APPENDIX D

REPORT OF THE WORKSHOP ON MANAGEMENT PROCEDURES

(Yokohama, Japan, 4 to 8 July 2005)

CONTENTS

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INTRODUCTION

1.1 The Workshop on Management Procedures to Evaluate Options for Subdividing the Krill Catch Limit among Small-scale Management Units was held at the National Research Institute of Fisheries Science (NRIFS), Yokohama, Japan. The workshop was conducted during the first week of WG-EMM-05 (4 to 8 July 2005) and was co-convened by Drs K. Reid (UK) and G. Watters (USA).

1.2 The Provisional 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 Drs A. Constable (Australia), R. Hewitt (USA), R. Holt (USA), S. Kawaguchi (Australia), G. Kirkwood (UK), D. Ramm (Data Manager) and P. Trathan (UK).

REVIEW OF AIMS OF THE WORKSHOP

2.1 The workshop Co-conveners presented the background to the workshop and how it had evolved since the establishment of the precautionary catch limit for krill in 1991, noting:

(i) the known overlap in spatial distributions of krill catches and foraging areas of dependent species and the potential for fishing to impact on those species;

(ii) the limitation of fishing to 620 000 tonnes in Area 48 until a method for distributing the catch amongst subareas has been determined (Conservation Measure 51-01);

(iii) the request by the Commission to advise on a subdivision of the krill catch limit in Area 48 according to the SSMUs developed by WG-EMM and endorsed by the Commission in 2002 (CCAMLR-XXI, paragraph 4.6).

2.2 Following the past four workshops at WG-EMM in support of the development of a revised management procedure for krill, there was agreement by WG-EMM, which was endorsed by the Scientific Committee, that the first workshop to evaluate management procedures for the krill fishery should examine how well six candidate methods for subdividing the krill catch would meet the objectives of CCAMLR (SC-CAMLR-XXIII, Annex 4, paragraphs 6.12 to 6.24). The candidate methods to be evaluated included subdivisions 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.

2.3 The workshop agreed that its overall aim was to evaluate these six allocation options for subdividing the catch limit of Area 48 amongst the 15 SSMUs to meet the objectives of CCAMLR. In order to meet these aims the workshop agreed that there was a requirement to:

(i) identify models suitable to make appropriate evaluations;

(ii) discuss key topics relating to uncertainty and structural assumptions of such models;

(iii) discuss information required to facilitate the provision of management advice;

(iv) consider a mechanism to advance the outcomes of the workshop.

STRUCTURAL AND NUMERICAL ASSUMPTIONS OF THE OPERATION OF THE ECOSYSTEM AND FISHERIES IN AREA 48

3.1 At the previous meeting of the Working Group, three correspondence groups were established to consider krill, krill predators and the krill fishery (SC-CAMLR-XXIII, Annex 4, paragraphs 6.12 to 6.24). Dr Reid reminded the workshop that these correspondence groups had been tasked with the following issues in anticipation of the current workshop:

(i) to consider the range of datasets that would be necessary to initialise any models formulated to consider the candidate procedures;

(ii) to consider the range of alternative structural and functional assumptions that would be relevant to the dynamics of the predator–krill–fishery system and the formulation of any models constructed to consider the candidate procedures;

(iii) to identify important measures of performance. These measures would be used to determine whether the candidate procedures would be likely to produce results that were robust or sensitive both to the initialisation data and conditions, and to the alternative structural assumptions.

Review of reports from the Krill Correspondence Group

3.2 Dr Hewitt reported on communications among members of the Krill Correspondence Group. The correspondence group advised that three datasets describing the demography, distribution and abundance of krill in portions of the Scotia Sea would be appropriate for initialising models used to examine candidate procedures. These include:

(i) the surveys conducted by the British Antarctic Survey in the vicinity of South Georgia;

(ii) the series of surveys conducted in the vicinity of the South Shetland Islands by the US AMLR Program and Germany;

(iii) the CCAMLR-2000 Survey.

3.3 The correspondence group also advised that the most important assumptions regarding the dynamics of the predator–krill–fishery system were those that described the movement of krill within the Scotia Sea. The correspondence group noted that the possible range of assumptions could be characterised by two extremes:

(i) krill populations actively maintain their position in the vicinity of the major archipelagos (South Shetlands, South Orkneys, South Georgia) and there is no exchange between them (i.e. a situation with no krill flux);

(ii) all krill passively drift with the ACC, generally moving west to east through the Scotia Sea.

3.4 The correspondence group further advised that neither extreme was likely and that reality was somewhere in between. However, the correspondence group advised that by modelling these two extremes the range of possibilities would be covered.

3.5 The correspondence group also advised that it was likely that there were two sources of krill in the Scotia Sea: the Bellingshausen Sea via the ACC and the Weddell Sea via the Weddell Gyre.

3.6 Dr Hewitt noted evidence within the datasets described in paragraph 3.2 for large interannual variations in krill recruitment and that these variations may be autocorrelated in time. He further suggested that krill recruitment parameters be adjusted to reflect the degree of variability observed and that competing hypotheses of random versus autocorrelated variability be investigated.

3.7 Two papers were tabled at WG-EMM-05 that provided further information to be considered in the initialisation of models used to examine candidate procedures. These were:

(i) WG-EMM-05/41, which described geostrophic flow across three sections of the ACC as derived from hydrographic data collected on Russian surveys in the Scotia Sea;

(ii) WG-EMM-05/42, which described a reanalysis of acoustic data collected during the CCAMLR-2000 Survey.

These papers provided the basis for computing alternative parameters for initialising the movement matrix and initial krill densities respectively.

Review of reports from the Predator Correspondence Group

3.8 Dr Trathan reported on the intersessional work of the Predator Correspondence Group.

Relevant datasets

3.9 The Predator Correspondence Group recommended that the workshop utilise available CEMP data to provide information on predator population size, diet and breeding success. Further, that the matrices of available data that were developed for the CEMP Review Workshop (SC-CAMLR-XXII, Annex 4, Appendix 3) should be used to identify the most useful combinations of data.

Alternative assumptions

3.10 The Predator Correspondence Group advised that the following assumptions were likely to have differing implications for krill management, and that these should therefore be considered during the workshop:

(i) The presence or absence of krill flux (paragraph 3.3) will affect the breeding performance of land-based predators.

(ii) Land-based predators do/do not have traditional foraging grounds, and may/may not use alternative locations under differing environmental conditions.

(iii) Different predator species do/do not target krill swarms that have different aggregation characteristics, as revealed by their foraging behaviour.

(iv) Krill predator responses (foraging behaviour, output performance etc.) do/do not differ as a result of prey density or prey switching.

(v) Predators do/do not spend their winter periods outside the main summer breeding areas.

Indicators

3.11 The correspondence group advised that field-based indicators of reproductive performance should have a defined set of characteristics; this recommendation was based on ideas developed at the CEMP Review Workshop (SC-CAMLR-XXII, Annex 4, Appendix 3). Thus:

(i) indicators should relate to the krill-based food web
(ii) they should be sensitive to change and be based on practical field methods
(iii) indicators should have sufficient statistical power to detect change
(iv) both step changes and trend changes in the food web should be detectable.

3.12 The correspondence group advised that, as the workshop would be exploratory, the range of data, assumptions and indicators suggested (paragraphs 3.9 to 3.11), would enable a range of scenarios to be tested and that these would help the workshop in its task.

Review of reports from the Krill Fishery Correspondence Group

3.13 Dr Kawaguchi provided a report from the Krill Fishery Correspondence Group.

Data to be used to initialise the candidate procedures

3.14 Among the six candidate management procedures to subdivide the precautionary catch limit in Area 48, the correspondence group thought options (i) and (vi) were the options to be commented on by the correspondence group.

The spatial distribution of catches (option i)

3.15 The correspondence group advised that historical catches are to be used to initialise management option (i), taking into account:

(i) resolution of the data (spatially and temporally)
(ii) seasons
(iii) definition of fishing seasons.

3.16 The spatial resolution of the data should preferably be haul-by-haul or as fine-scale as possible to account for the curved boundaries of the SSMUs.

3.17 Krill, predators and krill fishery all have seasonality in their properties and the correspondence group suggested that in many cases a separation of the timing of importance between the predators and the fishery occurs. Subdividing a fishing season into quarterly periods was thought to be necessary to adequately reflect seasonal factors in interactions between those components.

3.18 It was also suggested that there were shifts in the main fishing grounds due to changes in the nations engaged in the krill fishery. The largest change in the catch occurred with the changing economic circumstances of the former Soviet Union in the early 1990s.

3.19 From the 1992/93 fishing season onwards, the total annual catch has gradually increased and became stable around 100 000 tonnes with the highest proportion of catch taken by Japan.

3.20 Examples of how the historical catch could be used to subdivide the catch among the SSMUs are, although not exclusively, limited to:

(i) use all historical catch data without subdividing into four seasons;

(ii) use all historical catch data with subdivision into four seasons;

(iii) use historical catch data only from the 1992/93 season onwards without subdividing into four seasons;

(iv) use historical catch data only from the 1992/93 season onwards with subdivision into four seasons;

(v) use of all historical catch data with subdivision into four seasons but weighted by the similarity of the historical fleet to the current fleet.

Pulse-fishing between SSMUs (option vi)

3.21 It was suggested that historical catches could be used to initialise this option such that historical maximum annual catch (520 000 tonnes), the current trigger level (620 000 tonnes) and the recent annual catch level (120 000 tonnes) could be rotated among SSMUs within each of the subareas. This could be further divided into seasons.

