflect the current 'best' representation of the actual dynamics for these two resources and the associated major uncertainties. There are, however, some further uncertainties (in the data as well as in some of the assumptions made in the RS) that need to be taken into account when testing the performance of candidate OMPs. The performance of each candidate OMP was thus also assessed using a number of robustness tests to further ensure that the final choice of an OMP is robust to a full range of uncertainties related to both resource dynamics and future data. A series of robustness tests were developed from discussions in the SWG responsible for providing scientific advice for the management of this resource. The full list of robustness tests considered is given in Table 2. These include scenarios with different assumptions concerning discards and past catch series, biological information (including natural mortality, recruitment, maturity-at-age), changes in carrying capacity, current status of the resources and future data.

In the process of development of the revised OMP, initially the resource was projected forward under a constant catch for a fixed period of time for each of the 28 different robustness tests initially identified (Rademeyer and Butterworth 2006). Performance statistics were compared, and it was agreed by the SWG given pressures of time[3] to discontinue tests for a subset of the original 28 that provided results very similar to those of the RS. Further along in the development process, six robustness tests were identified as being either ones of immediate interest related to RS selection, or which had suggested appreciable sensitivity in previous tests. These were:

1. 'SR1': The assumed variance σ_R of variability about the stock-recruitment curve is fixed to 0.25 throughout (i.e. the estimates of recruitment strength for more recent cohorts are not shrunk further towards the stock-recruitment function expectation) in the assessment scenarios considered for the RS. This sensitivity was originally included in the RS; however, further data showed that the large recent recruitments suggested by such computations were less plausible.
2. 'Decr in *K*': In the RS, below average estimated recruitment for *M. capensis* throughout most of the 1990s and the early 2000s suggested a possible systematic deviation below the stock-recruitment curve (see Figure 8 in Rademeyer *et al*. 2008). To better reflect this reduced *M. capensis* recruitment (and continue this into the future), the carrying capacity for *M. capensis* is reduced by 20% from 1992 onwards.
3. 'A1b — disc1': Discarding for both inshore and offshore trawl fleets is modelled by increasing in commercial selectivity by 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 (to discarding as well as to 'theft' by predators) from longlines is also included by doubling the fishing mortality from this fleet. All discarding components are assumed to occur from the beginning of the fishery to the present but are not carried through to the projections. This robustness test was included as an extreme case to see if the OMP would react positively to a decrease in discarding in the future, by increasing catches compared with the RS.
4. 'A7b — Ricker forced': Instead of the Beverton-Holt stock-recruit relationship used in the RS, the stock-recruit relationship is of the Ricker form; this could reflect the possibility that cannibalism plays an appreciable role in the dynamics. Furthermore, the stock-recruit curve for each species is constrained so that maximum recruitment occurs when the spawning biomass is at 45% of the pristine level to avoid the possibility of estimated values corresponding to extreme values of MSYL.
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 with 0.25 for the RS). Although the assessments yield the lesser value, this is low compared with levels of and variability typical for other groundfish, and may reflect 'smearing out' of real fluctuations through inadequate methods to estimate catches-at-age (e.g. aggregating catches-at-length over sex when somatic growth rates are sex dependent).
6. 'B8 — decr *K* in future': The carrying capacity *K* for both species is assumed to decrease linearly by 30%, starting in 2007, to reach the reduced level in 2011. This is to ensure that the OMP adopted is robust to a decrease in carrying capacity that could arise from environmental changes for example.

Results

For each candidate OMP, 10 replicates of each of the 24 RS cases (i.e. a total of 240 simulations) were projected over a 20-year period into the future. The different replicates represent alternative plausible future 'states of nature' that are compatible with the available data. These different replicates vary due to stochastic effects — both recruitment variability and observation error added to future CPUE and survey abundance indices. Each of the 24 RS cases was equally weighted. Ideally more than 10 replicates per case would have been run, but computing time limitations precluded this; in any case, however, the primary concern was to capture uncertainty among rather than within the cases.

Although a large number of candidate OMPs were investigated during the development of OMP-2007, only five are presented here for illustrative purposes. These candidate MPs illustrate the two key trade-offs that faced stakeholders in making a final choice:

[3] MCM management required the OMP to be completed by October 2006 so as to be available for use in providing a hake recommendation for 2007

Table 2: List of robustness tests used

		I. Different assumptions about discards and catch series
1	A1a — disc1	Discarding by offshore and inshore trawlers modelled as increase in commercial selectivity of 0.2 for ages 1 and 2 for *M. capensis* and *M. paradoxus*, in the past only
2	A1b — disc2	As A1a above, but loss of fish from longlines also included by doubling *F* from this fleet in the past only
3	A1c — disc3	As A1a above, but from 1996 onwards, discarding of age 3 as well, in the past only
4	B3a — disc1	Past and future discarding by offshore and inshore fleets only, as in A1a
5	B3b — disc2	Past and future discarding by offshore and inshore fleets, as well as longline fleet, as in A1b
6	B3c — disc3	Past and future discarding by offshore and inshore fleets only, as in A1c
7	A2 — SC unrep catches	Includes small unreported catches from the South Coast offshore fleet from 1917 to 1967
8	A11 — line catches	Handline catches brought down from 5 941 t to 2 500 t in 2003 and from 6 888 t to 1 600 t in 2004
		II. Different assumptions about biological information
9	A5a — M2	Upper bounds on natural mortality of 1.0 y^{-1} and 0.3 y^{-1} for ages 2 and 5/5+ respectively
10	A5b — M3	Upper bounds on natural mortality estimates of 0.5 y^{-1} for both ages 2 and 5/5+
11	A7 — Ricker-like	Ricker-like stock recruitment relationship forced for *M. paradoxus.*
12	A9a — dens dep mat	Proportion of age 3 fish that are mature is density dependent
13	A9b — mat=3	3+ maturity (instead of 4+)
14	A10a — size-dep spawning	Size-dependent spawning, from age-dependent fecundity index
15	A10d — mat = 7	7+ maturity (instead of 4+)
		III. Others
16	A3 — σ_R=0.4	Variability for stock-recruitment fluctuations in the past is increased from σ_R=0.25 in the RS to σ_R=0.4. For the projections, σ_R is kept at 0.25
17	B7 — fut σ_R=0.4	In conjunction with increased variability for stock-recruitment fluctuations in the past, future variability also increased (σ_R=0.4)
18	A4 — decr *K* in past	Carrying capacity of both species assumed to have decreased linearly by 30% over the 1980 to 2000 period
19	A8a — force depletion	Current (2006) spawning biomass of *M. paradoxus* is forced upwards to 40% of pre-exploitation level, while spawning biomass of *M. capensis* forced downwards to 30% of its pre-exploitation level
20	A8b — force depletion	Current spawning biomass of *M. paradoxus* is forced upwards to 30% of pre-exploitation level
21	A8c — force depletion	Current spawning biomass of *M. capensis* is forced downwards to 30% of pre-exploitation level
22	A8d — force depletion	Current spawning biomass of *M. capensis* is forced downwards to 20% of pre-exploitation level
23	A8e — force depletion	Current spawning biomasses of both species forced to 30% of pre-exploitation levels
24	A8f — force depletion	Current spawning biomass of *M. capensis* is forced downwards to 20% of pre-exploitation level and the steepness parameter for this species is fixed at 0.7
25	A12 — diff off sel	Decrease in offshore trawlers selectivity of small *M. paradoxus* fish pre-1978
26	B4a — cal factor=0.6	Calibration factor between *Africana* with old gear and *Africana* with new gear for *M. capensis* is decreased from 0.8 to 0.6
27	B4b — cal factor=0.9	Calibration factor between *Africana* with old gear and *Africana* with new gear for *M. capensis* is increased from 0.8 to 0.9
		IV. Changes in the future
28	B1 — no fut surv	No survey biomass estimates in the future.
29	B2 — CPUE trend	Undetected upward trend in catching efficiency of 2% per annum in the future
30	B5a — F_{ratio} decr	F_{ratio} for offshore fleet decreased by 30% in projections to model increase in *M. capensis* catches
31	B5b — F_{ratio} incr	F_{ratio} for offshore fleet increased by 30% in projections to model decrease in *M. capensis* catches
32	B6 — ll sel	Increase in selectivity of longline fleet on ages 4 and 5 in the future
33	B8 — decr *K* in future	The carrying capacity for both species assumed to decrease linearly by 30%, starting in 2005, to reach the reduced level in 2009

(a) the extent of recovery sought for the *M. paradoxus* population: higher recovery targets mean lesser anticipated TACs (on average), though also higher CPUEs, in the medium term; and

(b) the limitations placed on the extent of the hake TAC change allowed from one year to the next: for the same level of risk of resource reduction, greater limitations will generally mean lesser TACs on average.

