APPENDIX D

REPORT OF THE SECOND WORKSHOP ON MANAGEMENT PROCEDURES

(Walvis Bay, Namibia, 17 to 21 July 2006)

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REPORT OF THE SECOND WORKSHOP ON MANAGEMENT PROCEDURES

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INTRODUCTION

1.1 The Second Workshop on Management Procedures to Evaluate Options for Subdividing the Krill Catch Limit among Small-Scale Management Units (SSMUs) was held at the Pelican Bay Hotel, Walvis Bay, Namibia. The workshop was conducted during the first week of WG-EMM-06 (17 to 21 July 2006) and was co-convened by Ms T. Akkers (South Africa) and Dr C. Reiss (USA).

1.2 The preliminary agenda was discussed and adopted without change (Attachment 1), and the meeting participants are listed in Attachment 2.

1.3 The report was prepared by Dr S. Hill (UK), Mr J. Hinke (USA), Drs C. Jones (USA), S. Nicol (Australia), M. Pinkerton (New Zealand), D. Ramm (Data Manager) and K. Reid (Convener, WG-EMM).

1.4 The first workshop was held in 2005 (SC-CAMLR-XXIV, Annex 4, Appendix D), and aimed to evaluate management procedures for the krill fishery by examining six candidate methods for subdividing the krill catch. The agreed candidate methods to be evaluated were based on:

(i) the spatial distribution of catches by the krill fishery;

(ii) the spatial distribution of predator demand;

(iii) the spatial distribution of krill biomass;

(iv) the spatial distribution of krill biomass minus predator demand;

(v) spatially explicit indices of krill availability that may be monitored or estimated on a regular basis;

(vi) pulse-fishing strategies in which catches are rotated within and between SSMUs.

1.5 At its meeting in 2005, WG-EMM welcomed the developments achieved during the first workshop, and agreed to a second workshop to continue the evaluation of procedures to allocate the precautionary krill catch limit in Area 48 among SSMUs.

1.6 The terms of reference for the second workshop were to (SC-CAMLR-XXIV, Annex 4, paragraph 6.44):

(i) Review the development of operating models since the 2005 Workshop on Management Procedures.

(ii) Explore the performance of the operating models submitted to the workshop by determining whether they meet necessary benchmarks and conducting appropriate sensitivity analyses.

(iii) Evaluate the candidate options for allocating the precautionary krill catch limit among the SSMUs in Statistical Area 48.

(iv) Summarise the results of those evaluations in the form of advice to the WG-EMM.

1.7 Papers tabled for consideration at the workshop were WG-EMM-06/12, 06/20, 06/22, 06/23, 06/28, 06/30 Rev. 1, 06/35, 06/38 Rev. 1 and 06/39.

STATE OF MODELLING

Requested model incorporations

2.1 WG-EMM-05 specified that models relevant to the evaluation of options for subdividing the precautionary limit of krill catch in Area 48 amongst SSMUs should include (SC-CAMLR-XXIV, Annex 4, paragraph 6.18):

(i) shorter time steps and/or seasonality
(ii) alternative movement (of krill between regions) hypotheses
(iii) a threshold krill density below which a fishery will not operate.

2.2 WG-EMM-05 requested that candidate operating models should include performance measures that allow results to be compared between models (SC-CAMLR-XXIV, Annex 4, paragraphs 2.3 and 6.45). The performance factors should include measures pertaining to: (i) predators, (ii) krill and (iii) fishery.

2.3 Three models relevant to the evaluation of options for subdividing the precautionary limit of krill catch in Area 48 amongst SSMUs were presented to the workshop. These models, and the relevant documents, were EPOC (Ecosystem, Productivity, Ocean, Climate) (WG-EMM-06/38 Rev. 1), SMOM (Spatial Multispecies Operating Model) (WG-EMM-06/12 and 06/28) and KPFM2 (Krill–Predator–Fishery Model) (WG-EMM-06/20 and 06/22).

2.4 The workshop recognised that it was important that models show how uncertainty in parameters, environmental effects and different model structures/assumptions change the predicted dynamics of the system. EPOC, SMOM and KPFM2 handle uncertainty in a similar way to produce a probability 'envelope' of future states that is considered likely to bound the true state.

Status of EPOC

2.5 The EPOC modelling framework was first presented in WG-EMM-05/33. WG-EMM-06/38 Rev. 1 described a model of krill productivity in Area 48 within the EPOC model framework. Krill productivity was parameterised using data including empirical data on krill growth and reproduction, insolation, and satellite data on ocean dynamics, sea-ice concentration, sea-surface temperature and surface chlorophyll concentration. EPOC was demonstrated to have the potential to investigate the productivity of krill under various scenarios of environmental variability/climate change.

Status of SMOM

2.6 WG-EMM-06/12 described SMOM, which is based on the dynamics of krill and two generic predators (penguins and fur seals). Coded in AD-ModelBuilder, SMOM aims to be a minimally realistic, quantitative representation of current reality and future dynamics.

2.7 WG-EMM-06/28 described an example of how a Management Strategy Evaluation (MSE) approach could be used to manage the allocation of krill catch in Area 48 amongst SSMUs. In this example, the available observations of the state of the system are first identified. Next, SMOM is used as an operating model to predict the state of the resource in the future from the observations under a given management strategy. The likely future states are evaluated using a set of performance statistics. The performance statistics are used to compare candidate management strategies that adjust catches according to control/management rules. The MSE approach suggested here illustrates the potential utility of feedback within a formalised adaptive management method.

Status of KPFM

2.8 KPFM was first presented in WG-EMM-05/13. This model is now referred to as KPFM1. KPFM2 was developed from KPFM1 to address the requirements given during WG-EMM-05 and summarised above (paragraphs 2.1 and 2.2). KPFM2 was recognised by the workshop as having addressed the issues raised in WG-EMM-05.

2.9 In addition, KPFM2 can take into account some further issues identified as potentially important during the WG-EMM-05 Workshop on Management Procedures (SC-CAMLR-XXIV, Annex 4, Appendix D, paragraph 3.36), namely:

- (i) predators that can forage outside their natal SSMUs
- (ii) various plausible relationships between predator survival and foraging success
- (iii) differential access to krill between different predators and fishery.

As well as those performance measures suggested by WG-EMM-05, some novel aggregate performance measures were also included in KPFM2.

2.10 KPFM2 follows from, but is substantially different to, KPFM1. However, WG-EMM-06/20 presented a comparison of KPFM1 and KPFM2 and the workshop was reassured that the models gave very similar results when they were applied to the same scenario.

2.11 WG-EMM-06/30 Rev. 1 presented a preliminary compilation of parameters that were applicable to models used to investigate interactions between krill, predators, environment and fishery in Area 48 (spatially resolved at the scale of the SSMUs and temporally resolved for a six-month time step). The workshop recognised the importance of developing a common parameter set applicable to multiple different models. It is also recognised as important that parameter values have an 'audit trail' so that values are traceable to their source.

2.12 Considerable discussion during the workshop addressed how aggregate performance measures should be used to present complex results to the Scientific Committee. Further work will be required to agree on a set of aggregate performance measures that are comprehensible and reliable, and cover the range of information deemed necessary. In particular, aggregate performance measures should, *inter alia*:

(i) take into account and appropriately combine all model outputs considered valuable;

(ii) take into account correlations between various measures;

(iii) provide sufficient information to enable performance to be assessed relative to Article II;

(iv) aim to be value-free (e.g. 'high versus low' rather than 'good versus bad' or 'acceptable versus not acceptable').

REVIEW OF PARAMETER PLAUSIBILITY AND SENSITIVITY

3.1 The workshop agreed that an appropriate way to use the three available models would be to use KPFM2 as the primary model to examine the implications of various catch allocation schemes, and to use EPOC and SMOM to provide additional insights and to examine sensitivities to specific sources of uncertainty.