Alternative structural and functional assumptions

3.22 The correspondence group listed the following possible structural and functional assumptions.

(i) Fishery–predator interactions

(a) the types of krill aggregations which fisheries are targeting are the same (different) from the ones that predators target (size and density of the patch, distance from shore etc.);

(b) the fishery does (does not) avoid the active foraging areas of predators.

(ii) Fishery–krill interactions

(a) the fishery avoids (does not avoid) low quality krill (green krill);

(b) the fishery prefers (has no preference for) gravid females;

(c) the fishery follows (does not follow) drifting patches;

(d) the fishery prefers (has no preference for) certain types of krill aggregation (e.g. swarms or layers);

(e) the fishery only operates above critical densities; below these densities, vessels move onto nearby SSMUs.

3.23 Interactions between the fishery and krill depend on the decisions on where to fish made by the fishing operators. Therefore, information on fishing strategies and their economic implications are extremely important to understand these processes.

Performance measures

3.24 The following were suggested as candidate performance measures:

(i) catch per towing volume
(ii) catch per towing time
(iii) catch per day
(iv) catch per haul
(v) catch per searching time
(vi) daily factory operation time.

3.25 Each of the performance measures may have different levels of sensitivity to the different processes and fishing strategies involved. Since the sensitivity of performance measures is likely to be dictated by the resolution of data and also how they are modelled, it was recognised that exchanging information between each of the correspondence groups is necessary to give further advice.

Implications of future technical advancement and market demand

3.26 Implications of future technical advances and market demand were considered in relation to size composition of the catch, swarm type targeted, quality of krill being caught, predator by-catch, daily catch and overall catch. Pumping was suggested to be a likely method in the future, where krill are pumped from the codend continuously without hauling the net (WG-EMM-05/12).

3.27 It was recognised that different krill products require a different grade (quality) of krill catch and that using the different conversion factors for these products can dramatically change the estimation of total krill catch. Changes in the market demand may also affect the required quality of krill and product types, which has implications for the fishing and processing methodology.

Analysis of historical catch

3.28 WG-EMM-05/5 reported the annual time series of krill catches from SSMUs in Area 48, which was derived from fine-scale data and scaled to the total catches reported in the STATLANT data (Table 1). Annual catches in excess of 30 000 tonnes of krill have been taken in nine SSMUs.

3.29 The document further presented time series of catch and effort and overlap measure between predators and fishery by SSMU. It was indicated that the relative fishing-to-predation index (FPI) shows the largest value in SOW. Within each SSMU the relative FPI peaked typically in the 10-year period between 1986/87 and 1995/96, however, in APBSW and APW it peaked more recently (2000/01 and 1998/99 respectively).

3.30 WG-EMM-05/28 summarised changes of fishing ground in space and time since the early 1980s. Patterns of fishing ground selection were characterised using STATLANT and CCAMLR fine-scale data. Catch by every quarterly period by each SSMU was analysed. It further noted how SSMUs of relative importance vary dramatically inter- and intra-annually.

3.31 Among the 15 SSMUs within Subareas 48.1, 48.2 and 48.3, including the pelagic SSMUs, only one-third were identified as the main contributors to the total catch (SGE, SOW, APEI, APDPE, APDPW), and these SSMUs generally seem to match with the area of high krill density, but at the same time, other areas identified to show high density, including pelagic areas, were not used as fishing grounds. Dr V. Sushin (Russia) noted that although there are cases when scientific surveys recorded high krill abundances in the pelagic SSMUs, there is published evidence that such aggregations are unstable and therefore it is hard to make a profit by operating on these (Sushin, 1998; Sushin and Myskov, 1992).

3.32 A shift of operational timing towards later months within fishing seasons was observed in Subarea 48.1 (December–February to March–May). However, operational timing stayed relatively constant in Subareas 48.2 (March–May) and 48.3 (June–August).

3.33 In WG-EMM-05/28 patterns of seasonal SSMU selection were characterised into three patterns using cluster analysis. Frequently used SSMUs did not always match the areas of high krill densities observed by scientific surveys. However, the reasons for this are not clear.

3.34 Japan voluntarily submitted its entire haul-by-haul catch and effort data from Area 48 for the purpose of conducting analyses in preparation for this workshop. The workshop welcomed this contribution.

3.35 The workshop recognised that the better resolution of the information provided gives better foundation of the way historical fishery data may be used to subdivide catch limits under candidate management options (i) and (vi).

General discussion on ecosystem structure and function

3.36 After reviewing reports from the three correspondence groups and the relevant papers (WG-EMM-05/13, 05/14, 05/33 and 05/34), the workshop had a more general discussion about the structural and functional issues relating to the operation of the ecosystem and the manner in which these could be represented in a plausible model. These included:

(i) The benefits of a seasonally resolved model, compared to those of a model with a single annual time step.

   (a) The workshop noted that it would need to explore seasonality, as ecosystem properties would probably change for different seasons. This was likely to be necessary irrespective of season length. The workshop further noted that physical and biological processes would need to be represented at the same temporal scale.

   (b) The workshop recognised that the parameterisation of a model with intra-annual time steps could potentially present a number of challenges, but would be valuable. For example, it may be important to ensure that annual rates are not simply scaled rates estimated from a single season (e.g. from summer) as this could introduce bias.

(c) The potential for spatial and/or temporal separation between harvesting and centrally placed predators foraging during the breeding season. This may be best represented in a seasonal model with intra-annual time steps.

(ii) The transport or flux of krill from one region (or SSMU) to another (or other SSMU). The workshop recognised that transport could be represented by a transition matrix of probabilities derived from an oceanographic model seeded with passive particles (WG-EMM-05/13; Murphy et al., 2004). The workshop noted that:

(a) a probability transition matrix could be derived from flow fields derived from different circulation models of the Scotia Sea, from geostrophic calculations (WG-EMM-05/41), from satellite altimetry, or from oceanographic surface drifters;

(b) different probability transition matrices could be built for years of extreme environmental differences;

(c) the choice of time step was critical to the flux process, particularly where transport rates were very high;

(d) flux was not instantaneous and that mortality could be important during movement;

(e) passive movement may be modified by behaviour.

(iii) The fact that predators and fisheries may have different selection criteria for krill.

(iv) The fact that the availability of krill to the fishery and to predators was important, and that factors such as density and/or swarm characteristics would be important.

(v) The recognition that the movement of predators between SSMUs was potentially important.

(vi) The recognition that the dynamics of some pelagic predators may be independent of krill availability assessed at the scale of SSMUs.

(vii) The method for allocating catch and consumption, particularly when the combined demand was greater than the available abundance of krill. The workshop recognised that a mechanism for altering the relative allocations between the fishery and predators could be included in a model.

(viii) The need to account for harvesting of fish that are krill predators in some SSMUs.

CANDIDATE PERFORMANCE MEASURES

Performance measures for krill

4.1 The Krill Correspondence Group advised that the performance measures currently used by CCAMLR in the management of the krill fishery would be appropriate. These are based on:

(i) the probability that the spawning stock declines below 20% of the median level of the unexploited spawning stock;

(ii) the median spawning biomass of the krill population divided by the median spawning biomass of the unexploited population.

Performance measures for krill predators

4.2 Two categories of potential performance measures for krill predators were presented. These were (i) assessment of the conservation status of local populations based on rates of decline and recovery that are scaled to generation times, and (ii) the frequency of time steps in which these populations were below a reference 'depletion' level or above a reference 'recovery' level.

4.3 It was noted that performance measures should be defined in a manner consistent with the ecological theory represented by a particular model. This may include criteria defined in the simulation environment that represent a healthy ecosystem function as well as critical threshold levels that ensure the stable recruitment of predator species. A large number of performance measures could be developed from the output of a suitable model of the krill–predator–fishery system. The workshop also considered that any such performance measures should reflect both local-scale (SSMU) and global-scale (Area 48) population changes.

Performance measures for the krill fishery

4.4 The following performance measures for the krill fishery were introduced by Dr S. Hill (UK):

- absolute catch
- catch as proportion of allocation
- probability of 'voluntary change' (where krill density falls below a specified threshold).

4.5 The workshop noted that catch rate may also be an appropriate performance measure.

4.6 Deviation of fishing patterns from historical patterns of spatial distribution may also be a useful performance measure for the krill fishery. However, use of deviation from the current fishing patterns as a performance measure may be problematic since fishing patterns may change as annual catch and the number of countries fishing increases.

Presentation of performance measures

4.7 Presentation of performance measure was discussed. Graphical presentation was thought to convey important properties of the measures, and what might be considered to be robust performance (paragraphs 6.1 to 6.3). On the other hand, tables with true/false (i.e. binary) information are difficult to interpret. Overall, the workshop preferred graphical presentation over tabular presentation.

4.8 It was also realised that precise description of presentations is essential to convey the meaning of the graphs correctly. For example, describing fishery performance as absolute catch will often lead to different interpretations than describing fishery performance as the ratio of realised catch to allocated catch.

MODELS FOR PROVIDING ADVICE

Review of models presented to the workshop

5.1 Three papers describing models relevant to the evaluation of options for subdividing the precautionary krill catch limit amongst SSMUs in Area 48 were available to the workshop. These were WG-EMM-05/13, 05/14 and 05/33. Also considered relevant to these discussions was WG-EMM-05/34.