OMP1 is tuned to three different recovery targets for *M. paradoxus* (median final spawning biomass depletions in 2027 of 15%, 20% and 25% of the pristine level — referred to as $OMP1_{15\%}$, $OMP1_{20\%}$ and $OMP1_{25\%}$ respectively). There is a limitation on the maximum allowed interannual TAC change for OMP1 of 10%. For OMP6 and OMP7, only the 20% median recovery tuning for *M. paradoxus* is shown. Both these last two candidate MPs include a fixed three-year phase-down of 7.5% per annum. After the three years, while both the maximum increase and decrease in TAC are fixed to 5% per annum for OMP6, the maximum annual decrease in TAC for OMP7 differs through dependence on the recent average CPUE relative to its 2002–2004 average level (see Equation App.1.5). This is so that TAC decrease proportions are kept low unless CPUE falls below some threshold level, following which greater drops (up to 15% in this case) may occur in order to reverse adverse resource abundance trends. Results from a constant catch harvesting strategy (tuned to a 20% median recovery target for *M. paradoxus* across the 240 simulations) are also presented for comparative purposes. The control parameter values for each of these candidate MPs are given in Table App.1.1.

Table 3: Summary of performance statistics for a series of candidate MPs (defined in the text; 'const catch' = constant catch) for the RS. For each statistic, the median (first row) and 90% probability intervals (second and third rows) are shown. Control parameter values of each candidate were tuned to yield values shown in bold

	$OMP1_{15\%}$	$OMP1_{20\%}$	$OMP1_{25\%}$	OMP6	OMP7	Const catch
			Species combined			
avTAC	129.52	125.19	120.78	122.93	123.89	124.50
	113.22	108.82	104.80	103.54	98.43	124.50
	144.51	139.43	134.32	137.93	139.80	124.50
AAV	5.10	5.03	4.92	4.01	4.10	0.85
	3.35	3.45	3.31	3.34	3.23	0.85
	7.01	6.85	6.73	4.93	5.95	0.85
$CPUE_{2016}/CPUE_{2003–2005}$	1.53	1.57	1.60	1.53	1.50	1.42
	1.24	1.26	1.30	1.17	1.21	0.88
	1.91	1.95	1.99	1.91	1.91	1.92
			M. paradoxus			
B_{2027}/K	**0.150**	**0.200**	**0.250**	**0.200**	**0.200**	**0.200**
	0.069	0.121	0.167	0.092	0.111	0.000
	0.259	0.313	0.372	0.325	0.396	0.351
B_{2027}/B_{2007}	2.13	2.88	3.79	3.03	3.05	2.99
	1.21	1.96	2.54	1.74	1.82	0.00
	3.82	4.86	5.98	5.39	6.68	6.97
			M. capensis			
B_{2027}/K	0.67	0.70	0.72	0.70	0.72	0.69
	0.56	0.59	0.61	0.56	0.59	0.04
	0.82	0.85	0.87	0.86	0.86	0.87
B_{2027}/B_{2007}	1.42	1.49	1.54	1.49	1.51	1.45
	1.17	1.22	1.26	1.17	1.24	0.11
	1.70	1.78	1.84	1.78	1.81	1.82

Key comparative results for the variety of candidate OMPs considered may be found in Table 3 and Figure 4 for the RS. Figure 5 shows trajectory envelopes of resource abundance, CPUE, catch and TAC change for an application of each of the candidate OMPs when tuned to the 20% median recovery target for *M. paradoxus* for the RS.

For the same *M. paradoxus* recovery tuning, OMP6 and OMP7 result in lower average catches compared to OMP1 (Figure 4a), this being the trade-off for providing greater TAC stability (Figure 4b). Although under the constant catch strategy comparatively good average catches are obtained, this strategy results in the extinction of the *M. paradoxus* resource in some instances[4] (Figure 4d). Furthermore, from the lower 90% probability interval for the *M. paradoxus* spawning biomass, it is clear that, although the median recovery is the same, the risk of the resource falling to an unacceptably low level is much greater when a fixed 5% maximum interannual change in TAC is enforced (OMP6) or there is no change at all (constant catch strategy) (Figures 4d, 5).

Comparative results for an application of $OMP1_{20\%}$ to a series of robustness tests are shown in Figure 6. Because of time constraints, only four of the corresponding 24 RS scenarios were run for those tests that involve changes to assumptions regarding past data and therefore refitting of the OM. The four scenarios include (see Rademeyer *et al.* 2008 for more details): (i) using the central of the three assumptions for the timing of historic change by the offshore trawlers from focusing on *M. capensis* alone to concentrate more on *M. paradoxus* (C1), together with (ii) the two alternative constraint sets for natural mortality (M1 and M4), and with (iii) only two of the options for steepness (H1 — steepness is estimated for both species, and H4 — *M. paradoxus* steepness fixed to 0.8 and *M. capensis* steepness fixed to 0.7). However, in the robustness with a decrease in future carrying capacity (B8 — Decr in *K* in future) for which only future projections are affected, the full 24 scenarios are run.

The four scenarios used for (most of) the robustness tests give a comparatively slightly more optimistic appraisal of the status of the *M. paradoxus* resource than does the full RS. The SR1 robustness test reflects better catches and better *M. paradoxus* recovery than for the RS. Similarly, assuming that the discarding that took place in the past is not continued in the projections (A1b — disc1), results (not surprisingly) in better *M. paradoxus* recovery and future increased catches compared with the RS. With the Ricker stock-recruitment curve (A7b — Ricker), the projected recovery for *M. paradoxus* is good (though note that this reflects in part the lower *K* for Ricker compared with Beverton-Holt fits of OMs); associated expected catches, however, do not increase substantially. As expected, increasing the variability in recruitment from σ_R=0.25 to σ_R=0.4 (σ_R=0.4) results in wider ranges for all statistics; average catches over the projection period for example could drop below 100 000 t. Assuming a decrease in the *M. capensis* carrying capacity in the past (Decr in *K*) does not affect the combined species or *M. paradoxus* results substantially. The robustness test

[4] Naturally, the validity of some assumptions of the projection methodology used would come into question before extinction might occur, but management would in any case seek to avoid the resource dropping to levels where calculations would need to take adjustments to those assumptions into account

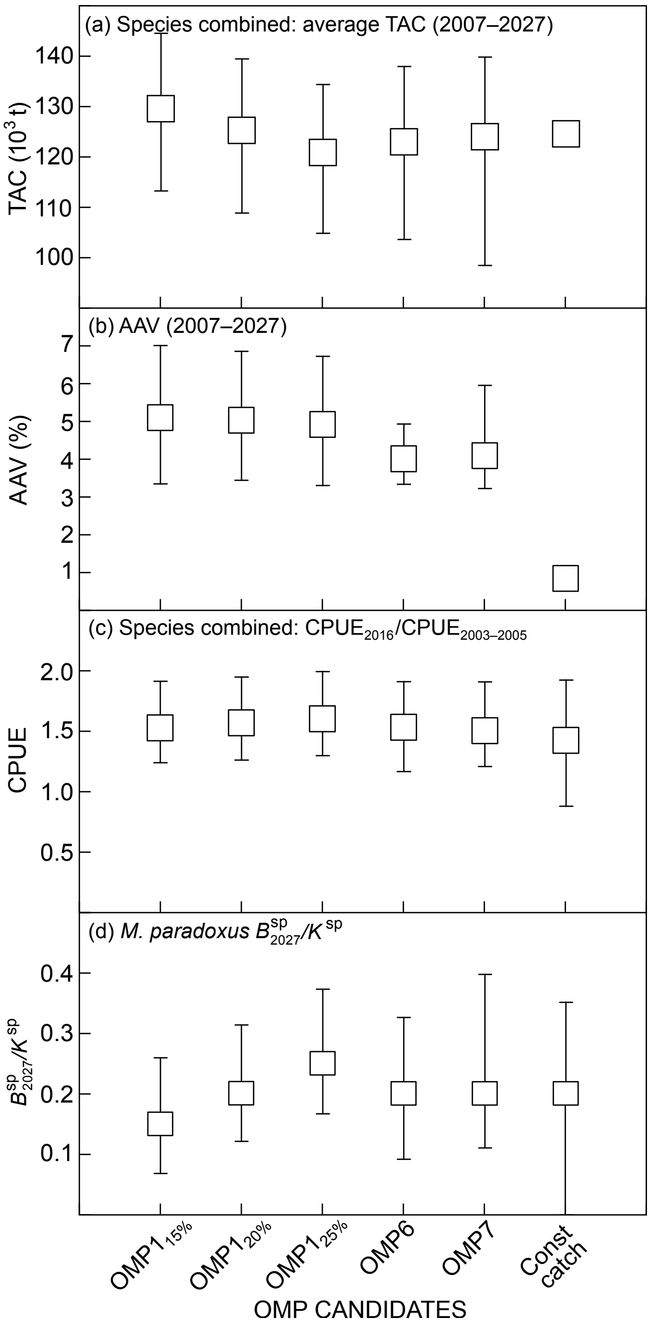

Figure 4: Graphical summary of performance statistics for a set of candidate MPs for the RS. Each panel shows medians together with 90% probability intervals

in which the carrying capacity of both species is decreased in the future (B8 — decr in K in future), however, shows an important drop in predicted average catches, and future CPUE does not increase as much as for the RS.