Requested model incorporations

Alternate parameterisation of transport and advection

3.2 The workshop reiterated that a key source of uncertainty is the role of advection (flux) in krill dynamics. The bounds on this uncertainty are: no flux, with local populations maintained by local recruitment; and flux with krill advected as passive drifters on ocean currents. In KPFM2, krill movement between areas is specified in a seasonally resolved matrix of instantaneous transport rates. No flux is represented by setting all cells to zero. Matrices parameterised using output from the circulation model developed by OCCAM are used to represent flux. SMOM can use random krill movements between areas. EPOC has the potential to simulate a range of flux scenarios.

3.3 WG-EMM-06/35 described an algorithm for modelling biomass flow between areas that reduces the underestimation of biomass retention within areas. Many movement algorithms assume instant mixing throughout an area once biomass has entered the area. While this may be satisfactory for modelling the behaviour within that area, it might not be satisfactory for modelling the subsequent departure of the biomass into other areas. This paper provides a solution to this problem and may be of assistance in developing operating models for evaluating krill management procedures. This algorithm has not been used to estimate potential krill flux, but the paper shows that the assumptions of mixing within models need to be considered before accepting that they will adequately reflect the desired movement patterns of the model species, such as krill.

3.4 The workshop agreed that the transport matrices presented in WG-EMM-06/30 Rev. 1 could be used to explore uncertainty about flux.

3.5 The influence of flux on predator populations will depend on the ability of predators to move between areas. Possible bounds on this uncertainty are no movement of predators between SSMUs and a homogenous distribution of predators during the winter (with no movement in summer). It was proposed that this may be a way of parameterising KPFM2 in order to explore this uncertainty. However, the homogenous distribution of all predators is not biologically sensible and produces implausible dynamics in KPFM2. The winter predator distributions presented in WG-EMM-06/30 Rev. 1 were considered more plausible.

Short time steps and/or seasonality

3.6 The time step in KPFM2 can be set to any period. The model runs presented to the workshop, and the parameters presented in WG-EMM-06/30 Rev. 1, were based on a seasonal time step of six months, which captures differences between SSMUs in the seasonal overlap between fishing activities and predator breeding. The time step in EPOC can be any period from one day upwards. SMOM is currently parameterised as an annual model.

Krill density to halt fishing

3.7 KPFM2 allows the analyst to specify the threshold SSMU-scale krill density that causes voluntary cessation of fishing operations. The workshop was unable to identify appropriate values for this threshold, but noted that it might be linked to predator foraging performance.

3.8 The average krill density in an SSMU may well be lower than the threshold density required for profitable operations by the fishing fleet. The average SSMU-scale density will not therefore reflect the density reacted to by the fleet on smaller-scale fishing grounds. Such considerations also apply to krill predators which also use only a portion of the SSMU for foraging. The SSMUs and the modelling process, however, were designed taking account of the distribution of historical catches and predator foraging locations.

Plausibility, sensitivity and uncertainty in other parameters

3.9 Another key source of uncertainty is the form of the relationship between prey availability and predator population responses and how this accommodates processes such as prey switching, predator saturation and dependence on highly aggregated resources. KPFM2 and SMOM can accommodate a range of responses from hyperstable, through linear to hyperdepletion (Figure 1). Uncertainty can be included in EPOC at desired points in the ecological functions of the taxa.

3.10 Other sources of uncertainty include:

(i) The role of mesopelagic fish in the system –

WG-EMM-06/30 Rev. 1 suggested that myctophids may be the most important krill consumers, but this is based on limited evidence (see also subparagraph (iii)).

(ii) The relative competitive abilities of predators and the fishery –

KPFM2 can be used to explore this issue.

(iii) The size and age ranges of krill targeted by different predators and the fishery –

KPFM2 does not represent size-selective targeting, but the competition settings might be used to explore this issue. However, it was noted that EPOC can include age structure in its representation of populations.

(iv) Starting conditions –

KPFM2 runs can be initialised with predator and prey populations at equilibrium. This can be used as a reference point against which to compare the effects of different fishing options. However, it is important to consider scenarios where predator populations might be increasing or decreasing.

(v) Trends in krill recruitment or its variability –

There is published evidence for such trends (Siegel and Quetin, 2003). Decreasing recruitment might make it difficult for the Commission to appropriately manage fisheries to achieve the objectives of Article II. EPOC can model krill recruitment from environmental variables.

(vi) Fleet dynamics –

The current models do not include explicit representations of fleet behaviour, however the aims of the workshop can be partly achieved by considering the distribution of catches at the SSMU scale.

(vii) The mechanisms through which krill availability affects predator dynamics –

In KPFM2 and SMOM this is modelled primarily as an effect on predator recruitment. However, both models can be used to explore the effects of krill availability on predator survival.

3.11 WG-EMM-06/30 Rev. 1 presented a compilation of parameter values for use in ecosystem models. Empirically derived predator parameters should be presented as means and ranges to represent uncertainty in these values. Fur seal mortality parameters were updated using data from WG-EMM-06/P7. This also affected fur seal recruitment parameters.

3.12 The workshop noted that the aggregation of diverse species into 'generic' predators might potentially mask important species-specific responses. It is therefore important that the range of 'generic' predators represents the range of life histories in the predator community.

3.13 The workshop noted that parameters and functions in the models should capture important aspects of the dynamics of krill and its predators but that the parameters do not necessarily need to represent specific biological processes to achieve this.

3.14 WG-EMM-06/22 presented further development of aggregate performance measures, including the use of aggregate trade-off plots to evaluate the candidate fishing options and other model output. Examples of these trade-off figures are presented in Figures 2(a) (using the arithmetic mean) and 2(b) (using the geometric mean). In these plots, the columns represent different fishing options and the rows represent SSMUs. The upper value in each cell represents the aggregate 'Fishery Performance' score, and the lower value represents the aggregate 'Ecosystem Performance' score (on a scale of 0 to 1 with 1 representing highest performance). Individual cells are shaded according to the magnitude of the difference between the two performance values and represent the aggregate trade-off.

3.15 The workshop agreed that aggregate trade-off plots are important in providing a basis for discussion, but should be interpreted with caution. The workshop considered that the value of the performance score may need to be interpreted relative to the range over which most important differences occur.

MODEL OUTPUTS AND PERFORMANCE MEASURES

4.1 The workshop agreed that the two major sources of uncertainty to be addressed in the workshop, and the appropriate parameter sets to bound these uncertainties in KPFM2, were:

(i) the role of flux in krill dynamics: bounded by the seasonal movement matrices based on OCCAM output and no movement;

(ii) the degree of stability in the relationship between krill availability and predator population responses: bounded by *rphi* values of 0.37 and 1 (see Figure 1).

4.2 The workshop noted the broad agreement in trajectories between SMOM and KPFM2 in simulation trials when the parameterisation of the two models was consistent. On this basis, as well as on biological plausibility of the results, it was agreed that there was confidence in these modelling approaches for evaluating the different fishing options.

4.3 The workshop examined results from a large number of KPFM2 scenarios. The workshop first considered the simulated trajectories of abundance for predator groups from trials using random recruitment and allocation of Fishing Options 1 to 4 with 60-year simulations and 50 Monte Carlo trials per simulation.

4.4 It was agreed that use of aggregate outputs of population trajectories should be examined, though it was recognised that: (i) aggregating can potentially smooth projections across all species, and relative effects on species may be different; (ii) the values of the aggregate measures will be influenced by the individual measures that are included; and (iii) the values of the aggregate scores may not be scaled correctly to appropriately reflect the magnitude of the effects of the fishing options. The workshop recognised the importance of examining all output components before making decisions. The workshop examined a variety of performance measures plotted against each other, and agreed that this was a useful way to examine trade-offs between different ecosystem and fishery characteristics.