5.2 WG-EMM-05/13 described a krill–predator–fishery model (KPFM) developed specifically to address options for subdividing the precautionary catch limit amongst SSMUs in Area 48. The model is designed to investigate the performance of the identified options and their sensitivity to numerical and structural uncertainty. The model is spatially resolved to the level of SSMUs and surrounding oceanic areas, and it includes the transport of krill between these areas. Krill and predator population dynamics are implemented with coupled delay-difference models, which are formulated to accommodate various assumptions about the recruitment and predation processes. The fishery is represented as a simultaneous and equal competitor with predators for available krill. Monte Carlo simulations can be used to integrate the effects of numerical uncertainty, and structural uncertainty can be assessed by comparing and merging results from multiple such simulations. A range of possible performance measures was also presented that can be used to evaluate catch-allocation procedures and assess trade-offs between predator and fishery performance. The paper provided basic instructions on running the model in S-Plus and illustrated its use. Although the model necessarily simplifies a complex system, it provides a flexible framework for investigating the roles of transport, production, predation and harvesting in the operation of the krill–predator–fishery system.

5.3 WG-EMM-05/14 outlined a proposed spatial modelling framework that could be used to quantify the flux of krill past islands in the Antarctic Peninsula region, in an attempt to quantify what level and localisation of the fishing effort might impact the predators negatively. The approach described represents work in progress as the focus thus far has been on first developing a model of the possible impact of pelagic fishing on seal and penguin colonies on the South African west coast. The latter ecosystem shares a number of common features with the Antarctic Peninsula ecosystem in that there is a substantial advective flux of either pelagic fish or krill, with both species serving as dominant prey items for colonies of land-based predators in the region concerned. Subject to the availability of data from both predator studies and krill surveys, the South African west coast model methodology could potentially be adapted to the Antarctic Peninsula region. This would permit the evaluation of a wide range of management options taking into account the needs of other species when setting precautionary krill catch limits at an appropriate spatial scale.

5.4 WG-EMM-05/33 described an ecosystem, productivity, ocean, climate (EPOC) model that has been developed in the R statistical language to help explore topical issues on Antarctic marine ecosystems, including impacts of climate change, consequences of overexploitation, conservation requirements of recovery and interacting species, and the need to evaluate whether harvest strategies are ecologically sustainable. As such, it can be used to facilitate the development of plausible ecosystem models for evaluating management procedures for krill following the recommendations of the workshop held by WG-EMM in 2004. The EPOC model has been designed as an object-oriented framework currently built around the following modules: (i) biota, (ii) environment, (iii) human activities, (iv) management, (v) outputs, and (vi) presentation, statistics and visualisation. Each element within a module is an object carrying all its own functions and data. The EPOC model is designed to be a fully flexible plug-and-play modelling framework. This is because of the need to easily explore the consequences of uncertainty in model structures but, more importantly, to enable ecosystem modelling to proceed despite widely varying knowledge on different parts of the ecosystem and avoiding the need to guess model parameters for which no information exists. The EPOC model provides these opportunities as well as examining the sensitivity of outcomes to changes in model structures, not only in the magnitude of parameters but in the spatial, temporal and functional structure of the system. The paper presented a case study for Antarctic krill as an example.

5.5 In presenting his model, Dr Constable also provided an example of alternative ways of modelling different taxa rather than solely as age-structured or biomass models. This example illustrated that, within the same simulation, different species can be modelled at different spatial and temporal scales as well as with different biological and ecological complexity.

5.6 WG-EMM-05/34 described a model of the dynamics of krill, including four baleen whale (blue, fin, humpback and minke) and two seal (Antarctic fur and crabeater) species in two large sectors of the Antarctic. The model was developed to investigate whether predator–prey interactions alone can broadly explain observed population trends since the onset of seal harvests in 1780. It concluded that the answer to this question is yes, although not without some difficulties.

5.7 The workshop agreed that given the limited time available, it would concentrate its review on the KPFM described in WG-EMM-05/13.

Discussion of model selection/suitability

5.8 The process adopted by the workshop for reviewing the KPFM involved a number of steps. These included:

(i) detailed examination of the dynamics of the modelled krill and predator populations in a single SSMU under a range of different key biological parameter values, a fixed fishing pattern, and with and without movement. The emphasis here was on confirming that trends predictable from the input parameters chosen could be reproduced by the model;

(ii) as for (i), but with two coupled SSMUs;

(iii) a review of structural assumptions made in the model, with particular emphasis on identifying any factors that were not currently accounted for in the model, but which should be;

(iv) a review of appropriate parameter values for each of the main processes (biological dynamics of krill and predators, fishery characteristics and movement patterns between SSMUs);

(v) examination of runs of the full model (with 15 SSMUs) using updated parameter values.

5.9 A summary report of the model performance with only one or two SSMUs is included in Attachment 3. The workshop agreed that the model had performed very satisfactorily on these trials, with outcomes corresponding to predictions in each trial experiment.

5.10 The review of structural assumptions of the model is discussed under Agenda Item 3 (paragraph 3.36). The workshop agreed that at least three key aspects should be given further attention in the models and their implementation:

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

5.11 In respect of seasonality, it was agreed that this was important both to model more accurately the seasonality of the dynamics and feeding behaviour of predators and to take account of variable timing within a year of the fisheries and peak predator foraging in different SSMUs (see also paragraphs 3.10 and 3.17).

5.12 At present, movement matrices estimated for the model allow either for no movement between SSMUs, or movements estimated from runs of the Ocean Circulation Climate Advanced Modelling (OCCAM) project (see Murphy et al., 2004). It was agreed that incorporation of a seasonal time step might allow a more realistic portrayal of movements between SSMUs than is currently possible with an annual time step.

5.13 Different movement patterns and rates may be implied by the results presented in WG-EMM-05/41, but it was not possible during the meeting to develop alternative movement matrices to reflect these (see paragraph 3.36(ii)). The workshop agreed that these should be developed during the coming year. However, it was noted that when different water movement rates are applied, the seasonal changes in krill abundance have to be considered along with the water exchange rates to avoid an overestimate of the overall annual krill flux.

5.14 Subject to incorporation of these structural changes, which could be carried out in the coming year, the workshop agreed that the KPFM was in principle suitable for use to investigate the different options for catch limit subdivision, however it noted that a final decision would have to await demonstration of suitable performance of the model when applied to all 15 SSMUs and revised parameter sets. This is discussed in the next section.

5.15 The workshop congratulated the authors of WG-EMM-05/13 for the large amount of work they had carried out, and especially for the excellent progress that had been made on model development and parameterisation in such a short time. In particular, several participants noted that, despite many attempts elsewhere in the world, there are very few examples of ecosystem models that are being, or are capable of being, used to develop explicit management advice on catch limits or the subdivision of catches in an ecosystem context. The progress that has been achieved so far with the KPFM is therefore very encouraging.

Choice of parameters for the KPFM

5.16 Small groups of workshop participants with expertise in each of the main species groups were asked to review the parameters used to generate the KPFM results presented in WG-EMM-05/13 for the full set of SSMUs. Unfortunately, only limited time was available for this after completion of the initial model structural review. Consequently, while some revisions were made to parameter values, each group reported that it had had insufficient time to consider these in sufficient depth and to take account of all relevant data.

5.17 It was therefore not entirely unexpected that when these revised parameter sets were used in test runs of the full model, it became clear that additional work would be needed to further refine the parameter values and to ensure consistency between them. In the absence of time to allow this, the workshop agreed that it would not be appropriate to attempt to conduct simulation trials with a view to providing advice on the different catch allocation options or subdivision of catch limits amongst SSMUs at this meeting.

Future work necessary to provide advice on SSMU catch limit subdivision

5.18 The workshop agreed that sufficient progress had been made with the KPFM development this year for it to believe that a further year's work should allow appropriate advice based on runs with a revised version of the simulation model to be provided by WG-EMM to the Scientific Committee and Commission next year.

5.19 In order to achieve this, however, it is essential that appropriate benchmarks be established. It was agreed that it would be necessary to present to WG-EMM next year sets of results that demonstrated the sensitivity of results and performance measures to plausible ranges of model parameters and structural hypotheses and robustness to uncertainties.

5.20 For the KPFM, the work required is relatively easily specified. The workshop agreed, however, that it would also be valuable if results were also available from other models (see also paragraph 5.26).

5.21 In relation to the model in WG-EMM-05/14, Dr É. Plagányi (South Africa) commented that she was now more confident that data were available to allow her to attempt to apply the approach. Preliminary work on this would be carried out in the next few months. If this confirmed the potential applicability of the model, she hoped to be able to present a paper describing its application to Area 48 at the next meeting of WG-EMM.

5.22 In relation to the EPOC model (WG-EMM-05/33), Dr Constable indicated that he had already started work on developing a model that would be complementary to the KPFM, and that he intended to continue this work in the coming months. He noted that one of the potential advantages of the EPOC framework was that it was possible to incorporate different assumptions regarding the dynamics of the main component species. By doing so and comparing results with those of the KPFM, this may allow identification of which are the key parameters in the system and allow partial validation of the results of the two models. He noted, however, that an important difference at present between the EPOC model and the KPFM was that the former is much slower to run.

5.23 The workshop noted that it would be desirable for WG-EMM to provide opportunities for the Working Group to become familiar with these models when they are presented, as was done for the KPFM.

5.24 Dr Plagányi noted that the model in WG-EMM-05/34 is not currently suitable for the development of management advice in this context, but could be used to explore the effect of trends in abundances over larger spatial scales than those addressed in the KPFM.

5.25 The workshop agreed that, in order to be in a position to provide advice next year, it is essential that the benchmarks identified in paragraph 5.19 be achieved. The workshop further agreed that scientists undertaking development of the KPFM or other models during the intersessional period coordinate as necessary through the steering group set up by WG-EMM last year (SC-CAMLR-XXIII, Annex 4, paragraph 5.62). Given the experience of the workshop, however, it is essential that this group include the full range of necessary expertise. It therefore recommended that WG-EMM bear this in mind when reviewing the group at its meeting this year (see also paragraph 7.6).