Discussion

Why select an empirical-based MP?

Age-aggregated model approaches (Fox and Pella-Tomlinson) for model-based OMPs were investigated during the development of the current OMP-2007. However, they failed to outperform the empirical-based candidate OMPs, because they could not mimic the future CPUE and survey data adequately, seemingly because of age/selectivity effects. Indeed, in many projections, the survey trends are flat because they are dominated by younger fish, whereas the CPUE trends are more sensitive to trends in the numbers of older fish. This leads to features in the time-series of abundance indices that an age-aggregated model cannot reproduce. Although an age-structured production model-based OMP would be able to capture such features, this was not considered as the basis for an OMP because of the practical constraints of the very long computing time required for tests.

An empirical-based OMP that included a recruitment index was also investigated, with the intent that by taking more immediate action in response to indications (from the age distribution of survey catches) of recruitment falling above or below past average levels, target recovery levels would be more closely attained, with catches raised or lowered correspondingly and appropriately. However, it was found that any advantage in principle that use of recruitment estimates in setting TACs would appear to provide is offset by the poor precision with which such recruitments can be estimated from survey results.

Furthermore, an empirical-based OMP allowed for an easier acceptance by stake-holders because it was more easily understood.

Final OMP selection

The two major focuses in the selection of the final OMP were (1) the recovery target for *M. paradoxus*, which correlated closely with expected levels of increase in CPUE in the medium term and (2) the interannual TAC variation constraints. A series of candidate OMPs were initially tuned to median final depletions for *M. paradoxus* in 2027 of 15%, 20% and 25% of pristine level. The attention was directed mainly at this species as it is estimated to be in a poor state compared with the *M. capensis* resource that is estimated to be above its MSYL. A median recovery target of 20% was selected. The SWG agreed that a median recovery to 15% in 2027 was insufficient from both resource and CPUE considerations, but that targeting 25% (above the estimated MSYL for this species) might have serious negative economic impacts through large TAC reductions in the short term.

It is evident from the lower 90% probability intervals for the *M. paradoxus* spawning biomass projections (Figure 5) that restricting the interannual change in TAC to 5% (OMP6) leads to greater biological risk, even given a fixed TAC phase-down for three years. In OMP7, the restriction in TAC changes is also 5%, but there is the possibility for the TAC to decrease by as much as 15% in one year, if CPUE results are well below the recent average. Although the risks for the *M. paradoxus* resource are similar for OMP7 compared with OMP1, the industry did not feel comfortable with the possibility (despite the small associated estimated probability of occurrence) of such a decrease in the TAC.

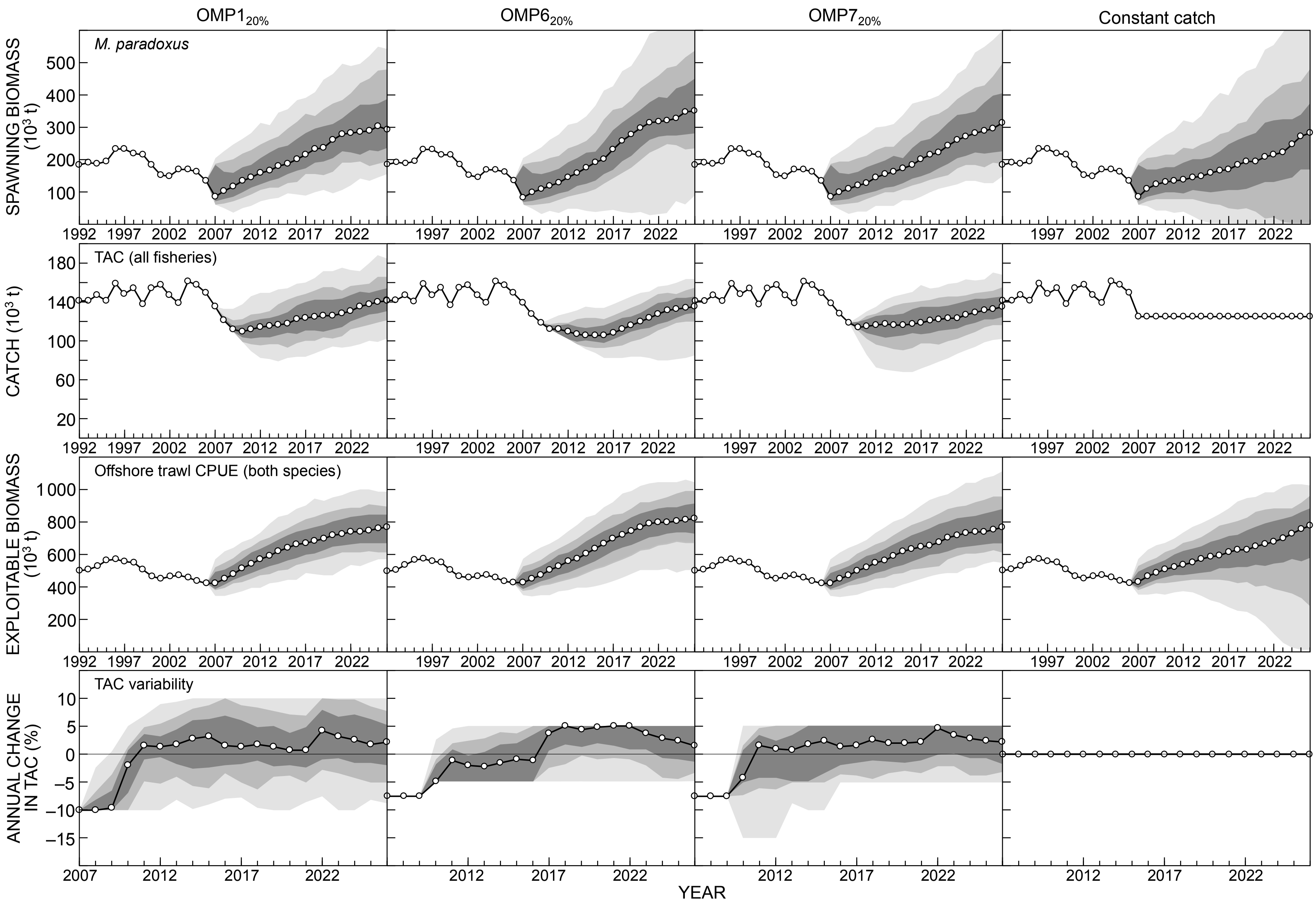

Figure 5: Trajectories of *M. paradoxus* resource abundance, CPUE, catch and variation in catch for an application of OMP1$_{20\%}$, OMP6$_{20\%}$, OMP7$_{20\%}$ and the constant catch strategy to the RS. In each panel, the median, 50%, 75% and 90% probability intervals are shown. Units for species-combined CPUE are those of the exploitable biomass to which it corresponds. For pre-2007, the average spawning biomass and species combined CPUE trajectories of the RS and the actual species-disaggregated CPUE (divided by the estimated *q*) and total catch are also shown