4.5 The workshop examined several types of aggregate trade-off plots to evaluate the candidate fishing options. While plots such as these are ultimately desirable to summarise outcomes and trade-offs, it was recognised that at present they require further development. However, they provided a very useful mechanism towards generating discussions (see paragraphs 3.12 to 3.14).

4.6 The workshop agreed that KPFM2 could first be used to explore a fishing scenario which originally concerned the Commission. This scenario is the continued development of the krill fishery towards taking the full catch limit with the potential to concentrate all its fishing effort in only a small area. This scenario was the reason for establishing the process of subdividing the Area 48 krill catch limit amongst SSMUs.

4.7 To examine this concern, a primary simulation scenario was performed where fishing was conducted only in Subarea 48.1 under a constant quota determined as 0.09 (γ) of an estimate of biomass just prior to the fishing period. Other trials were also undertaken, these included having fishing mostly in Subarea 48.1 (87.5%) with some fishing in Subareas 48.2 and 48.3 (12.5%) and carrying out scenarios using different values of γ (0.03, 0.06, 0.09). Each scenario included 50 Monte Carlo trials across 60 years (with fishing starting at year 21 and stopping at year 41 and the sources of uncertainty outlined in paragraph 4.1).

4.8 On the basis of an examination of individual trajectories and performance indicators from these trials, the workshop agreed that under a flux model, increasing fishing in Subarea 48.1 can have an impact on other areas. The magnitude of these effects is dependent on the level of the quota. The workshop noted that if models are run with no movement, localised effects could be more substantial. Results for the primary scenario are presented in Figure 3.

4.9 The workshop agreed that these results corroborate the concerns of the Commission about the effects of localised fishing and are consistent with the notion that this fishery should be managed on a spatial basis.

4.10 SMOM was modified during the workshop to be comparable with KPFM2. SMOM was set up with similar parameters to KPFM2 in terms of: (i) periods of fishing and recovery in the simulation; (ii) allocated fishing catch; (iii) predator depletion and recovery performance measures; and (iv) the parameter set originally detailed in WG-EMM-06/30 Rev. 1 and modified during the workshop.

4.11 Differences between the versions of SMOM and KPFM2 used in the workshop, and the simulations performed, included: (i) penguins and seals are the only predators in SMOM – fish and whales are not included explicitly, though their consumption is included in the model indirectly; (ii) uncertainty in the adult survival rates for predators is included in SMOM; (iii) movement of krill in SMOM is not comparable with movement in KPFM2, so the comparison can only usefully be completed under the ‘no movement’ scenario; and (iv) the present version of SMOM does not consider differential access to krill between predators and the fishery.

4.12 The workshop next considered the performance measure trade-offs associated with Fishing Options 1 to 4. As an example of this, Figure 4(a) shows predator trajectories (seals, penguins, whales and fish) in two selected SSMUs under Fishing Options 1 and 4 (overlaid). A comparison of Fishing Options 1 and 4 in this figure demonstrated that the former was skewed towards relatively higher fishery performance and the latter slightly skewed towards relatively higher ecosystem performance. Figure 4(b) shows predator trajectories (penguins and seals) from the SMOM model and demonstrates similar trajectories to those from KPFM2, supporting the suggestion that Fishing Option 1 results in lower ecosystem performance.

4.13 Results from the modified SMOM agree well (qualitatively) with simulation results from KPFM2 in those scenarios that could be tested (e.g. Figures 4(a) and 4(b)). The modified SMOM also demonstrated that it can compare performance measures across different management schemes in a similar way to KPFM2. This shows that multiple approaches are useful in exploring how ecosystem dynamics can be modelled for management purposes.

4.14 The workshop next considered the trade-offs under Fishing Option 5. Figure 5(a) shows output from KPFM2 illustrating an example of changes in catch and predator trajectories when catch is adjusted in response to periodic reassessments of resource status. An illustrative feedback catch control rule using SMOM also highlighted the contrast in predator trajectories when assuming that initial catch allocations are fixed over time rather than being adjusted in response to changes in trends observed from monitoring data (Figure 5(b)). Additional KPFM2 and SMOM results showed the extent to which the efficacy of a feedback mechanism relied on the number and types of future monitoring data available. The workshop agreed that this demonstrates how monitoring standing stock and consequent adjustments in fishing allocation can improve performance measures.

4.15 An example was given of how SMOM can be used to develop a management scheme for Area 48 which includes feedback through management control rules. Two management responses to negative changes in monitoring indicators in an SSMU were discussed: (i) transfer of catch from an affected SSMU to a pelagic SSMU with no land-based predators; and (ii) a reduction of catch in the affected SSMU resulting in a lower overall catch.

4.16 The workshop considered how to make judgments regarding optimal trade-offs, and agreed that this was more appropriate to the role of the Commission. However, it was recommended that advice should be developed based on trade-offs relative to Article II of the CAMLR Convention.

4.17 When the workshop specifically considered the trajectories of fish using KPFM2, it was noted that there appear to be more dynamic responses in the model results than might be expected in reality. The parameterisation of this generic predator group may need to be revised.

4.18 The workshop discussed other aspects of the results of Fishing Option 1 and agreed that the performance of this option is highly dependent on the particular subset of the historical catch data used to initialise this option.

4.19 The workshop next examined fishery-based performance measures, which included an analysis of catch versus CV of catch (Figure 6). It was noted that the variance in catch is similar for all allocation options in most SSMUs.

4.20 In addition, the workshop examined the trade-off between the mean realised catch versus the distribution of catch relative to the historical catch. This demonstrated considerable differences between fishing options, including that distribution of catch in Fishing Option 1 most closely represents the historical distribution of catch (Figure 7).

4.21 Due to time constraints some members felt that while Fishing Option 1 had been vetted, other fishing options had not been similarly examined.

ADVICE TO WG-EMM

5.1 The workshop agreed that there had been a considerable amount of work done since WG-EMM-05 to develop models on which the provision of advice could be based (paragraphs 2.5 to 2.10).

5.2 In simulation trials conducted in KPFM2 it was apparent that, should the fishery occur entirely in Subarea 48.1 and catch an amount of krill equivalent to 9% of B_0, then there will be considerable negative impacts on the ecosystem in that region and, under the assumptions of flux, there would also be negative consequences for the downstream SSMUs in Subareas 48.2 and 48.3 (paragraphs 4.6 and 4.7).

5.3 In simulation trials both KPFM2 and SMOM indicated that Fishing Option 1 would have relatively greater negative impacts on the ecosystem compared to the other fishing options (paragraphs 4.12 and 4.13).

5.4 The workshop agreed that even when KPFM2 and SMOM were used to integrate uncertainties there were apparent differences in the consequences of the different fishing options, but the workshop agreed that further evaluation of Fishing Options 2 to 4 will require additional work on the development and interpretation of performance measures (paragraphs 4.13 and 4.16).

5.5 The workshop also agreed that all simulations indicated that the performance of Fishing Options 2 to 4 would be improved when monitoring data are used to update the allocation of catches among SSMUs, i.e. in a manner analogous to Fishing Option 5 (paragraphs 4.14 to 4.17).

FUTURE WORK

EPOC

6.1 The workshop reviewed EPOC and the way that model was used to explore the potential variability, between SSMUs and across Area 48, of the productivity of krill based on a model of krill food using ice, sea-surface temperature and chlorophyll data from satellites (WG-EMM-06/38 Rev. 1). Model results showed that: (i) local productivity (biomass, length and recruitment) can vary widely between SSMUs at a given time, (ii) variation in recruitment over the time series can be up to 1.2 in some SSMUs, (iii) SSMU-scale processes may be too small for modelling krill dynamics, and (iv) regional movement models may not be needed to model areas within regions. The fits to existing data for the Antarctic Peninsula are promising.