5.26 The workshop noted that procedures will need to be determined for how to assess and use the results of multiple models in this work, given that three models may be available to assist with this task. It recommended that WG-EMM ask the steering committee to provide advice on this to the Working Group next year.

PERFORMANCE OF INDIVIDUAL OPTIONS

6.1 The workshop noted that the evaluation of the candidate options for subdividing catch limits required an examination of their robustness in meeting the objectives of CCAMLR. This is achieved in a number of steps:

- erecting a sufficiently plausible description of the ecosystem, the fishery and the candidate option in a simulation model, termed the ‘operating model’;

- using the operating model to simulate the system, keeping track of the important states of each species, the fishery as well as other parameters;
- determining the performance of the system according to important ecosystem and fishery 'performance measures';
- doing this many times to account for natural variability and uncertainty, thereby providing probabilities of different levels of the chosen performance measures.

6.2 A candidate strategy would be considered 'robust' to underlying uncertainties if the objectives of CCAMLR can be met, irrespective of model structure, uncertainty in parameter estimates or natural variability. Robustness is estimated by the probability of 'good' performance shown by the performance measures. As such, the measures of performance need to relate to the objectives of CCAMLR; each performance measure articulates, in a quantitative way, aspects of the objectives.

6.3 Of course, each candidate option will not perform the same way across all performance measures. The important part of this evaluation work is to illustrate the trade-offs between performance measures as well as to present the potential consequences of different options to krill, dependent species and the fishery. The workshop agreed that advice may not be able to be provided as to the relative importance of different measures. It agreed that methods for presenting the trade-offs need to continue to be explored but that a graphical presentation, such as in Figure 1, would be a good foundation for such presentations.

6.4 The workshop agreed that it was unable, at this time, to comment on the robustness of the candidate options for subdividing the catch limit for krill in Area 48 amongst SSMUs. Nevertheless, it has made substantial progress in developing the tools and parameter sets for providing advice on a subdivision of the Area 48 catch limit in the near future. The workshop agreed that advice to the Scientific Committee should be possible next year.

ADVICE TO WG-EMM

7.1 Following the past four workshops at WG-EMM in support of the development of a revised management procedure for krill, there was agreement by WG-EMM in 2004 (SC-CAMLR-XXIII, Annex 4, paragraph 6.13), which was endorsed by the Scientific Committee (SC-CAMLR-XXIII, paragraphs 3.86 to 3.90), that the first workshop to evaluate management procedures for the krill fishery should examine how well six candidate methods for subdividing the krill catch would meet the objectives of CCAMLR (paragraph 2.2).

7.2 The workshop agreed that the performance measures for krill based on the current operational decisions used by CCAMLR in the management of the krill fishery would be appropriate (paragraph 4.1). Two categories of potential performance measures for krill predators were suggested (paragraphs 4.2 and 4.3). In addition, performance measures for the krill fishery were provided (paragraph 4.4).

7.3 Three papers describing models relevant to the evaluation of options for the subdivision of the precautionary krill catch limit in Area 48 amongst SSMUs were presented (paragraphs 5.1 to 5.7). The workshop agreed that, given the limited time available, it would concentrate its review on the KPFM described in WG-EMM-05/13.

7.4 The workshop agreed that sufficient progress had been made with the KPFM development this year for it to believe that a further year's work should allow appropriate advice based on runs with a revised version of the simulation model to be provided by WG-EMM to the Scientific Committee and Commission next year (paragraph 5.18). The workshop agreed, however, that it would be valuable if results were also available from other models (paragraphs 5.20 to 5.26).

7.5 The workshop noted that the evaluation of the candidate options for subdividing catch limits required an examination of their robustness in meeting the objectives of CCAMLR. This could be achieved by the work and approaches outlined in paragraphs 6.1 to 6.3.

7.6 The workshop discussed possible ways of continuing its work intersessionally, and recommended that a means to facilitate this be considered by WG-EMM.

ADOPTION OF THE REPORT AND CLOSE OF THE MEETING

8.1 The report of the workshop was adopted.

8.2 The workshop agreed that the KPFM, with its extensive documentation, graphic outputs and diagnostics, had successfully engaged participants from a wide range of backgrounds, including those with and without sophisticated modelling skills. This level of participation encouraged exploration of the effects of various parameter combinations and structural assumptions, as well as facilitated consensus agreement on future work.

8.3 The Co-conveners of the workshop, Drs Reid and Watters, thanked the participants for their work and cooperation during the workshop. They also thanked Drs Hewitt, Kawaguchi and Trathan, the coordinators of the correspondence groups, for their contributions in preparation for, and during, the workshop, and the Secretariat for its contribution and support.

8.4 Dr Constable, on behalf of the participants, thanked the Co-conveners for their leadership in developing an approach to the evaluation of the management procedures for the krill fishery. The workshop also thanked the Co-conveners, and Dr Hill and Mr J. Hinke (USA), the co-authors of the KPFM, for their great effort in developing and testing that model.

8.5 The Co-conveners thanked Dr Naganobu and his organising team for their support and hospitality.

8.6 The workshop closed on 8 July 2005.

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Table 1: Annual catch (tonnes) of krill from the fishery in Area 48, by season and SSMU. Antarctic Peninsula (AP) SSMUs: Pelagic Area (APPA); Bransfield Strait East (APBSE); Bransfield Strait West (APBSW); Drake Passage East (APDPE); Drake Passage West (APDPW); Antarctic Peninsula West (APW); Antarctic Peninsula East (APE); Elephant Island (APEI). South Orkney Islands (SO) SSMUs: Pelagic Area (SOPA); North East (SONE); South East (SOSE); West (SOW). South Georgia (SG) SSMUs: Pelagic Area (SGPA); East (SGE); West (SGW). Other: Area 48, unspecified or outside SSMUs. Source: fine-scale data weighted to catches reported in the STATLANT data (see WG-EMM-05/5 for detail).

Season	SSMU group weighting factor			Total catch (tonnes)	SSMU																Other
	AP	SG	SO		APBSE	APBSW	APDPE	APDPW	APE	APEI	APPA	APW	SGE	SGPA	SGW	SONE	SOPA	SOSE	SOW	
1980/81	18.9		*	154474	887	27	22047	8522	134	16199	45630	271					*60540			217
1981/82	13.2		187.2	326788		1	7277	15186		5062	40407	260				1081	238628		18887	
1982/83	1.2	*	13.5	65115				4			2290			*2004		631	51731		7710	745
1983/84	1.0	*	1.0	40534	5	0	9725	3619	17	4196	12411	258		*73		1145	59	1	9025	
1984/85	1.2	*	6.2	212011	6		3108	477		6370	2961	11		*60724		8517	10975		118863	
1985/86	1.2	*	12.2	378739	32		8317	2705		21051	7367	1574		*110596		4656	5336		217104	1
1986/87	1.0	3.6	1.0	400835		1	9022	187		53785	7274		312134			196	1102		17128	5
1987/88	1.1	1.0	1.0	388953		0	34171	10363		24967	9387	30	105990	105636	24	4323	4627	19284	70047	104
1988/89	1.0	1.0	1.0	352271		18	37689	17193		42132	8490	33	157204	1412		14	72755		15332	
1989/90	1.0	1.0	1.0	376099	106		13847	691		24002	6097	8	89557	11349	6907	12657	81808		129067	
1990/91	1.0	1.2	1.0	331318	1035	6	16580	15508		29719	6818		88023	8339	5307	12774	5249		141961	
1991/92	1.0	0.9	1.4	257663	32	5	21668	40754		6355	6735	15	49115	331	14801	3665	48708		65429	50
1992/93	1.0	1.1	1.0	60783		43	928	29870		2373	54		3478	124	11139	4111	1253		7306	104
1993/94	1.0	1.0	1.0	84645		107	1066	26237		17659	11	5	19908	381	11	80	4	1303	17872	
1994/95	1.0	1.2	1.0	134420		179	2922	11674		15030	8359		46624	473	325	1273	27	24	47509	
1995/96	1.0	1.0	1.3	91150		507	5772	36695	25	12613	6351		23872	14	2566	4	51		2679	
1996/97	1.0	1.0	*	75653	13	87	17489	20389		9143	1722		26605		106		*99			
1997/98	1.0	1.0	1.0	90024	102	679	18853	24205		5808	4047	2879	23301	54	3422	290	602		5781	
1998/99	1.0	*	1.0	101957	914	24	10732	11364		8970	2982	3910		*985		3379	984	12324	45389	
1999/00	0.9	1.3	1.0	114425	3728	4950	21073	30090		10673	1362	101	14992	8335	2230	1130	3145	1493	11123	
2000/01	0.9	1.5	1.0	104182	609	3255	16444	21902		4133	5	430	37186	534	14703	1354	2	2511	1114	
2001/02	1.0	1.1	1.3	125987	94	285	1449	4672		4114	32		30856	3079	9346	3354	70	1161	67474	
2002/03	1.1	1.0	0.9	117728	18	256	2029	31905		1040	67	62	52003	791	14131	54	509	44	14821	
2003/04	2.3	1.2	1.7	118166	4282	862	439	3534		3414	836	514	26158	309	31362	348	261	17	45830	

* Weighting cannot be determined (STATLANT data reported for SSMU group, fine-scale data for related SSMU insufficient), catch is for the SSMU group.