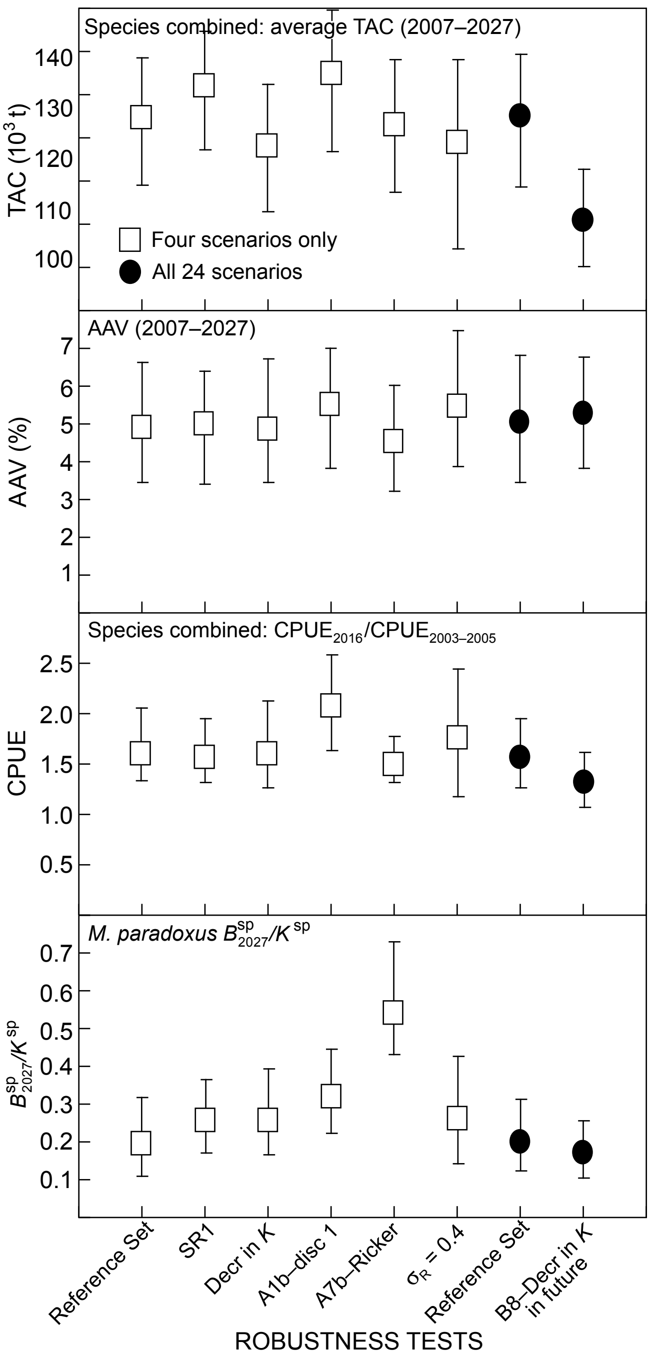

Figure 6: Graphical summary of performance statistics for candidate OMP1$_{20\%}$ for the RS and a series of robustness tests. Each panel shows medians together with 90% probability intervals. The ratios associated with the estimates of K^{sp} are for the present (2006) K^{sp}, i.e. in the case of the 'Decr in *K*' test, including the 20% decrease, and in the case of test B8 before the future decrease in carrying capacity

'Exceptional circumstances'

The intention in designing any OMP is that it can be used on a routine basis to provide scientific management advice, subject (in South Africa) to regular four-yearly reviews. However, occasionally 'exceptional circumstances' can arise which may indicate the need for recommendations to deviate from the outputs from such OMPs, or necessitate bringing the regular review forward. Appendix 2 is a document agreed by MCM Scientific Working Groups to be used for a number of species to specify the procedures governing the identification of such circumstances, and the resultant actions that may follow.

During the development of OMP-2007, a call of such exceptional circumstances was made, as a result of which the RS of OMs was revised. The RS that had initially been used for OMP testing was based on data to 2003. A further two years data became available and, although the survey biomass estimates for both species and the CPUE for *M. paradoxus* were within 90% probability intervals predictions (albeit marginally so in some cases), the 2005 CPUE value for *M. capensis* was appreciably outside the range predicted (Figure 7). The SWG agreed that an exceptional circumstances situation applied, with the original RS deemed to cover an insufficient range of possibilities to be considered as a totally reliable basis for selecting a new OMP. The decision was therefore made to refit the OMs within the RS taking account of these new data before proceeding to the OMP testing and selection phases.

What if the TAC could be disaggregated by species?

Initial OMP trials revealed that the major limitation to finding a suitable procedure that yields higher catches is related to the inability to simultaneously obtain adequate performance in terms of risk to the *M. paradoxus* resource. Furthermore, results reflect a slight drop over time in the utilisation of the *M. capensis* resource (Figure 8) — a characteristic whose desirability might be questionable given the relatively healthy status estimated for this resource, but which is difficult to avoid without exposing the *M. paradoxus* resource to greater risk. The reason underlying this problem appears to be that, while a candidate OMP advocates decreasing the *M. paradoxus* catch, this is not achieved in reality, because the F_{ratio} prescription sees a larger component of *M. paradoxus* in the total catch ultimately achieved than was intended.

Within the constraints of the management system assumed thus far, it appears that it is not possible to simultaneously improve catch levels and guard against risk to the *M. paradoxus* resource. It has been shown that, if the management could adjust the future F_{ratio} achieved each year by controlling the ratio of *M. paradoxus*:*M. capensis* in the deep-water trawl sector (e.g. by broadly regulating the depths at which fishing takes place), substantially higher catches could be achieved.

The overall process

A disappointing aspect of the overall process was the relatively rushed concluding phases that were necessitated to meet the October 2006 deadline for completion. This required reduction of the extent of robustness testing, in particular, compared with initial plans. These plans had left adequate time between OM finalisation and the final deadline for the OMP selection process for robustness testing to have been more thoroughly addressed. However, the target date

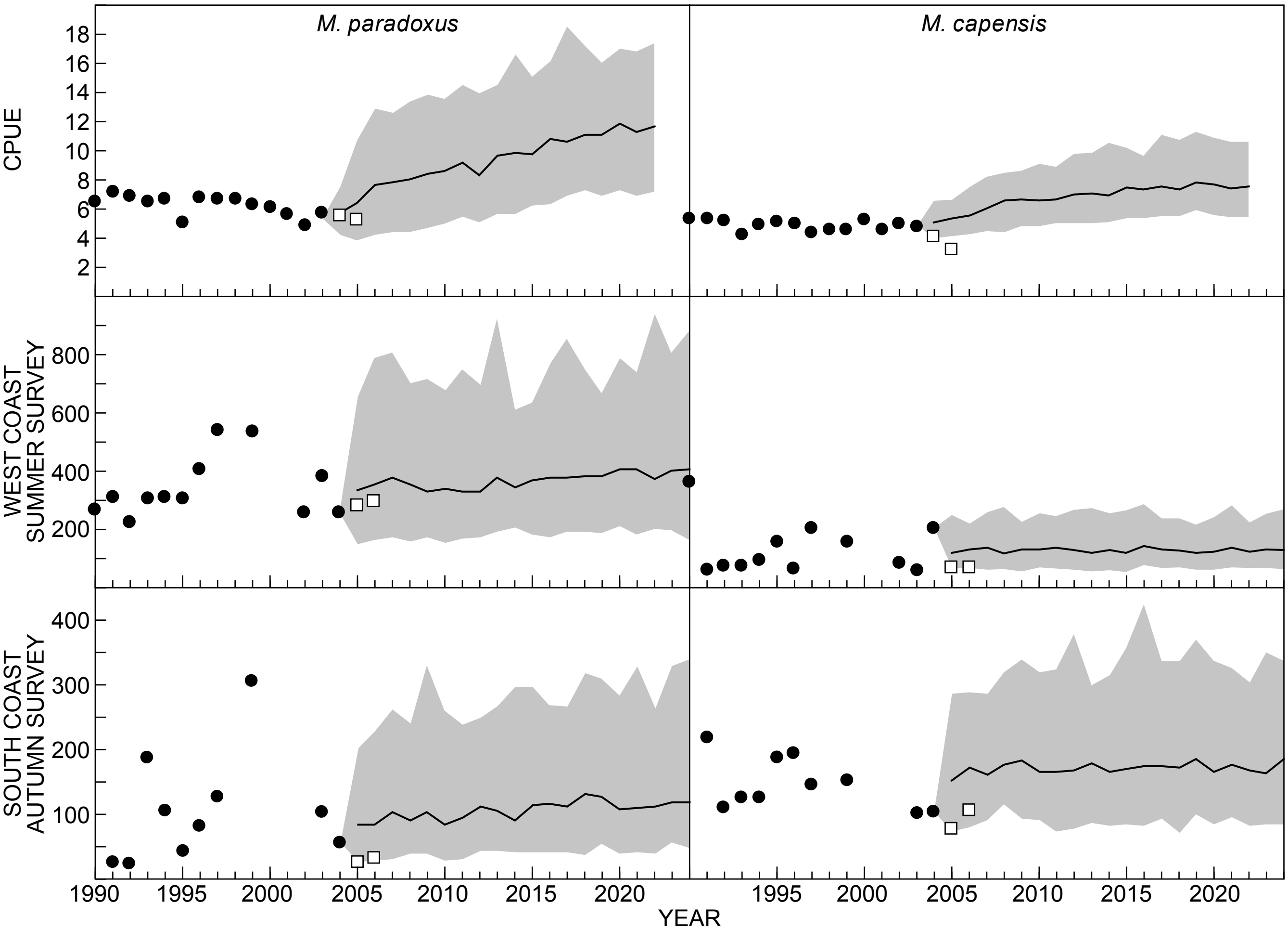

Figure 7: Projections under the original RS (fitted to data up to 2003 — solid circles) compared with the most recent two years' resource abundance index data. The open squares show the new data points. The lines are projected medians under the original RS for an illustrative candidate MP and the shaded areas the corresponding 90% probability intervals (including the uncertainty associated with observation error)

for OM finalisation slipped as a joint consequence of the need to refit the OMs, given additional data, and to secure stake-holder buy-in to the results that industry questioned as indicating a better status for *M. capensis* than seemed compatible with their perceptions of a recent appreciable downturn in CPUE.