6.2 The workshop noted that larger areas, such as SSMU groups and subareas, may be better suited to the modelling of krill dynamics. The workshop also noted that the scale of SSMUs was appropriate for the modelling of predator dynamics, and the interactions between predators and the fishery.

6.3 The workshop encouraged future work to tune the EPOC models to data and to provide important parameters for existing models (see also paragraph 2.5).

SMOM

6.4 The workshop encouraged future work to further develop the adaptive management framework in SMOM (see also paragraph 2.7). It was noted that some of this development would require considerable work.

KPFM2

6.5 The workshop recognised the considerable work in the development of KPFM2 to date and encouraged the authors to continue that development, particularly in relation to evaluation of feedback management procedures and conditioning to data.

Aggregate performance measures

6.6 The workshop encouraged the development of an agreed set of aggregate performance measures which are comprehensive and reliable, and cover the range of information outlined in paragraph 2.12.

Understanding fleet dynamics

6.7 The workshop recognised that it will be important for future modelling frameworks to capture some of the dynamics of the fishery. For example, how skippers make decisions about where they fish and when. Factors such as the abundance of krill, sea-ice conditions and the condition, location and colour of krill, as well as fishing experience, are important considerations in targeted fishing.

6.8 The workshop encouraged WG-EMM to consider this issue further.

Technical forum

6.9 The workshop encouraged intersessional discussions to provide guidance to model developers on issues such as:

- improvements and refinements to models
- incorporation of future needs into models
- developing datasets to provide further parameter estimations
- evaluation of the performance of models in relation to agreed technical requirements.

Spatially explicit management procedures

6.10 The workshop agreed that Fishing Options 5 (feedback management) and 6 (pulse fishing) need to be explored further. In that respect, the workshop recommended that consideration be given to defining what is meant by Fishing Option 6. In considering and evaluating both options, the workshop recommended that WG-EMM consider how knowledge, such as through field research including monitoring programs, might be acquired to assist in designing these options and for effectively implementing them in the longer term.

6.11 The workshop encouraged further development of spatially explicit management frameworks and to advance methods for use by CCAMLR to evaluate such management frameworks for krill, including, *inter alia*:

(i) development of operating models;

(ii) development and evaluation of decision rules for adjusting fishing activities (e.g. catch limits) based on field data in the future;

(iii) further development of performance measures and the means for providing integrated advice to the Commission on the relative merits of different strategies with respect to Article II.

ADOPTION OF REPORT AND CLOSE OF WORKSHOP

7.1 The report of the workshop was adopted.

7.2 In closing the workshop, the Co-conveners of the workshop, Ms Akkers and Dr Reiss, thanked Drs É. Plagányi (South Africa), A. Constable (Australia), G. Watters (USA), Hill, Mr Hinke and Dr Reid for further developing the three models which had been used by the workshop, and for undertaking numerous trials during the workshop. The Co-conveners also thanked the participants for their contributions which led to the success of the workshop. The workshop had been difficult and covered a substantial amount of work. The Co-conveners also thanked the Secretariat staff for their support.

7.3 Dr Constable, on behalf of the workshop, thanked the Co-conveners for their thorough preparations which had kept the workshop on track. Their guidance and leadership had allowed the workshop to articulate important issues and to achieve its aims.

7.4 The workshop was closed.

REFERENCES

Siegel, V. and R.M. Quetin. 2003. Krill (*Euphausia superba*) recruitment indices from the western Antarctic Peninsula: are they representative of larger regions? *Polar Biol.*, 26: 672–679.

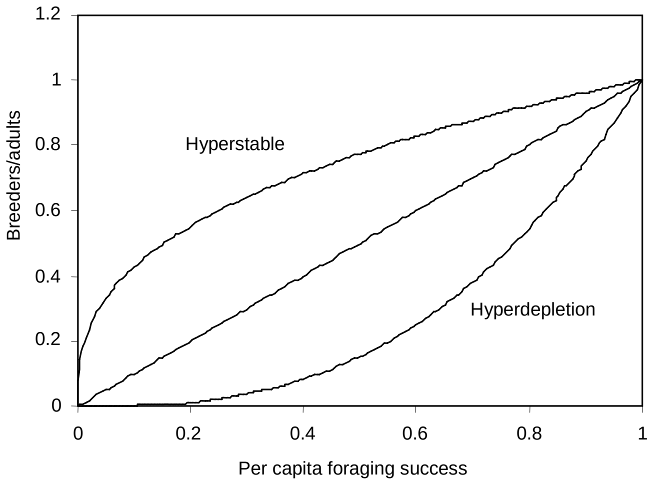

Figure 1: Potential forms of the relationship between prey availability (expressed as per capita foraging success) and the dynamic response of a predator population (the proportion of adults that breed). The central line shows a proportional response (shape parameter used in KPFM2, *rphi* = 1), while the upper (*rphi* = 0.37) and lower curves (*rphi* = 2.70) show the hyperstable and hyperdepletion situations respectively.