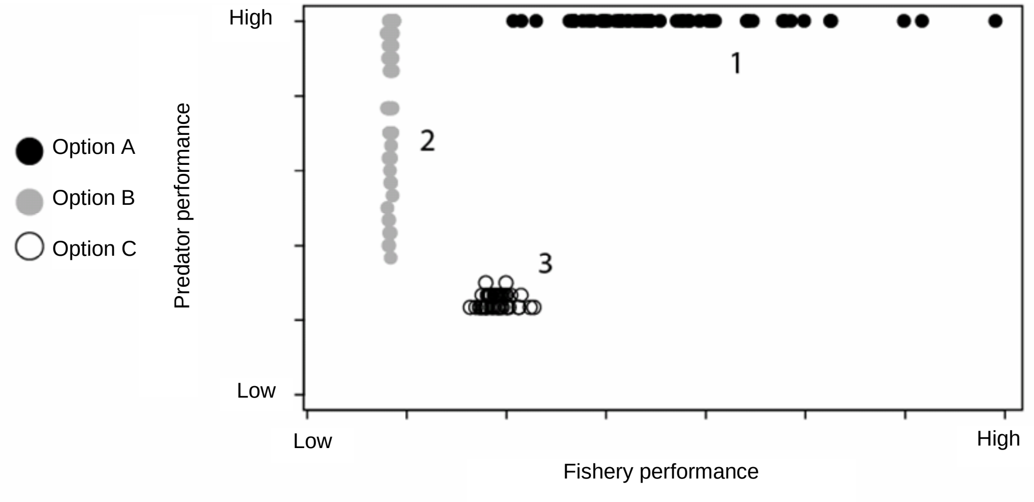

Figure 1: An example illustration of the trade-offs associated with three candidate management procedures (identified as Options A–C). A hypothetical measure of fishery performance is used to define the x-axis of the plot, and a hypothetical measure of predator performance is used on the y-axis. Three groups of points are illustrated in the plot, and each group is associated with one of the candidate procedures. The points in group 1 illustrate the outcomes of simulations in which Option A is used as the fishery management procedure. This procedure results in variable fishery performance and high predator performance. The points in group 2 illustrate the outcomes of simulations using Option B; this procedure results in poor fishery performance and variable predator performance. The points in group 3 illustrate simulated outcomes from Option C. This management procedure results in low fishery performance and low predator performance. The examples presented here are simply illustrative.

ATTACHMENT 1

AGENDA

Workshop on Management Procedures
(Yokohama, Japan, 4 to 8 July 2005)

1. Introduction
   1.1 Opening of the workshop
   1.2 Adoption of the agenda and organisation of the workshop

2. Review of aims of the Workshop on Management Procedures to evaluate options for subdividing the krill catch limit among SSMUs

3. Structural and numerical assumptions of the operation of the ecosystem and fisheries in Area 48
   3.1 Review of the reports from the Correspondence Group on Krill
   3.2 Review of the reports from the Correspondence Group on Predators
   3.3 Review of the reports from the Correspondence Group on the Krill Fishery

4 . Candidate performance measures
   4.1 Performance measures for krill
   4.2 Performance measures for krill predators
   4.3 Performance measures for the krill fishery

5. Models for providing management advice
   5.1 Review of model(s) presented to the workshop
   5.2 Discussion of model selection/suitability
   5.3 Choice of parameters for model(s) selected in subitem 5.2

6. Performance of individual options

7. Advice to WG-EMM.

ATTACHMENT 2

LIST OF PARTICIPANTS

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(Yokohama, Japan, 4 to 8 July 2005)

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ATTACHMENT 3

SOME EXPLORATIONS WITH KPFM –
MOVING FROM PREDICTING OUTCOMES TO EXPLAINING OUTCOMES

SOME EXPLORATIONS WITH KPFM –
MOVING FROM PREDICTING OUTCOMES TO EXPLAINING OUTCOMES

The Workshop on Management Procedures used a set of simplified examples to review the Krill–Predator–Fishery Model (KPFM) (paragraphs 5.7 and 5.8). Those examples are provided in this attachment. Tables 1 and 2 provide the parameter values and initial information used to generate the examples. This attachment is presented as a series of Microsoft Powerpoint slides that are taken from an original presentation made at the workshop.

Table 1: State variables and parameters for krill and other initial conditions used in Examples 1 to 13. Parameter and variable names are identified as they are implemented in the S-Plus version of the KPFM; definitions of these parameters and variables are provided in WG-EMM-05/13. In the movement matrices (v.matrix), the letter 'S' is used to indicate an SSMU, and the letters 'BT' are used to indicate boundary areas.

Parameter or variable name in S-Plus	Values used in Examples 1–9	Values used in Examples 10–13
M0	Examples 1–9: 0	Examples 10–13, SSMUs 1–2: 0
Ralpha	Examples 1–3, 7–9: $2.5{\cdot}10^{11}$ Examples 4–6: $2.7{\cdot}10^{11}$	Examples 10–13, SSMUs 1–2: $2.5{\cdot}10^{11}$
Rbeta	Examples 1–9: $1.0{\cdot}10^{8}$	Examples 10–13, SSMUs 1–2: $1.0{\cdot}10^{8}$
krill.Rage	Examples 1–9: 2	Examples 10–13, SSMUs 1–2: 2
Rphi	Examples 1–9: 0	Examples 10–13, SSMUs 1–2: 0
wbar	Examples 1–9: 1	Examples 10–13, SSMUs 1–2: 1
historical.catch	Examples 1–9: $2.28{\cdot}10^{11}$	Examples 10–13: SSMU 1: $4.56{\cdot}10^{11}$ SSMU 2: $2.28{\cdot}10^{11}$
areas	Examples 1–9: $1.58{\cdot}10^{10}$	Examples 10–13, SSMUs 1–2: $1.58{\cdot}10^{10}$
v.matrix	Examples 1–7: (from \\ to) $\begin{array}{c\|ccc} & S1 & BT1 & BT2 \\ \hline S1 & 0 & 0 & 0 \\ BT1 & 0 & 0 & 0 \\ BT2 & 0 & 0 & 0 \end{array}$	Examples 10, 12–13: (from \\ to) $\begin{array}{c\|cccc} & S1 & S2 & BT1 & BT2 \\ \hline S1 & 0 & 0 & 0 & 0 \\ S2 & 0 & 0 & 0 & 0 \\ BT1 & 0 & 0 & 0 & 0 \\ BT2 & 0 & 0 & 0 & 0 \end{array}$
	Example 8: (from \\ to) $\begin{array}{c\|ccc} & S1 & BT1 & BT2 \\ \hline S1 & 0 & 0 & 0.1 \\ BT1 & 0.5 & 0 & 0 \\ BT2 & 0 & 0 & 0 \end{array}$	Example 11: (from \\ to) $\begin{array}{c\|cccc} & S1 & S2 & BT1 & BT2 \\ \hline S1 & 0 & 0.1 & 0 & 0 \\ S2 & 0 & 0 & 0 & 0 \\ BT1 & 0 & 0 & 0 & 0 \\ BT2 & 0 & 0 & 0 & 0 \end{array}$
	Example 9: (from \\ to) $\begin{array}{c\|ccc} & S1 & BT1 & BT2 \\ \hline S1 & 0 & 0 & 1 \\ BT1 & 0.1 & 0 & 0 \\ BT2 & 0 & 0 & 0 \end{array}$	
sd.krill.Rdev	Examples 1–9: not used (random.Rkrill = F)	Examples 10–13: not used (random.Rkrill = F)
env.index	Examples 1–9: not used (env.index = NULL)	Examples 10–13: not used (env.index = NULL)
init.density	Examples 1–9: 37.7	Examples 10–13, SSMUs 1–2: 37.7
available.fraction	Examples 1–6, 8–9: 0.95 Example 7: 0.2	Examples 10–12, SSMUs 1–2: 0.95 Example 13: SSMU 1: 0.8 SSMU 2: 0.2
actual.gamma	Examples 1–9: 0.17	Examples 10–13: 0.17
nyears	Examples 1–9: 50	Examples 10–13: 50
start.fishing	Examples 1–9: 11	Examples 10–13: 11
stop.fishing	Examples 1–9: 31	Examples 10–13: 31
fishing.option	Examples 1, 3–4, 7–9: NULL Examples 2, 5–6: 1	Examples 10–11: NULL Examples 12–13: 1

Table 2: State variables and parameters for predators used in Examples 1 to 13. Parameter and variable names are provided as they are implemented in the S-Plus version of the KPFM; definitions of these parameters and variables are provided in WG-EMM-05/13.

Parameter or variable name in S-Plus	Values used in Examples 1–9	Values used in Examples 10–13
M	Examples 1–9, Penguins: 0.16	SSMUs 1–2, Penguins: 0.16
	Examples 3–6, Seals: 0.08	
Rage	Examples 1–9, Penguins: 7	SSMUs 1–2, Penguins: 3
	Examples 3–6, Seals: 3	
Ralpha	Examples 1–9, Penguins: 0.5	SSMUs 1–2, Penguins: 0.5
	Examples 3–6, Seals: 0.5	
RRpeak	Examples 1–5, 7–9, Penguins: $8.2 \cdot 10^5$	SSMUs 1–2, Penguins: $8.2 \cdot 10^5$
	Example 6, Penguins: $6.56 \cdot 10^5$	
	Examples 3–5, Seals: $1.153 \cdot 10^4$	
	Example 6, Seals: $6.9 \cdot 10^3$	
RSpeak	Examples 1–5, 7–9, Penguins: $2 \cdot 10^6$	SSMUs 1–2, Penguins: $2 \cdot 10^6$
	Example 6, Penguins: $2.5 \cdot 10^6$	
	Examples 3–5, Seals: $7.3 \cdot 10^4$	
	Example 6, Seals: $1 \cdot 10^5$	
QQmax	Examples 1–9, Penguins: $4.3 \cdot 10^5$	SSMUs 1–2, Penguins: $4.3 \cdot 10^5$
	Examples 3–6, Seals: $1.7 \cdot 10^6$	
Rphi	Examples 1–5, 7–9, Penguins: 2	SSMUs 1–2, Penguins: 2
	Example 6, Penguins: 1	
	Examples 3–5, Seals: 2	
	Example 6, Seals: 0.1	
Qk5	Examples 1–9, Penguins: 20	SSMUs 1–2, Penguins: 20
	Examples 3–6, Seals: 20	
Qq	Examples 1–9, Penguins: 0	SSMUs 1–2, Penguins: 0
	Examples 3–6, Seals: 0	
init.demand	Examples 1–9, Penguins: $2.505 \cdot 10^{11}$	SSMUs 1–2, Penguins: $2.505 \cdot 10^{11}$
	Examples 3–6, Seals: $1.98 \cdot 10^{10}$	

Slide 1: Description of the initial conditions for Examples 1 to 9, where krill–predator–fishery interactions were simulated in a single SSMU.