The process described above led to the recommendation that $OMP1_{20\%}$ be adopted as OMP-2007, the basis for recommending hake TACs over the 2007–2010 period until the next scheduled major review. Application for 2007 saw the TAC reduced from 150 000 t to 135 000 t.

Future Focus

Probably the greatest immediate source of concern about this OMP and the OMs that underlie its evaluation and selection relates to the indirect methods (species ratio vs depth relationships estimated from survey results) used to disaggregate the commercial catches by species. These will be re-evaluated once sufficient data from a recently enhanced observer programme to monitor the species composition of the catch on board trawlers become available.

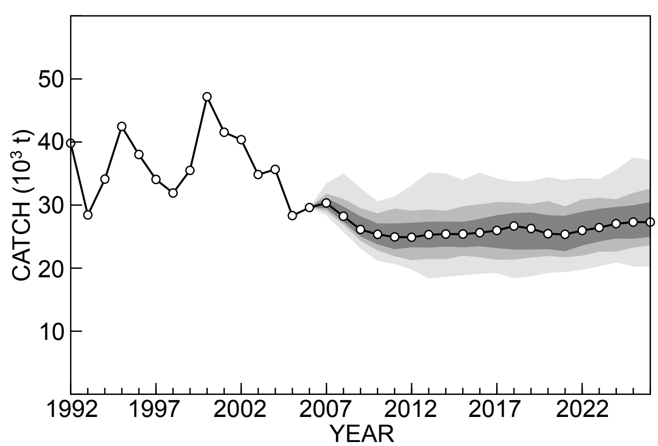

Figure 8: Projected catch of *M. capensis* under $OMP1_{20\%}$

Acknowledgements — The procedures set out in Appendix 2 had their origins in similar specifications developed in the Scientific Committee on the Commission for the Conservation of the Southern Bluefin Tuna; the genesis for these was in turn crafted by Marinelle Basson, Dale Kolody and Tom Polacheck of CSIRO, Australia (Basson *et al*. 2004, Basson and Polacheck 2005). We thank also Dr Rob Leslie and Jean Glazer from MCM for assistance with data, Neil Klaer and Andre Punt for their reviews, and the MCM Demersal Working Group and the BENEFIT Workshops for helpful suggestions, and to MCM for financial support.

References

Andrew PA, Butterworth DS (1987) Is $f_{0.1}$ an appropriate harvesting strategy for the Cape hakes? In: Payne AIL, Gulland JA, Brink KH (eds) *The Benguela and Comparable Ecosystems*. *South African Journal of Marine Science* **5**: 925–935

Basson M, Polacheck T, Kolody D (2004) Discussion of scientific issues related to metarules and the implementations of a management procedure for southern bluefin tuna. Unpublished document, Committee on the Commission for the Conservation of the Southern Bluefin Tuna **CCSBT-MP/0404/05**

Basson M, Polacheck T (2005) Metarules and implementation: Notes for discussion of the scientific issues. Unpublished document, Committee on the Commission for the Conservation of the Southern Bluefin Tuna **CCSBT-MP/0505/05**

Brandão A, Rademeyer RA, Butterworth DS (2004) First attempt to obtain a multiplicative bias calibration factor between the *Africana* with the old and the new gear. Unpublished report, Marine and Coastal Management, South Africa **WG/11/04/D:H:26**

Butterworth DS, Andrew PA (1984) Dynamic catch-effort models for the hake stocks in ICSEAF Divisions 1.3–2.2. *Collection of Scientific Papers of the International Commission for the Southeast Atlantic Fisheries* **11**(1): 29–58

Butterworth DS, Punt AE (1999) Experiences in the evaluation and implementation of Management Procedures. *ICES Journal of Marine Science* **56**: 985–998

Geromont HF, Butterworth DS (1997) Assessments of West Coast hake using an age-structured production model to provide a basis for simulation testing of a revised Operational Management Procedure. Unpublished report, Marine and Coastal Management, South Africa **WG/08/97/D:H:35**

Geromont HF, Butterworth DS (1998) Initial evaluation of a range of possible management procedures for west coast hake. Unpublished report, Marine and Coastal Management, South Africa **WG/02/98/D:H:18**

Geromont HF, Butterworth DS (1999) A fleet-disaggregated age-structured production model applied to the south coast hake fishery for *Merluccius capensis* and *M. paradoxus*. Unpublished report, Marine and Coastal Management, South Africa **WG/05/99/D:H:01**

Geromont HF, Butterworth DS (2000) Candidate management procedures robustness trials for south coast *Merluccius capensis* east of 20ºE. Unpublished report, Marine and Coastal Management, South Africa **WG/06/00/D:H:12**

Geromont HF, Glazer JP (1998) The 1998 Revised Management Procedure for the South African west coast hake resource. Unpublished report, Marine and Coastal Management, South Africa **WG/11/98/D:H:49**

MCM (1991) Recommendation to the Sea Fishery Advisory Committee for a revised hake TAC for 1991 and provisional TAC for 1992. Unpublished report, Marine and Coastal Management, South Africa **WG/06/91/D:H:13**

MCM (1992) Recommendation to the Sea Fishery Advisory Committee for a revised hake TAC for 1992 and provisional TAC for 1993. Unpublished report, Marine and Coastal Management, South Africa **WG/05/92/D:H:16**

MCM (1993) Recommendation to the Sea Fishery Advisory Committee for a revised hake TAC for 1993 and provisional TAC for 1994. Unpublished report, Marine and Coastal Management, South Africa **WG/05/93/D:H:14**

MCM (1994) Recommendation to the Sea Fishery Advisory Committee for a revised hake TAC for 1994 and provisional TAC for 1995. Unpublished report, Marine and Coastal Management, South Africa **WG/05/94/D:H:9**

MCM (1995) Recommendation to the Sea Fishery Advisory Committee for a revised hake TAC for 1995 and provisional TAC for 1996. Unpublished report, Marine and Coastal Management, South Africa **WG/05/95/D:H:10**

MCM (1996) Recommendation to the Sea Fishery Advisory Committee for a revised hake TAC for 1996 and provisional TAC for 1997. Unpublished report, Marine and Coastal Management, South Africa **WG/05/96/D:H:7**

MCM (1997a) Recommendation to the Sea Fishery Advisory Committee for a revised hake TAC for 1997. Unpublished report, Marine and Coastal Management, South Africa **WG/05/97/D:H:15**

MCM (1997b) Hake TAC recommendation for 1998. Unpublished report, Marine and Coastal Management, South Africa **WG/10/97/D:H:49**

MCM (1998) Recommendation for the finalization of the provisional hake TAC for 1999. Unpublished report, Marine and Coastal Management, South Africa **WG/07/98/D:H:39**

MCM (1999) Recommendation to the Consultative Advisory Forum for the hake TAC for the year 2000. Unpublished report, Marine and Coastal Management, South Africa **WG/05/99/D:H:8**

MCM (2000) Recommendation to the Consultative Advisory Forum for the hake TAC for the year 2001. Unpublished report, Marine and Coastal Management, South Africa **WG/08/00/D:H:19**

MCM (2001) Recommendation to the Consultative Advisory Forum for the hake TAC for the year 2002. Unpublished report, Marine and Coastal Management, South Africa **WG/08/01/D:H:23**

MCM (2002) Recommendation on the hake TAC for 2003. Unpublished report, Marine and Coastal Management, South Africa **WG/11/02/D:H:27**

MCM (2003) Recommendation on the hake TAC for 2004. Unpublished report, Marine and Coastal Management, South Africa **WG/11/03/D:H:26**

MCM (2004) Recommendation on the hake TAC for 2005. Unpublished report, Marine and Coastal Management, South Africa **WG/11/04/D:H:31**

MCM (2005) Recommendation on the hake TAC for 2006. Unpublished report, Marine and Coastal Management, South Africa **WG/11/05/D:H:50**

MCM (2006) Recommendation on the hake TAC for 2007. Unpublished report, Marine and Coastal Management, South Africa **WG/10/06/D:H:48**

Punt AE (1992) Management procedures for Cape hakes and baleen whale resources. PhD thesis, University of Cape Town, South Africa

Punt AE (1993) The comparative performance of production-model and *ad hoc* tuned VPA based feedback-control management procedures for the stock of Cape hakes off the west coast of South Africa. In: Smith SJ, Hunt JJ, Rivard D (eds) *Risk Evaluation and Biological Reference Points for Fisheries Management. Canadian Special Publication of Fisheries and Aquatic Sciences* **120**: 283–299