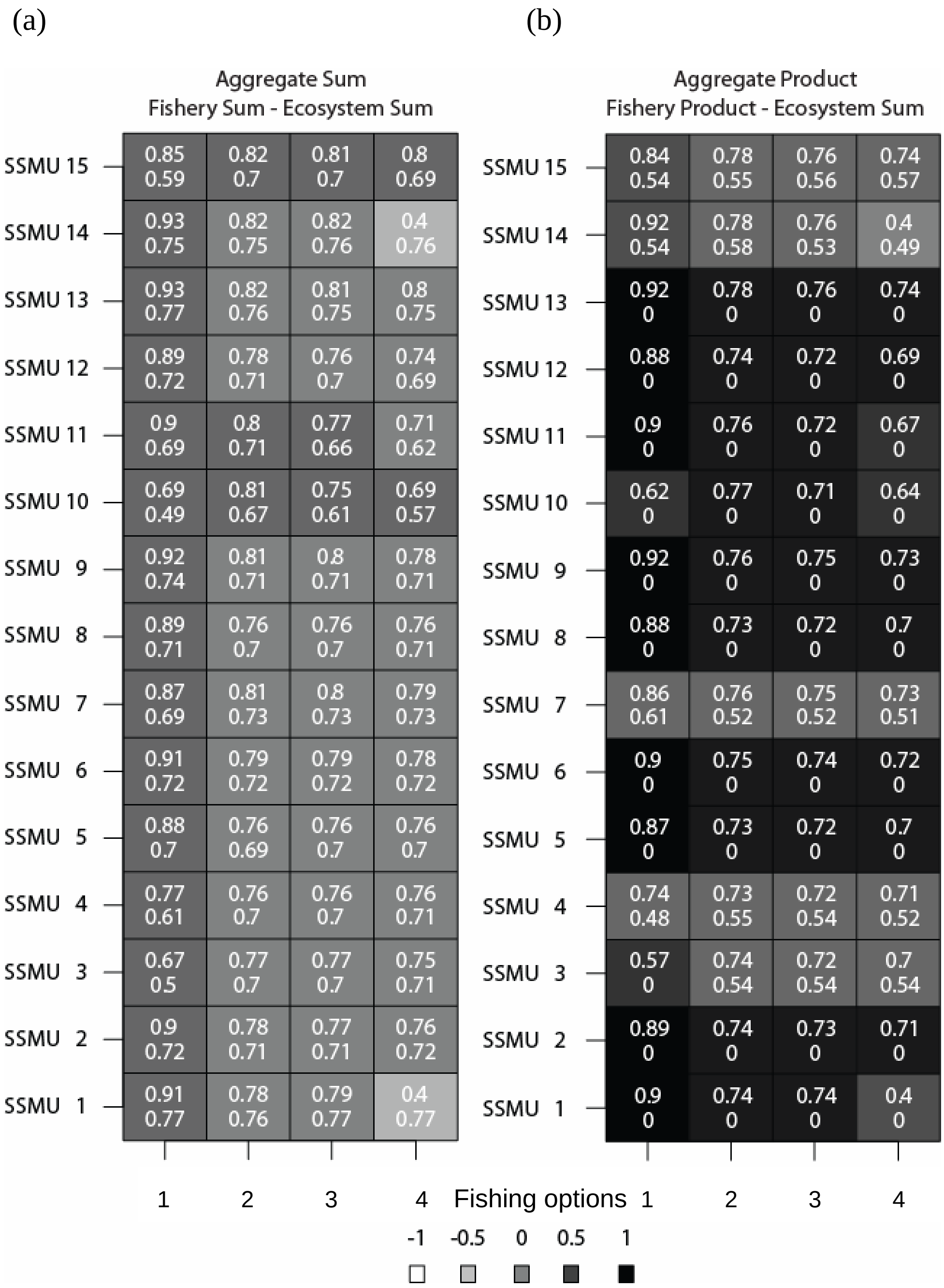

Figure 2: Examples of summarised results from KPFM2. Tables (a) and (b) present aggregate measures of fishery performance (top number in each cell) and ecosystem performance (lower number in each cell), for each SSMU (rows) resulting from each of four fishing options (columns). The shade of each cell indicates the relative value of the fishery and ecosystem aggregates. Dark shades indicate that fishery performance exceeds ecosystem performance while light shades indicate that ecosystem performance exceeds fishery performance. Intermediate shades are closer to a balanced trade-off where fishery and ecosystem performance are similar. The aggregate values in (a) are arithmetic means of component performance measures while those in (b) are geometric means. While arithmetic means show the average performance across components, geometric means indicate the simultaneous performance. Geometric means are sensitive to zeros. An ecosystem aggregate value of zero suggests that at least one ecosystem component is not meeting a performance criterion. The SSMUs are as follows: Antarctic Peninsula pelagic area (1), west (2); Drake Passage west (3), east (4); Bransfield Strait west (5), east (6); Elephant Island (7), east (8); South Orkney Islands pelagic area (9), west (10), northeast (11), southeast (12); and South Georgia pelagic area (13), west (14), east (15).

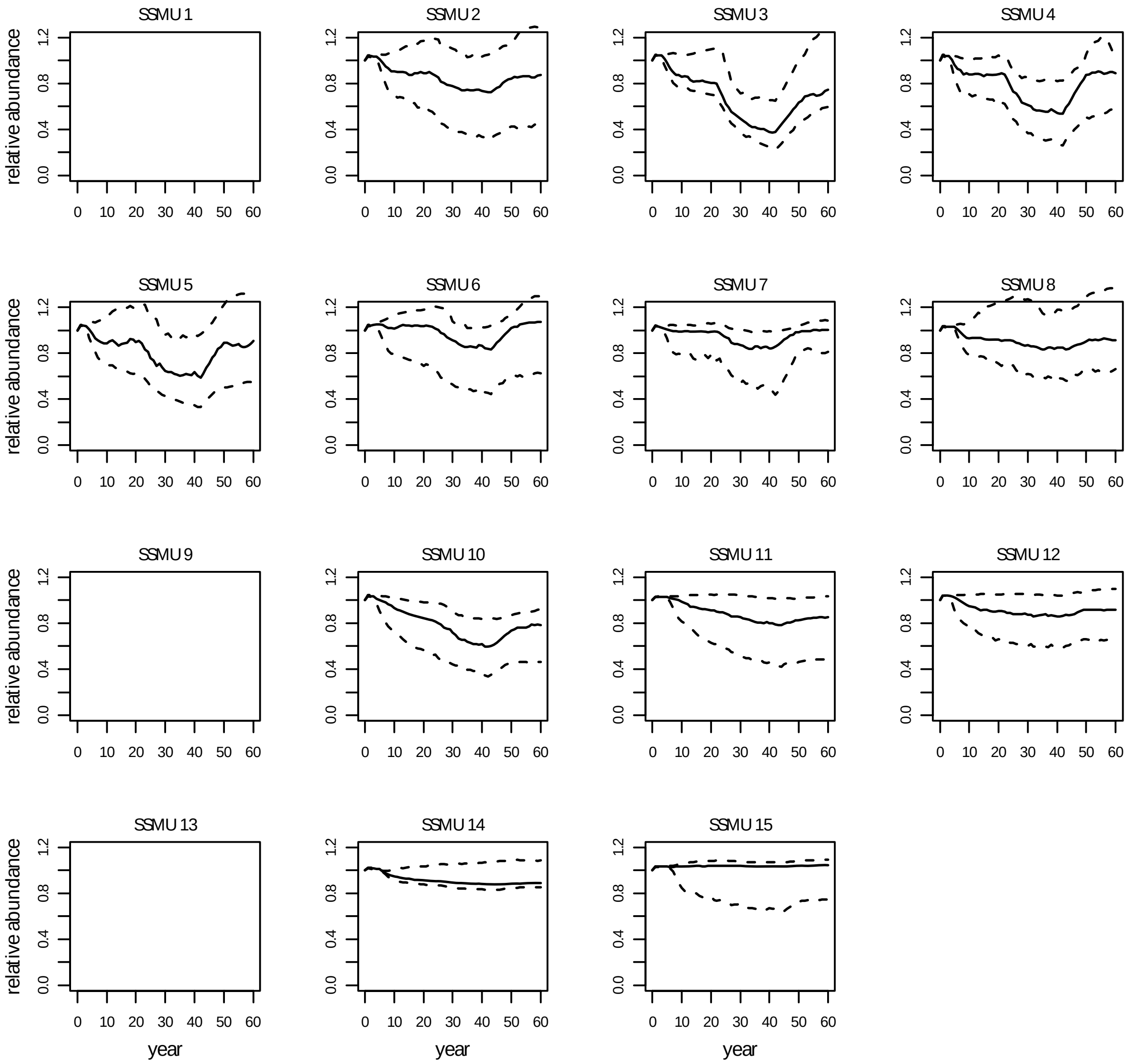

Figure 3: Penguin abundance trajectories demonstrating the effect of fishing occurring only in the SSMUs in Subarea 48.1 (SSMUs 1–8). The solid black lines are medians and the dashed black lines bound the 90% probability envelopes. These simulations were conducted with γ equal to 0.09. Penguins do not breed in SSMUs 1, 9 and 13. See Figure 2 for the list of SSMUs.