Basic Setup for 1 SSMU

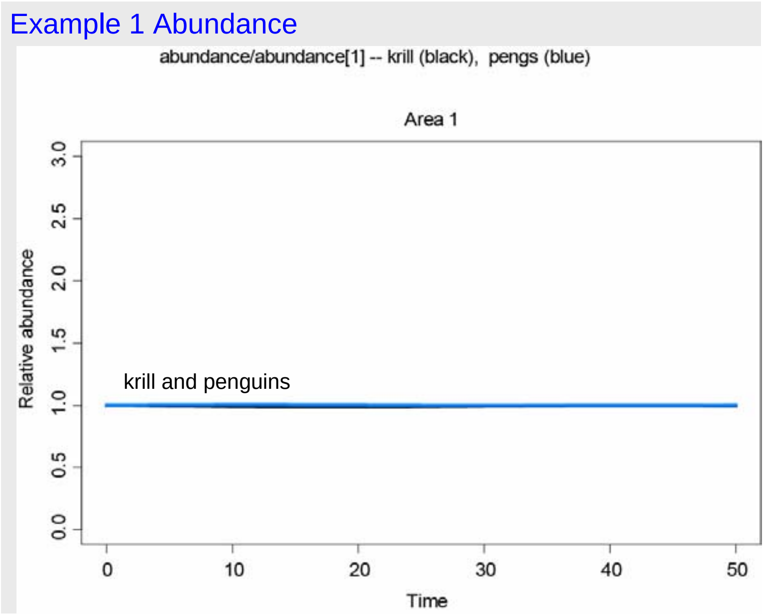
- 50-yr simulations
- If **FISHING** then start = 11 and stop = 31
- No random variation in krill recruitment
- Hyperdepletion in relationship between relative consumption and relative breeders
- Penguins recruit at age 7 and seals recruit at age 3
- If **MOVEMENT** then immigration from and emigration to single bathtub
- If **LOW available.fraction** then change 0.95 to 0.2

Slide 2: The sequence of examples used to review the KPFM when interactions inside a single SSMU are simulated (Examples 1 to 9). The column marked 'setup' describes each example. The column marked 'conditions' describes the initial relationship between krill recruitment (R), demand by predators (D1 for penguins and D2 for seals), and the catch allocated to the fishery (AC). The conditions also describe whether, when the setup includes movement of krill between a boundary area (BT) and the SSMU, imports (I) are greater or less than exports (E). The column marked 'expectations' provides a short description of the dynamics that would be expected in each example.

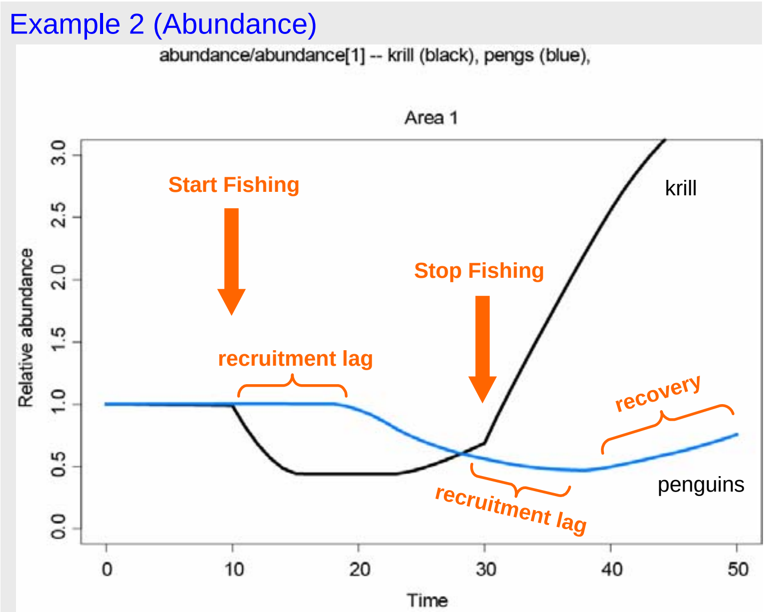
Sequence with Single Area

#	Setup	Conditions	Expectations
1	Penguin	R = D1	Flat lines
2	1 + Fishing	R < D1+AC	Decreases then Increases
3	1 + Seal	R < D1+D2	Decreases
4	3 + More Krill R	R = D1+D2	Flat lines
5	4 + Fishing	R < D1+D2+AC	Decreases & Lagged Increases
6	5 + Proportional Penguins + Hyperstable Seals	R < D1+D2+AC	Increases from 5 with Seals increasing more
7	1 + low available.fraction	R = D1	Penguins decrease then increase and krill increase
8	1 + Movement from BT	R = D1, I > E	Increases
9	1 + Movement from BT	R = D1, I < E	Decreases

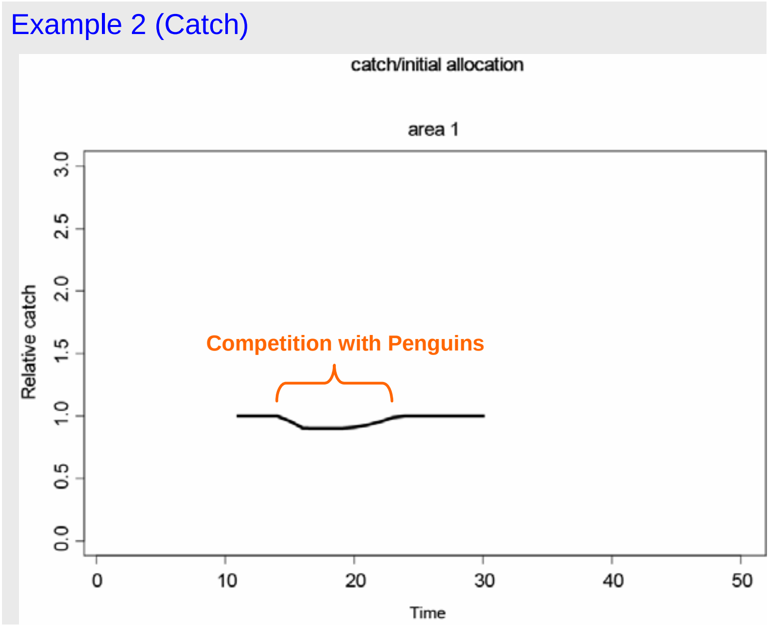
Slide 3: Simulation with a single SSMU and one predator (penguins). Recruitment of krill satisfies predator demand.



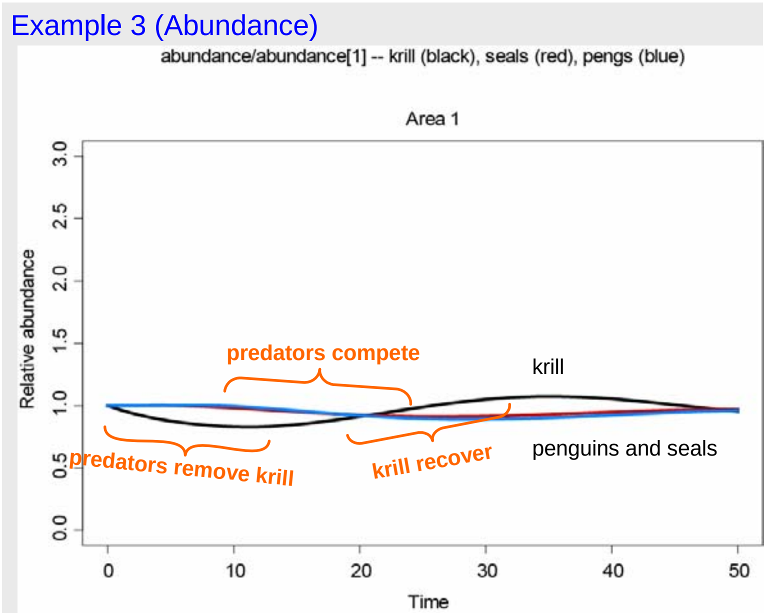
Slide 4: Simulation with a single SSMU, one predator (penguins), and krill fishing. Krill recruitment does not satisfy the sum of demand by predators and catch allocated to the fishery.