Rademeyer RA, Butterworth DS (2006) Management Procedure robustness tests for the South African *Merluccius paradoxus* and *M. capensis* resources under a constant catch scenario. Unpublished report, Marine and Coastal Management, South Africa **WG/03/06/D:H:6**

Rademeyer RA, Butterworth DS, Plagányi ÉE (2008) Assessment of the South African hake resource taking its two-species nature into account. *African Journal of Marine Science* **30**(2): 263–290

Smith ADM, Sainsbury KJ, Stevens RA (1999) Implementing effective fisheries management systems – management strategy evaluation and the Australian partnership approach. *ICES Journal of Marine Science* **56**: 967–979

Appendix 1: The 2007 Species-combined OMP Specifications (OMP-2007)

The formula for computing the TAC recommendation is as follows:

$$TAC_y = C_y^{para} + C_y^{cap} \quad \text{(App.1.1)}$$

with

$$C_y^{spp} = C_{y-1}^{*spp}\left[1+\lambda_y\left(s_y^{spp} - \text{target}^{spp}\right)\right] \quad \text{if } y \le 2006+Y$$

and

$$C_y^{spp} = C_{y-1}^{*spp}\left[1+\lambda_y\left(s_y^{spp}\right)\right] \quad \text{if } y > 2006+Y \quad \text{(App.1.2)}$$

where:

TAC_y is the total TAC recommended for year y,
C_y^{spp} is the intended species-specific TAC for year y (spp = cap or para),
C_{y-1}^{*spp} is the achieved catch[5] of species spp in year y–1,
λ_y is a year-dependent tuning parameter,
Y is a tuning parameter,
target^{spp} is the target rate of increase for species spp, 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 ($I_y^{surv1,spp}$) and South Coast autumn survey ($I_y^{surv2,spp}$) indices:

- linearly regress $\ln I_y^{CPUE,spp}$ vs year y' for $y' = y - p - 1$ 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 $y' = y - p$ 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. 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 would be 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. Note also that surveys carried out using the old gear are rendered comparable to those carried out using the new gear by multiplying them by a species specific calibration factor (0.95 for *M. paradoxus* and 0.8 for *M. capensis*; Rademeyer *et al*. 2008).

Then a weighted average of the slopes is taken to provide a composite value:

$$s_y^{spp} = \left(\frac{s_y^{CPUE,spp}}{2} + \frac{s_y^{surv1,spp}}{4} + \frac{s_y^{surv2,spp}}{4}\right) \quad \text{(App.1.3)}$$

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 in Figure App.1.1:

$$\text{if } y < 2006 + y_{join}: \quad \lambda_y = \begin{cases} \left(\dfrac{\delta_3 - \delta_1}{y_{join}}\right)(y - 2006) + \delta_1 & \text{if } s_y > 0 \\ \left(\dfrac{\delta_3 - \delta_2}{y_{join}}\right)(y - 2006) + \delta_2 & \text{if } s_y \le 0 \end{cases} \quad \text{(App.1.4)}$$

if $y \ge 2006 + y_{join}$: $\lambda_y = \delta_3$.

TAC change constraints

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

if $TAC_y > (1 + \alpha) \times TAC_{y-1}$ then $TAC_y = (1 + \alpha) \times TAC_{y-1}$.

The maximum decrease allowed for the TAC in year y (D_y^{max}) depends on the recent average CPUE as at year y (I_y) expressed relative to its 2002–2004 average level, the underlying rationale being that TAC decrease proportions are kept low unless CPUE falls below some threshold level, following which greater drops are allowed to attempt to reverse adverse resource abundance trends (see Figure App.1.2):

$$D_y^{max} = \begin{cases} D_1 & \text{if } I_y > L_1 \\ D_1 + \dfrac{(D_2 - D_1)}{(L_1 - L_2)^2}(L_1 - I_y)^2 & \text{if } L_1 \ge I_y \ge L_2 \\ D_2 & \text{if } I_y < L_2 \end{cases} \quad \text{(App.1.5)}$$

where:

D_1, D_2, L_1 and L_2 are constants, and $I_y = \dfrac{\sum_{i=y-2}^{y-1} CPUE_i / 2}{\sum_{i=2002}^{2004} CPUE_i / 3}$

This maximum decrease is computed for both species and the maximum of the two is applied when computing the TAC.

The control parameter values for each of the candidate MPs referred to in the main text are given in Table App.1.1.

[5] Implemented by applying the species ratio of the catch in year y–2 to the TAC for year y–1, as the species ratio for year y–1 would not yet be known by the time at which a recommendation for the TAC for year y would be required

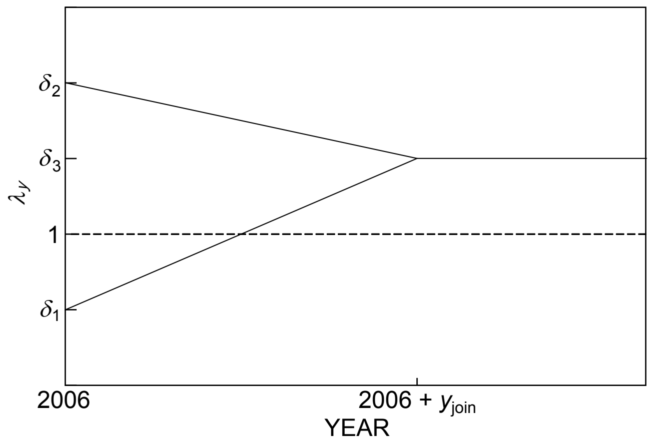

Figure App.1.1: Dependence of the catch control law tuning parameter λ_y on year y

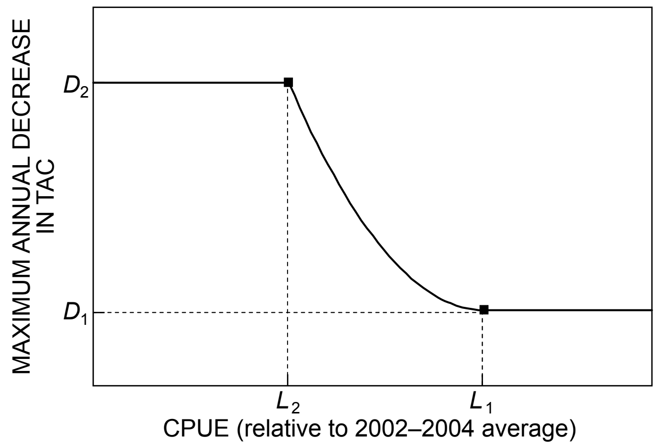

Figure App.1.2: Relationship of the maximum annual decrease in TAC to CPUE relative to 2002–2004 average

Table App.1.1: Control parameters for each candidate OMP are referenced in the main text. The selected OMP-2007 is shown in bold. 'Fixed phase-down' indicates an initial period of a certain number of years over which the TAC is reduced by a certain percentage irrespective of the values of further monitoring data becoming available during that period

Case	Fixed phase-down	p	δ_1	δ_2	δ_3	y_{join}	$Target^{para}$	$Target^{cap}$	Y	α	D_1	D_2	L_1	L_2
OMP1$_{15\%}$	–	6	0.40	2	1.1	10	0.0183	0	10	10%	10%	–	–	–
OMP1$_{20\%}$	**–**	**6**	**0.40**	**2**	**1.1**	**10**	**0.0240**	**0**	**15**	**10%**	**10%**	–	–	–
OMP1$_{25\%}$	–	6	0.40	2	1.1	10	0.0303	0	20	10%	10%	–	–	–
OMP6	3 × 7.5%	6	0.50	4	1.1	10	0.0620	0	10	5%	5%	–	–	–
OMP7	3 × 7.5%	6	0.50	4	1.1	10	0.0380	0	10	5%	5%	15%	0.6	0.8
Const catch	Constant annual catch of 124 000 t													

Appendix 2: Procedures for Deviating from OMP Output for the Recommendation for a TAC, and for Initiating an OMP Review

Preamble

Currently, scientific recommendations for management controls (e.g. total allowable catch [TAC] or total allowable effort [TAE]) for South Africa's major fisheries are provided by Operational Management Procedures (OMPs). These are pre-agreed formulae for computing these control levels (usually annually), based on pre-agreed resource monitoring data inputs. This combination of formulae and data will have been simulation tested to ensure anticipated performance that is adequately robust given inevitable scientific uncertainties about data and models of the resource dynamics and fishery. (Typically these tests are divided into a core set (or Reference Set) of Operating Models (OMs) for the underlying dynamics, which cover the more plausible scenarios that have quantitatively important implications, and Robustness tests that involve operating models for scenarios considered relatively less plausible or important.)

The intention is that these OMPs be used on a routine basis to provide such scientific management advice, subject to regular four-yearly reviews. However, occasionally 'exceptional circumstances' can arise which may indicate the need for recommendations to deviate from the outputs from such OMPs, or necessitate bringing the regular review forward. The purpose of this document is to specify the procedures governing the identification of such circumstances, and the resultant actions that may follow.