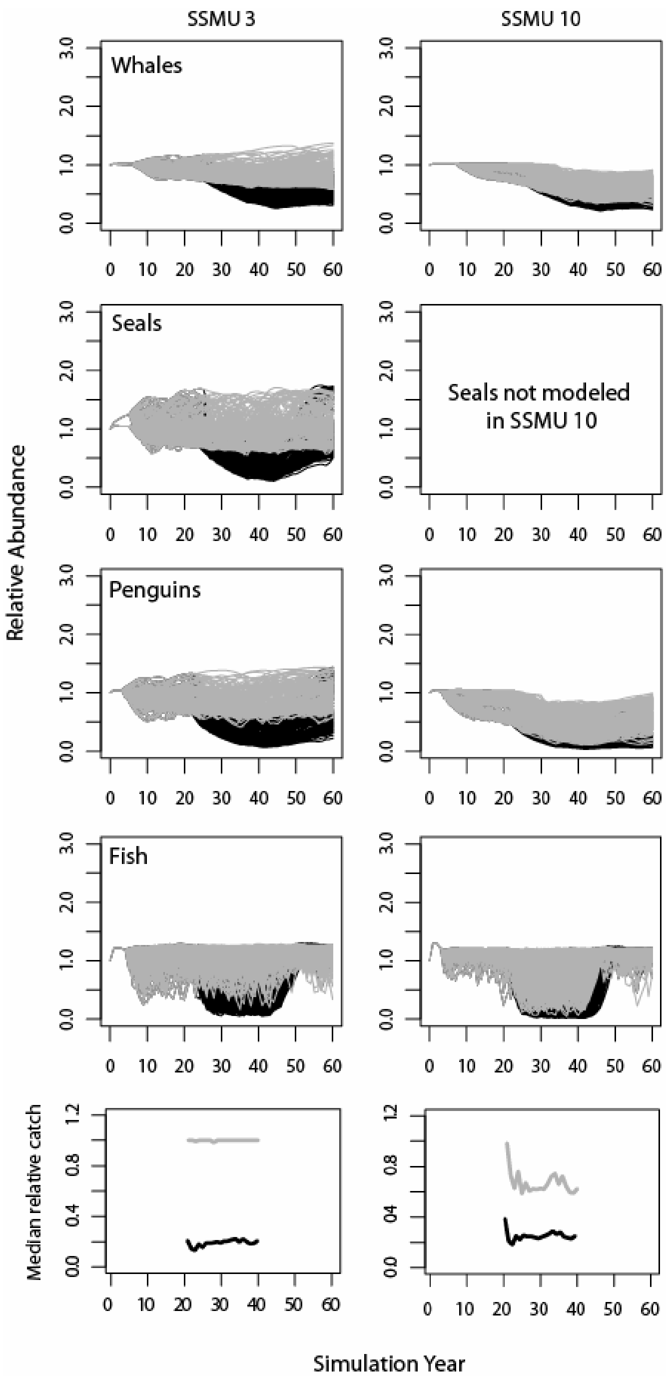

Figure 4(a): Predator abundance trajectories (seals, penguins, whales and fish) and median relative catch from KPFM2 under Fishing Options 1 (black) and 4 (grey) in SSMU 3 (Drake Passage west) and in SSMU 10 (South Orkney west).

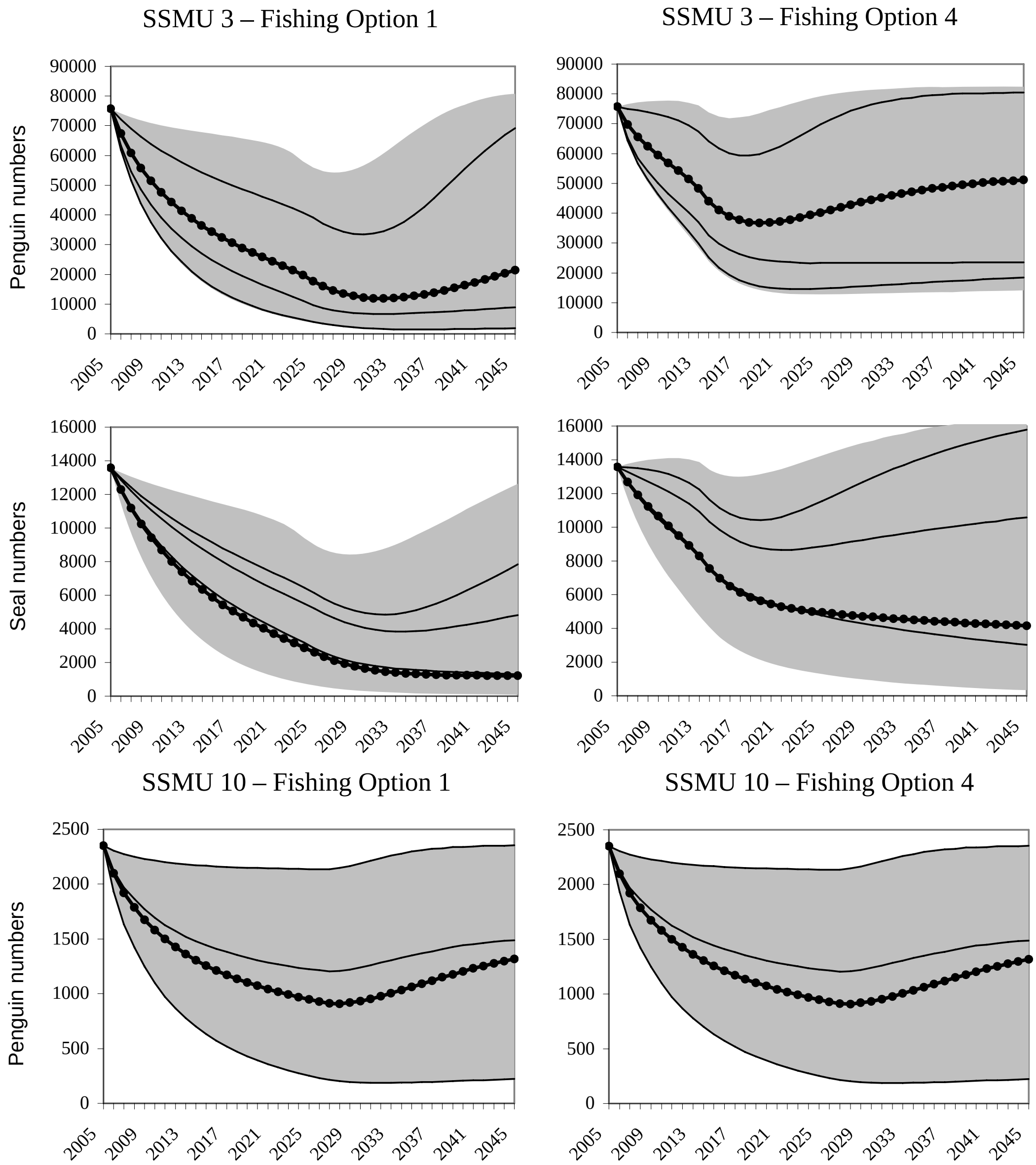

Figure 4(b): Population trajectories generated by SMOM of penguin and seal abundance (in terms of numbers) in SSMU 3 (Drake Passage west) and SSMU 10 (South Orkney west) compared under Fishing Options 1 and 4, from 120 model representations and when using a model version that assumes no krill movement between SSMUs. Three individual trajectories are shown, with the median represented as a dark dotted line and the shaded areas showing the 90% probability envelopes. Note that trajectories assume fishing occurs for the first 20 years, but is set to zero thereafter to assess resource recovery.