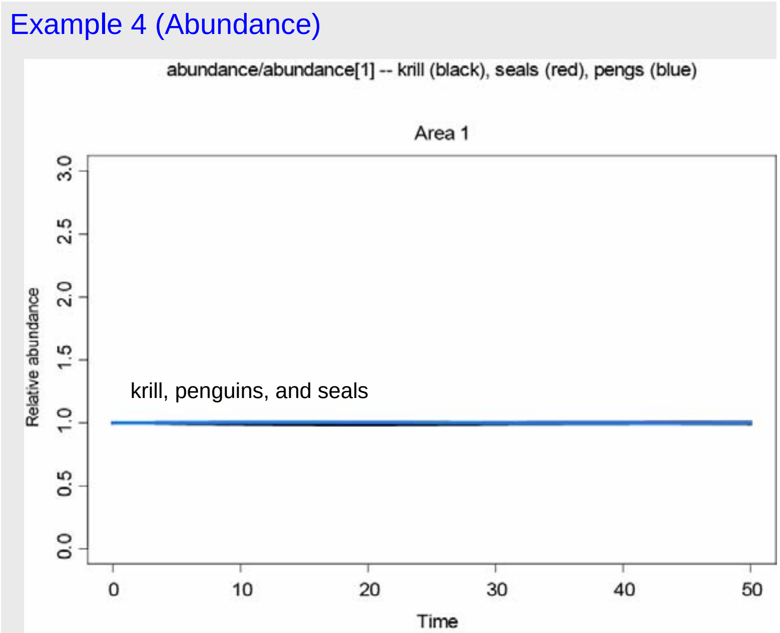
Slide 5: Simulation with a single SSMU, one predator (penguins), and krill fishing. Krill recruitment does not satisfy the sum of demand by predators and catch allocated to the fishery.



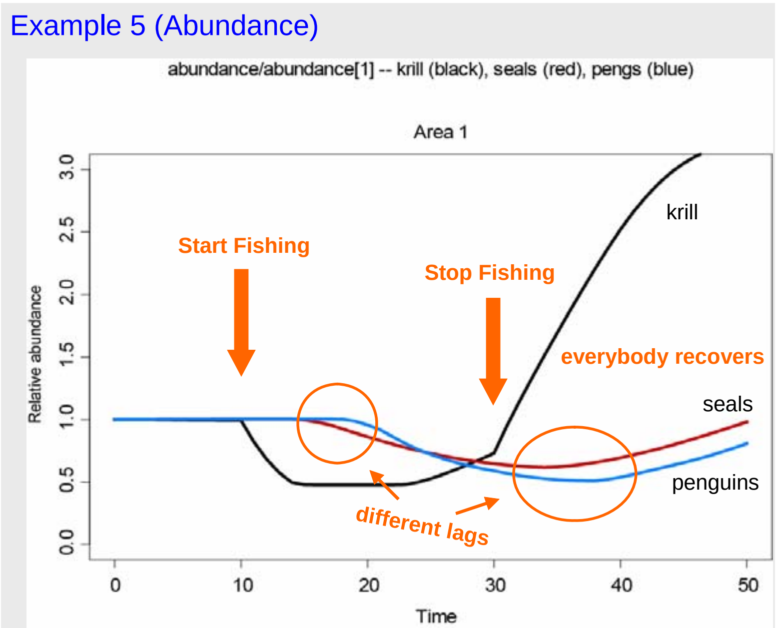
Slide 6: Simulation with a single SSMU and two predators (penguins and seals). Krill recruitment does not satisfy the sum of the demands by both predators.



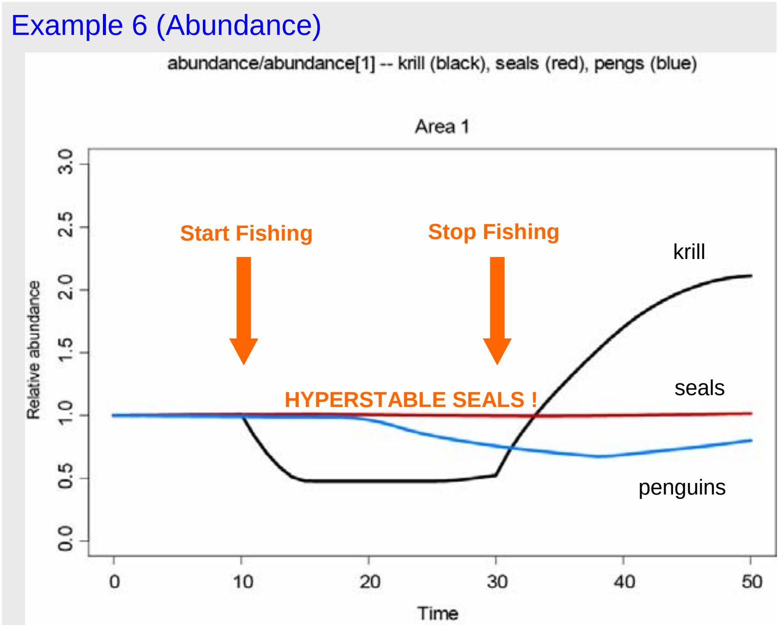
Slide 7: Simulation with a single SSMU and two predators (penguins and seals). Krill recruitment satisfies the sum of the demands by both predators.



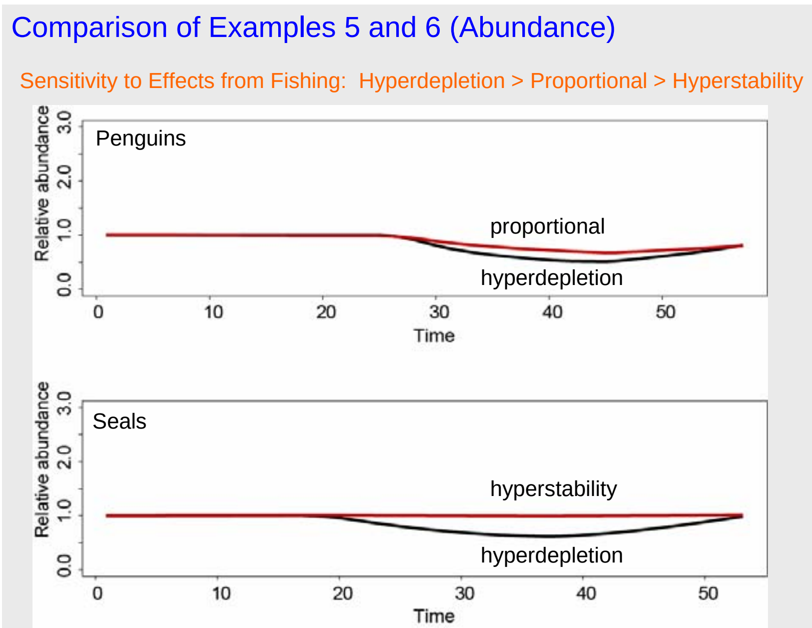
Slide 8: Simulation with a single SSMU, two predators (penguins and seals), and krill fishing. Krill recruitment does not satisfy the sum of demands by predators and catch allocated to the fishery.



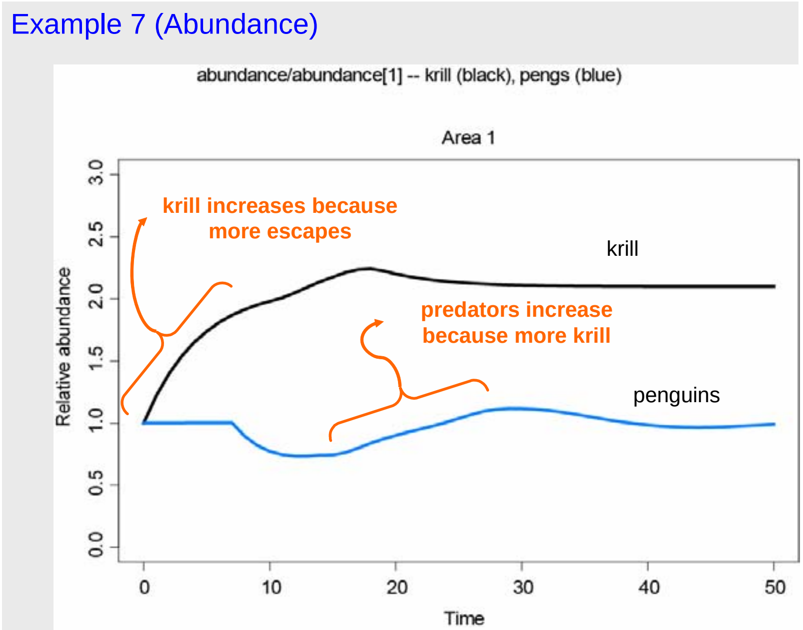
Slide 9: Simulation with a single SSMU, two predators (penguins and seals), and krill fishing. Krill recruitment does not satisfy the sum of demands by predators and catch allocated to the fishery, but decreases in krill consumption have reduced effects on predator breeding.



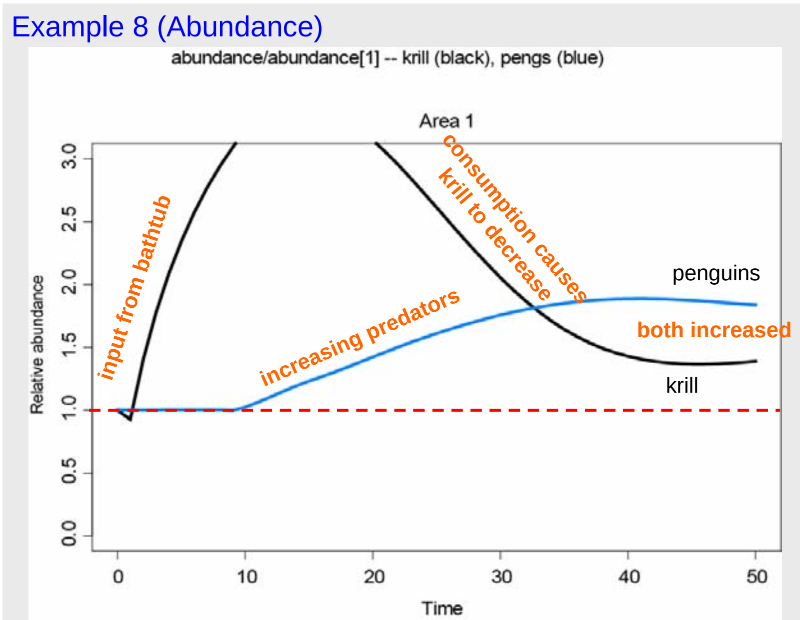
Slide 10: Comparison of simulations presented in Slides 8 and 9.