This document is constructed as a template that applies generally to OMPs, whatever the fishery to which they apply, but it does also include sections which are fishery-specific. Places where entries pertinent to a specific OMP are to be made are indicated by [ ][6]. These entries, and possible additions to them, require review and finalisation by the relevant MCM Scientific Working Group in parallel with adoption of a new/revised OMP for a specific fishery.

Note that, purely for simplicity of expression, the text that follows is written as if a global TAC were the only management recommendation output by an OMP. However, the provisions following should be understood to apply equally should global effort, either on its own or in conjunction with a global TAC, be the output, and similarly if either or both of such measures are disaggregated by space or time or both.

When an OMP is adopted, the Working Group concerned will ratify a document that contains a complete specification of the formulae used by the OMP to compute recommended management control levels, and of the data to be input. The latter may, as appropriate, contain details concerning pre-processing of such data: for example, the specification of a GLM to standardise a resource abundance index for the effects of covariates other than the year factor related to the abundance trend.

On a number of occasions below, the text requires judgements to be made of whether an effect is 'appreciable' (for example, whether an abundance survey result is *appreciably* outside the range predicted in the simulation tests used in selecting the OMP). Such judgements are the province of the Scientific Working Group concerned.

Simulation tests of OMPs assume, at basis, that future resource monitoring data required for input into the OMP will indeed become available as assumed, and that OMP recommendations will be implemented (and in an effective manner). Specific OMPs may include (simulation tested) rules for dealing with the absence of (some) such data, and to indicate adjustments perhaps necessary if implementation differs from the scientific recommendation arising from a previous application of the OMP. To the extent that circumstances arise that are not covered by such rules, and are adjudged by the Working Group to have a likely appreciable impact on the performance of the OMP that would otherwise have been anticipated, the Working Group may consider such an instance of exceptional circumstances as conceived in the text following.

Metarule process

Metarules can be thought of as 'rules' that pre-specify what should happen in unlikely, exceptional circumstances when application of the TAC generated by the OMP is considered to be highly risky or highly inappropriate. Metarules are not a mechanism for making small adjustments, or 'tinkering' with the TAC from the OMP. It is difficult to provide firm definitions of, and to be sure of including all possible, exceptional circumstances. Instead, a process for determining whether exceptional circumstances exist is described below (see Figure App.2.1). The need for invoking a metarule should be evaluated by the MCM [Demersal] Working Group (hereafter indicated by WG), but only provided that appropriate supporting information is presented so that it can be reviewed at a WG meeting.

Description of process to determine whether exceptional circumstances exist

While the broad circumstances that may invoke the metarule process can be identified, it is not always possible to pre-specify the data that may trigger a metarule. If a WG member or observer, or MCM management, is to propose an exceptional circumstances review, then such person(s) must outline in writing the reasons why they consider that exceptional circumstances exist, and must either indicate where the data or analyses are to be found supporting the review, or must supply those data or analyses in advance of the WG meeting at which their proposal is to be considered.

Every year the WG will:

- Review population and fishery indicators, and any other relevant data or information on the population, fishery and ecosystem, and conduct a simple routine updated assessment (likely no more than core reference set models used in the OMP testing refitted taking a further year's data into account)
- On the basis of this, determine whether there is evidence for exceptional circumstances

[6] Although this is a general template, the sections in square brackets are hake-specific; different entries would be made in those sections for an OMP for another species

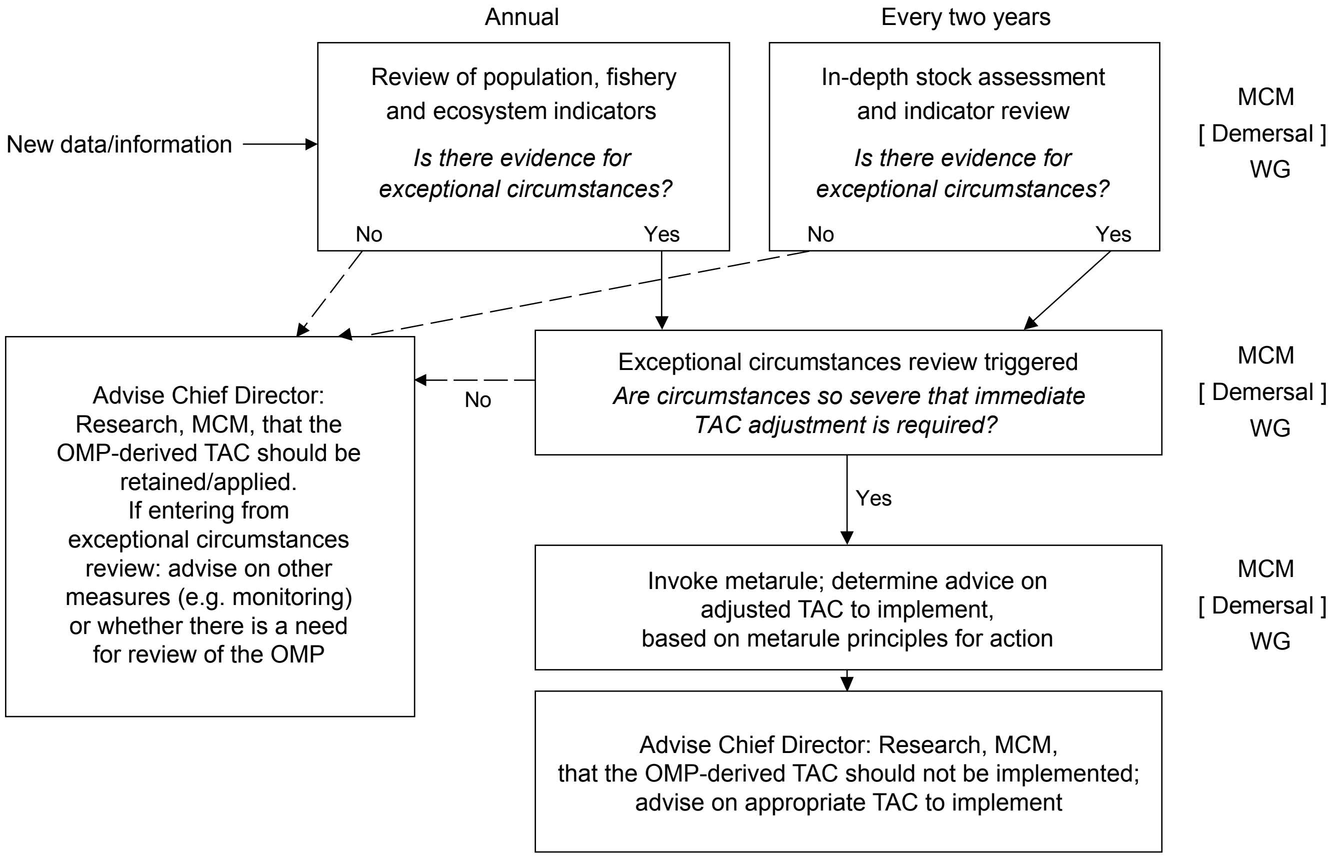

Figure App.2.1: Flowchart for metarules process

Examples of what might constitute an exceptional circumstance in the case of [hake] include, but are not necessarily limited to:

- [Survey estimates of abundance that are appreciably outside the bounds predicted in the OMP testing
- CPUE trends that are appreciably outside the bounds predicted in the OMP testing
- Catch species composition in major components of the fishery or surveys that differ markedly from previous patterns (and so may reflect appreciable changes in selectivity)]

Every two years the WG will:

- Conduct an in-depth stock assessment (more intensive than the annual process above, and in particular including the conduct of a range of sensitivity tests)
- On the basis of the assessment, indicators and any other relevant information, determine whether there is evidence for exceptional circumstances

The primary focus for concluding that exceptional circumstances exist is if the population assessment/indicator review process provides results appreciably outside the range of simulated population and/or other indicator trajectories considered in OMP evaluations. This includes the core (Reference case or set of) operating models used for these evaluations, and likely also (though subject to discussion) the operating models for the robustness tests for which the OMP was considered to have shown adequate performance. Similarly, if the review process noted regulatory changes likely to effect appreciable modifications to outcomes predicted in terms of the assumptions used for projections in the OMP evaluations (e.g. as a result, perhaps, of size limit changes or closure of areas), or changes to the nature of the data collected for input to the OMP beyond those for which allowance may have been made in those evaluations, this would constitute grounds for concluding that exceptional circumstances exist in the context of continued application of the current OMP.