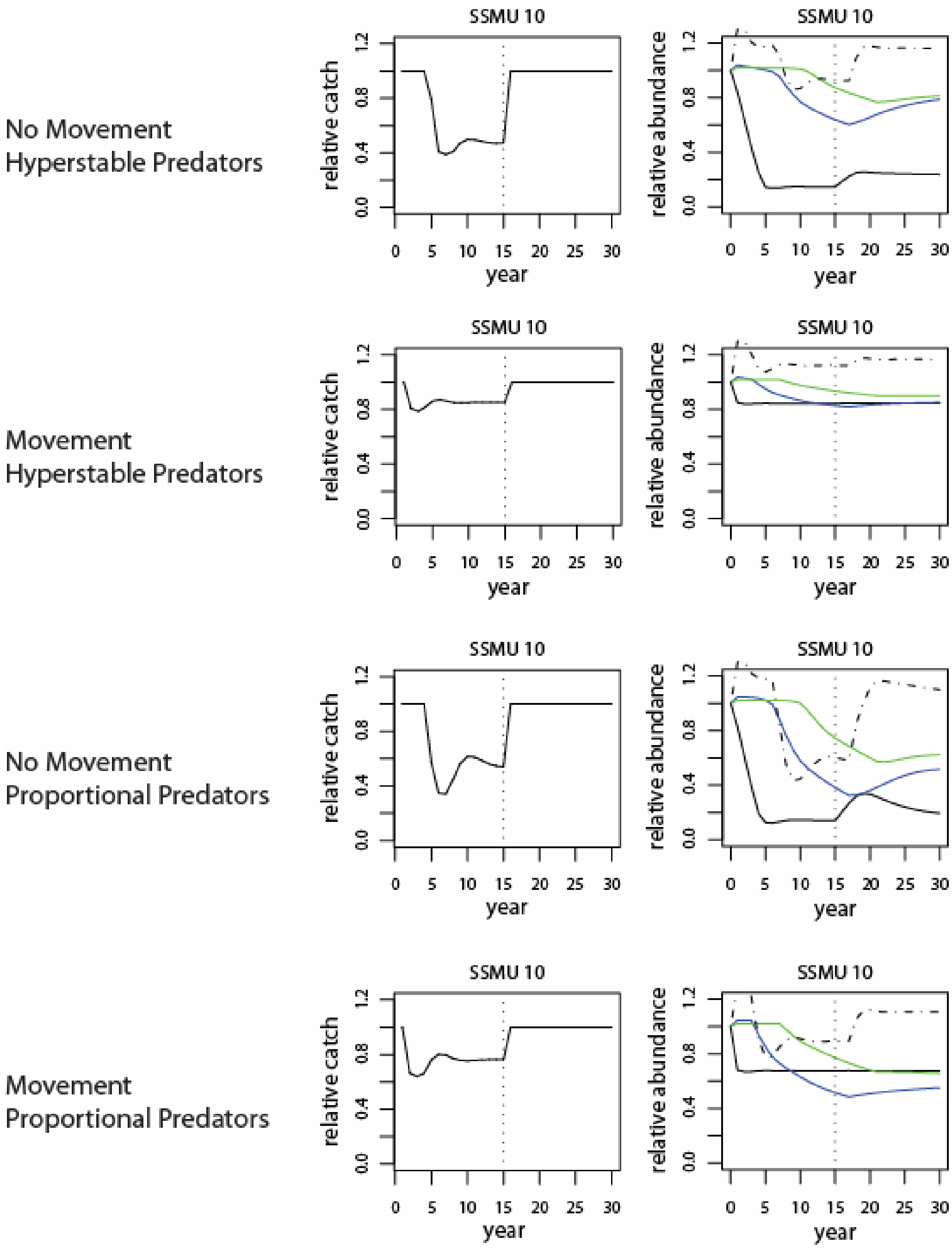

Figure 5(a): KPFM2 example output of an MSE leading to reallocation of fishery catch under four combinations of model uncertainty. In each example, a single reassessment of the difference between krill standing stock and predator demand is conducted in year 15 that results in a reduced reallocation of catch to the fishery in SSMU 10 (South Orkney west). The panels illustrate two main effects of the reallocation. The fishery is able to catch the full allocation after the reassessment because the allocation has been reduced, and predators recover in response to reduced catches (but the degree of this response is uncertain).

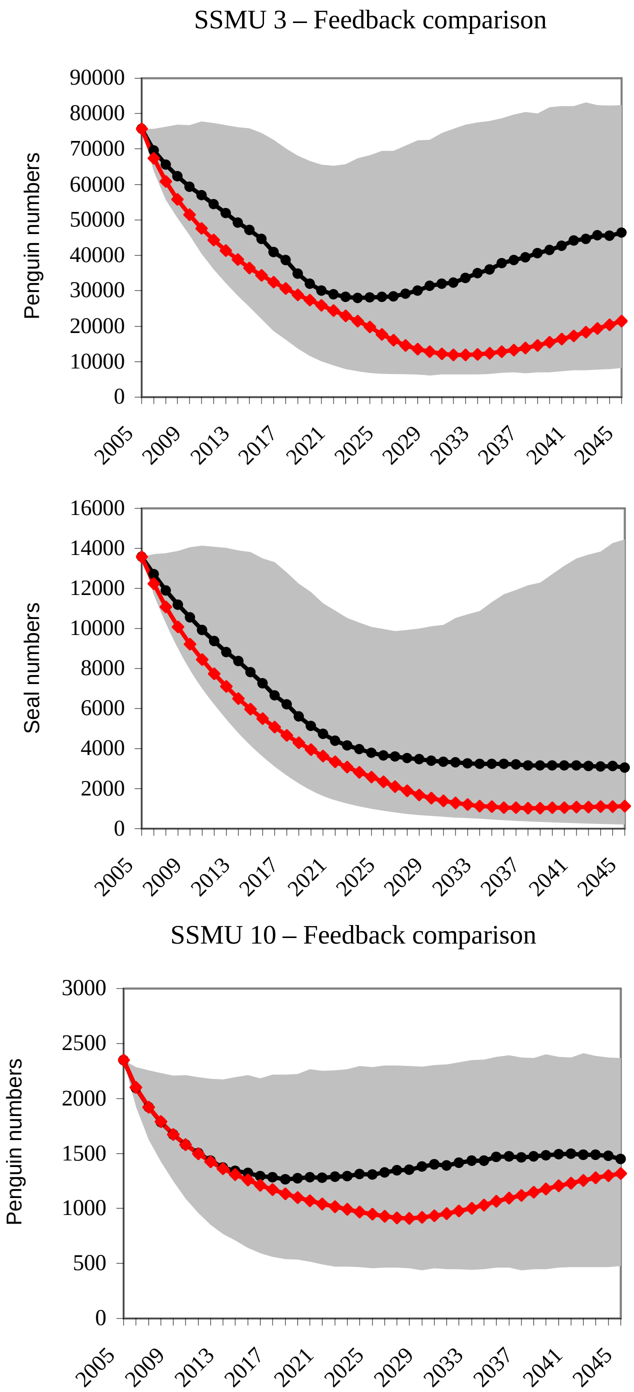

Figure 5(b): SMOM example output of an MSE. Plots show predicted change in abundance for penguins and seals in SSMU 3 (Drake Passage west) and SSMU 10 (South Orkney west, no seals) compared under two scenarios: no feedback in catch allocations (i.e. catches constant as per Fishing Option 1) (diamond symbols); and using a feedback control rule (circle symbols) based on a moderate amount of monitoring information available for all SSMUs. Trajectories represent the median and the shaded areas show the 90% probability envelopes for the feedback scenario – note that the lower 5%ile of the corresponding probability envelop for the no-feedback scenario is not shown but is necessarily lower.

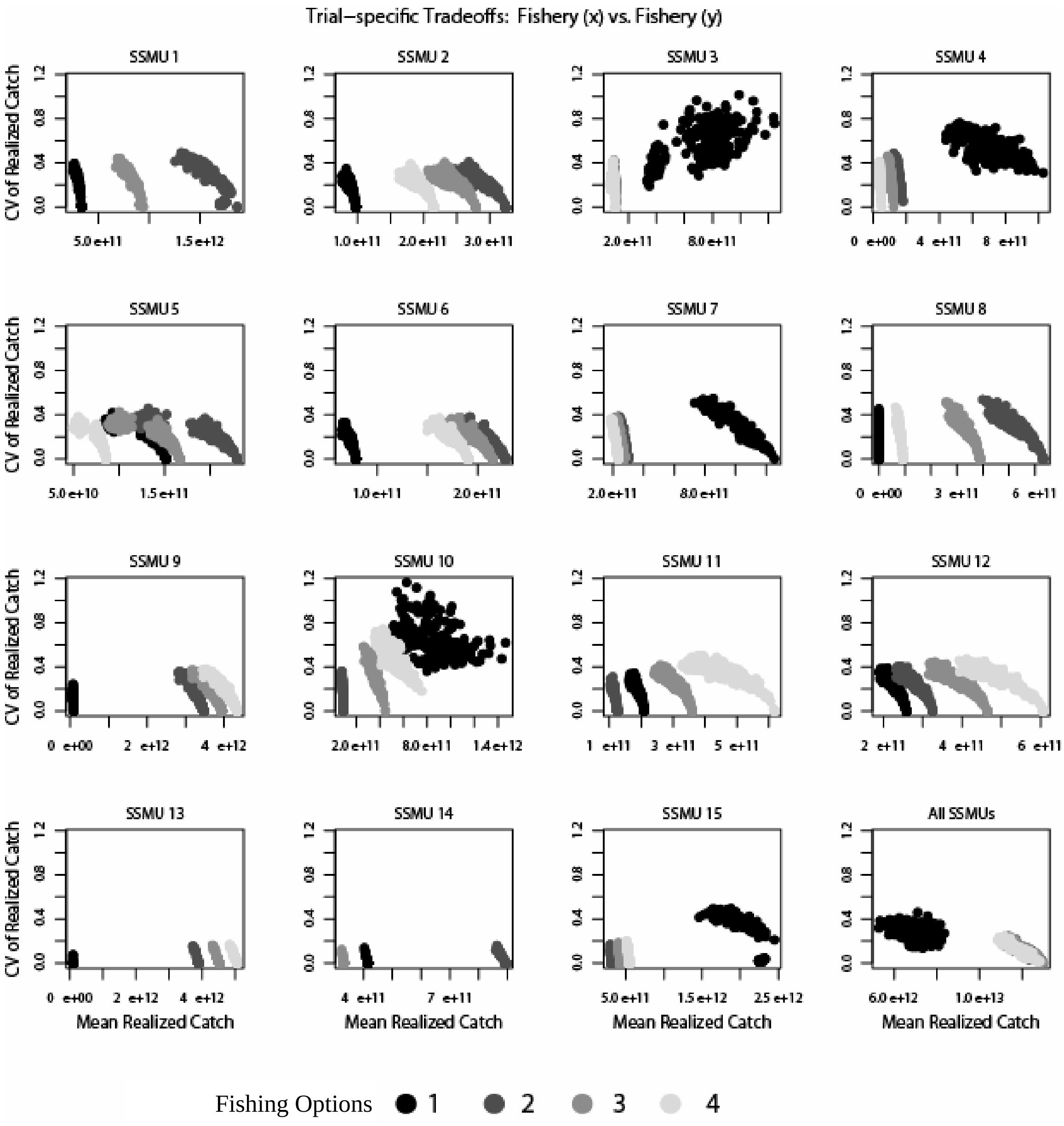

Figure 6: KPFM2 predictions of the trade-offs between mean realised catch and the CV of the catch under the four fishing options. Each cloud of points incorporates four sources of model uncertainty for each fishing option. Fishing Options 1 to 4 are identified by a shaded dot.

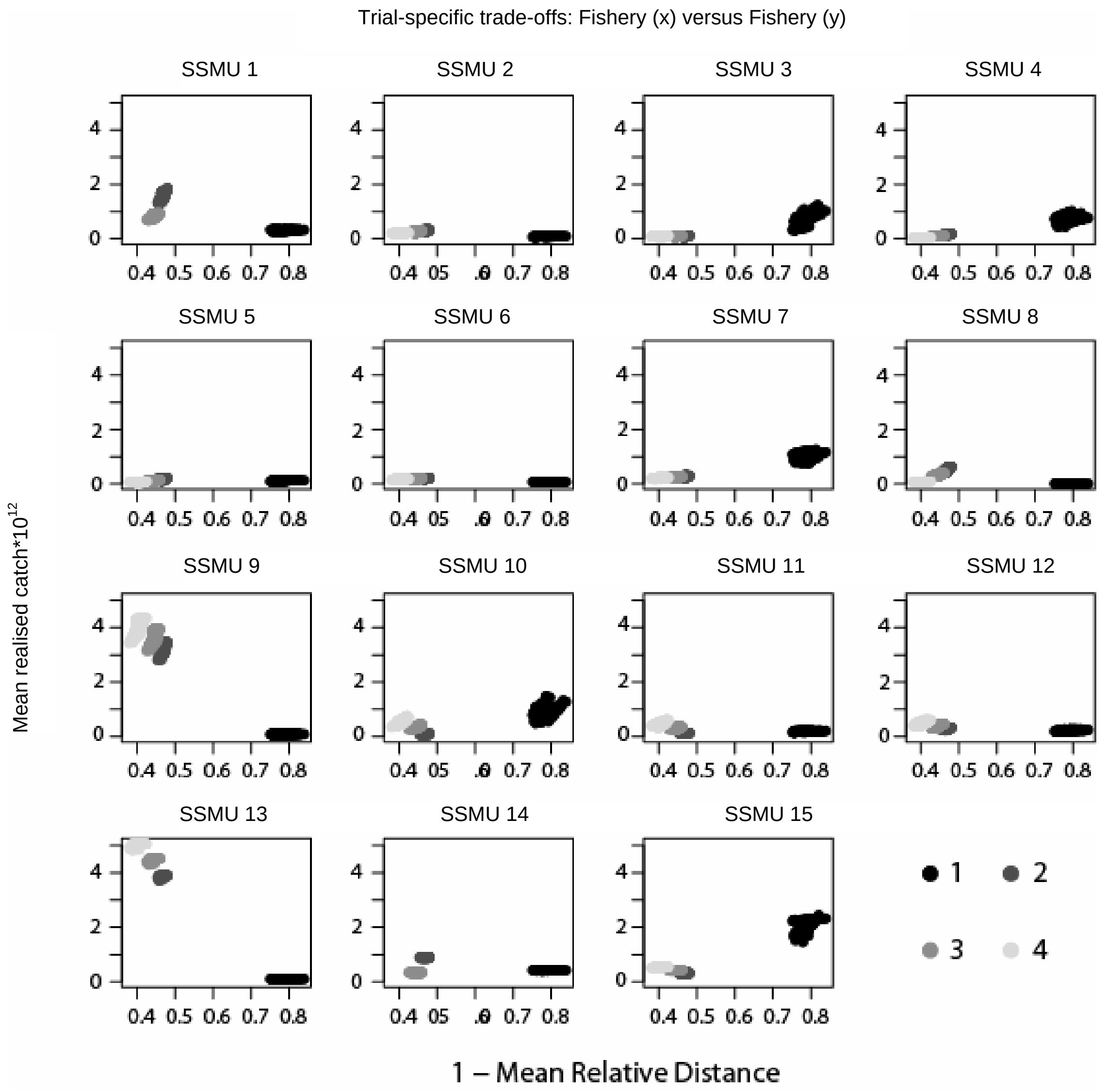

Figure 7: Fishery performance trade-offs between the distributions of catch relative to the historical distributions of catch versus the mean realised catch. Note the scale of each panel is the same, allowing for direct comparison of realised catches in each area. Fishing Options 1 to 4 are identified by a shaded dot and represent model simulations that incorporated the two main sources of uncertainty.

ATTACHMENT 1

AGENDA

Second Workshop on Management Procedures
(Walvis Bay, Namibia, 17 to 21 July 2006)

1. Introduction
   1.1 Adoption of agenda
   1.2 Co-convener presentation review of 2005 workshop findings: How did we get here?
   1.3 Papers tabled for consideration during the workshop

2. State of modelling
   2.1 Requested model incorporations
   2.2 Status of EPOC
   2.3 Status of SMOM
   2.4 Status of KPFM

3. Review of parameter plausibility and sensitivity
   3.1 Alternate parameterisation of transport and advection
   3.2 Short time steps and/or seasonality
   3.3 Krill density to halt fishing
   3.4 Review plausibility, sensitivity and uncertainty in other parameters

4. Model outputs and performance measures

5. Provisional advice to WG-EMM

6. Future work

7. Adoption of report and close of workshop.

ATTACHMENT 2

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