If the WG concludes that there is no or insufficient evidence for exceptional circumstances, the WG will:

- Report to the Chief Director: Research, MCM, that exceptional circumstances do not exist

If the WG has agreed that exceptional circumstances exist, the WG will:

- Determine the severity of the exceptional circumstances
- Follow the 'Process for Action' described below

Specific issues that will be considered annually (regarding underlying assumptions of the OMs for the OMP testing process)

The following critical aspects of assumptions underlying the OMs for [hake] need to be monitored after OMP implementation. Any appreciable deviation from these underlying assumptions may constitute an exceptional circumstance (i.e. potential metarule invocation) and will require a review, and possible revision, of the OMP:

- [Over recent years species splits of catches from the major fisheries considered in projections are not substantially different from those assumed for the OM projections, or (as appropriate) not outside the bounds for which associated feedback to changes has been incorporated within the OMP
- Selectivities-by-age of the major fisheries do not differ substantially from assumptions made for OM projections
- New CPUE and survey abundance estimates are within the bounds projected by the OMs
- Recruitment levels are within bounds projected by the OMs]

Description of process for action

If making a determination that there is evidence of exceptional circumstances, the WG will with due promptness:

- Consider the severity of the exceptional circumstances (for example, how severely 'out of bounds' are the recent survey results or recruitment estimates)
- Follow the principles for action (see examples below)
- Formulate advice on the action required (this could include an immediate change in TAC, a review of the OMP, the relatively urgent collection of ancillary data, or conduct of analyses to be reviewed at a further WG meeting in the near future)
- Report to the Chief Director: Research, MCM, that exceptional circumstances exist and provide advice on the action to take

The Chief Director: Research, MCM, will:

- Consider the advice from the WG
- Decide on the action to take, or recommendations to make to his/her principals

Examples of 'Principles for Action'

If the risk is to the resource, or to dependent or related components of the ecosystem, principles may be:

— The OMP-derived TAC should be an upper bound

— Action should be at least an *x*% decrease in the TAC output by the OMP, depending on severity

If the risk is to socio-economic opportunities within the fishery, principles may be:

— The OMP-derived TAC should be a minimum

— Action should be at least a *y*% increase in the TAC output by the OMP, depending on severity

For certain categories of exceptional circumstances, specific metarules may be developed and pre-agreed for implementation should the associated circumstances arise (for example, as has been the case for OMPs for the sardine–anchovy fishery where specific modified TAC algorithms come into play if abundance estimates from surveys fall below pre-specified thresholds). Where such development is possible, it is preferable that it be pursued.

Regular OMP review and revision process

The procedure for regular review and potential revision of the OMP is the process for updating and incorporating new data, new information and knowledge into the management procedure, including the OMs used for testing the procedure. This process should happen on a relatively long time-scale to avoid jeopardising the performance of the OMP, but can be initiated at any time if the WG consider that there is sufficient reason for this, and that the effect of the revision would be substantial. During the revision process, the OMP should still be used to generate TAC recommendations unless a metarule is invoked.

Description of Process for Regular Review (see Figure App.2.2)

Every year the WG will:

- Consider whether the procedure for metarule process has triggered a review/revision of the OMP. Note that if proposals by a WG member or observer, or MCM management, for an exceptional circumstances review include suggestions for an OMP review and possible revision, they must outline in writing the reasons why they consider this necessary, and must either indicate where the data or analyses are to be found supporting their proposed review, or must supply those data or analyses in advance of the WG meeting at which their proposal is to be considered. This includes the possibility of a suggested improvement in the manner in which the OMP calculates catch limitation recommendations; this would need to be motivated by reporting results for this amended OMP when subjected to the same set of trials as were used in the selection of the existing OMP, and arguing that improvements in anticipated performance were evident.

Every two years the WG will:

- Conduct an in-depth stock assessment and review population, fishery and related ecosystem indicators, and any other relevant data or information on the population, fishery and ecosystem
- On the basis of this, determine whether the assessment (or other) results are outside the ranges for which the OMP was tested (note that evaluation for exceptional circumstances would be carried out in parallel with this process; see procedures for the metarule process), and whether this is sufficient to trigger a review/revision of the OMP
- Consider whether the procedure for the metarule process triggered a review/revision of the OMP

Every four years since the last revision of the OMP the WG will:

- Review whether enough has been learnt to appreciably improve/change the operating models (OMs), or to improve the performance of the OMP, or to provide new advice on tuning level (chosen to aim to achieve management objectives)
- On the basis of this, determine whether the new information is sufficient to trigger a review/revision of the OMP

In any year, if the WG concludes that there is sufficient new information to trigger a review/revision of the OMP, the WG will:

- Outline the workplan and timeline (e.g. over a period of one year) envisaged for conducting a review
- Report to the Chief Director: Research, MCM, that a review/revision of the OMP is required, giving details of the proposed workplan and timeline
- Advise the Chief Director: Research, MCM, that the OMP can still be applied while the revision process is being completed (unless exceptional circumstances have been determined to apply and a metarule invoked)

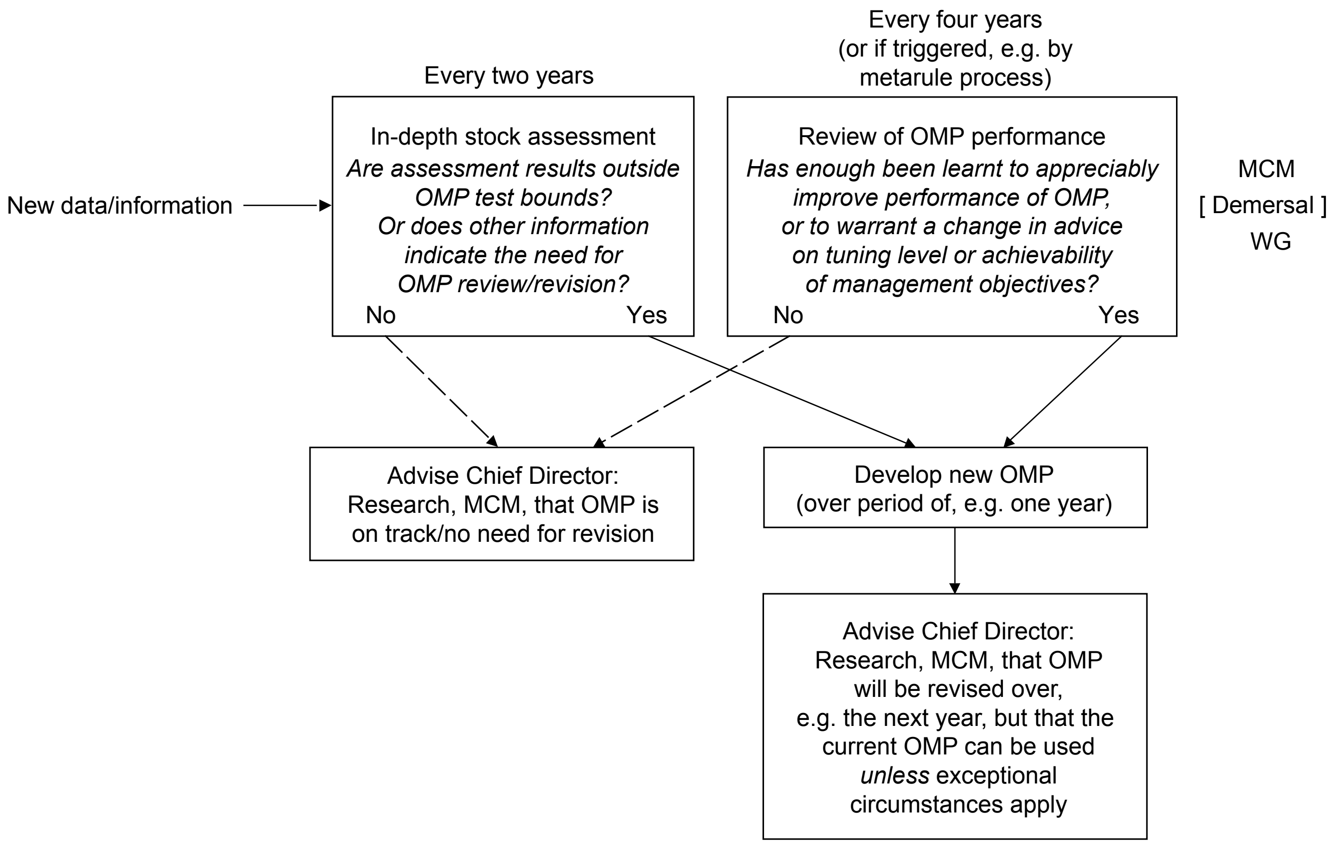

Figure App.2.2: Flowchart for regular review and revision process

In any year, if the WG concludes that there is no need to commence a review/revision of the OMP, the WG will:

- Report to the Chief Director: Research, MCM, that a review/revision of the OMP is not yet required

The Chief Director: Research, MCM, will:

- Review the report from the WG
- Decide whether to initiate the review/revision process