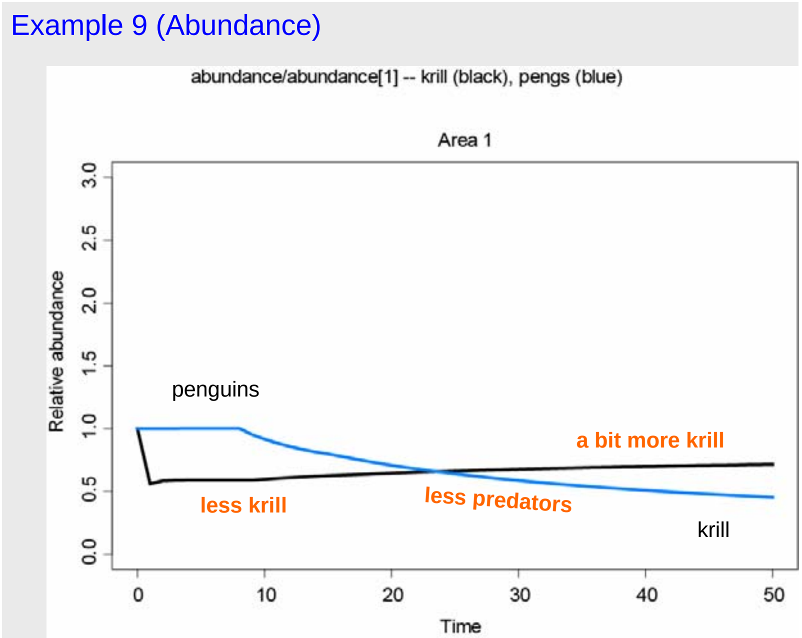
Slide 11: Simulation with a single SSMU and one predator (penguins). Recruitment of krill is sufficient to satisfy predator demand, but less krill are available for consumption.



Slide 12: Simulation with a single SSMU and one predator (penguins). Initially, local recruitment of krill is sufficient to satisfy predator demand, then krill are moved through the SSMU using boundary areas. Movement into the SSMU is greater than movement out of the SSMU.



Slide 13: Simulation with a single SSMU and one predator (penguins). Local recruitment of krill is sufficient to satisfy predator demand, but krill are moved through the SSMU using boundary areas. Movement into the SSMU is less than movement out of the SSMU.



Slide 14: Description of the initial conditions for examples in which krill–predator–fishery interactions were simulated in two SSMUs.

Basic Setup for 2 SSMUs

- 50-yr simulations
- If **FISHING** then start = 11 and stop = 31
- If **FISHING** then AC1 = 2 x AC2
- No random variation in krill recruitment
- Hyperdepletion in relationship between relative consumption and relative breeders
- If **MOVEMENT** then krill move from SSMU 1 to SSMU 2
- If **2 available.fractions** then SSMU 1 = 0.8 and SSMU 2 = 0.2

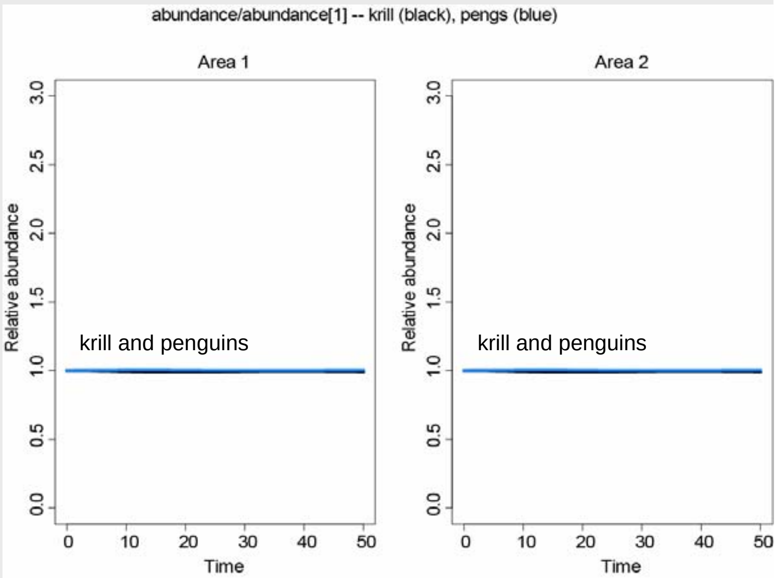
Slide 15: The sequence of examples used to review the KPFM when interactions within two SSMUs are simulated. The column marked ‘setup’ describes each example. The column marked ‘conditions’ describes the initial relationship between krill recruitment (R1 for recruitment in SSMU 1 and R2 for recruitment in SSMU 2), demand by predators (D1 for penguins in SSMU 1 and D2 for penguins in SSMU 2), and the catch allocated to the fishery (AC1 and AC2 for the catch respectively allocated to SSMUs 1 and 2). The column marked ‘expectations’ provides a short description of the dynamics that would be expected in each example.

Sequence with Two Areas

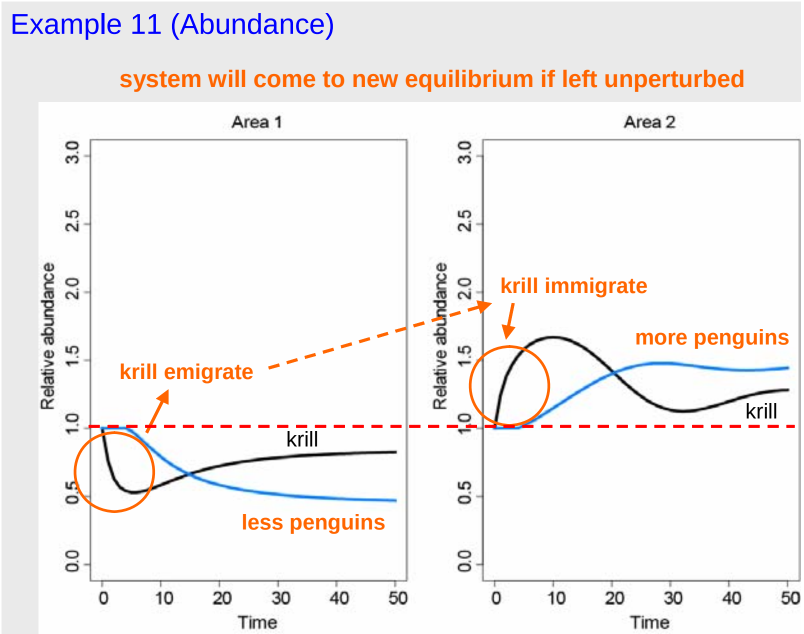
#	Setup	Conditions	Expectations
10	Two Penguins	R1 = D1, R2=D2	Flat lines
11	10 + Movement	R1 = D1, R2=D2	P1 Decreases, P2 Increases
12	10 + Fishing	R1 < D1+AC1, R2 < D2+AC2	Unequal Decreases & Increases
13	12 + Two available.fractions	R1 < D1+AC1, R2 < D2+AC2	?

Slide 16: Simulation with two SSMUs and one predator (penguins) in each SSMU. Local recruitment of krill satisfies predator demand in each SSMU.

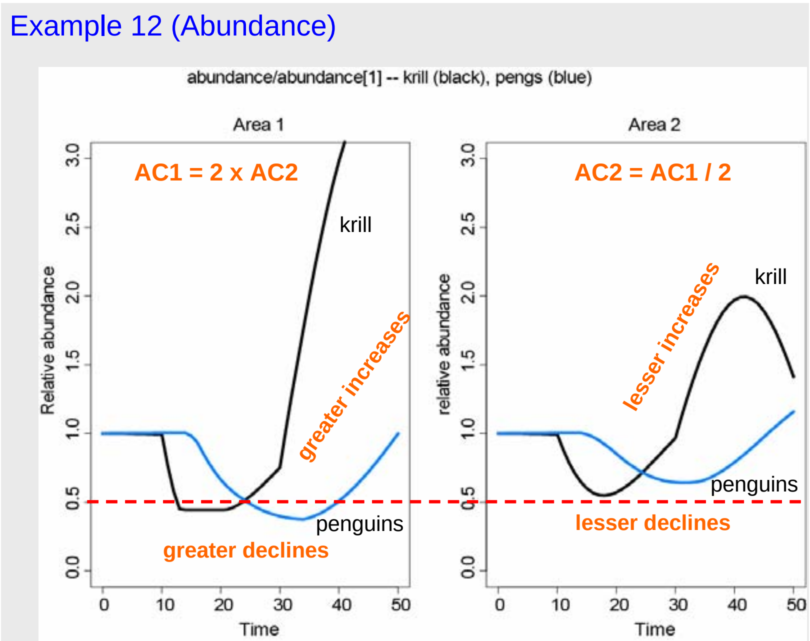
Example 10 (Abundance)



Slide 17: Simulation with two SSMUs and one predator (penguins) in each SSMU. Local recruitment of krill is sufficient to satisfy predator demand in each SSMU, but there is net movement of krill from SSMU 1 into SSMU 2.



Slide 18: Simulation with two SSMUs, one predator (penguins) in each SSMU, and krill fishing in both SSMUs. Local recruitment of krill is not sufficient to satisfy the combined predator demand and allocated catch in each SSMU.



Slide 19: Comparison of the simulation presented in Slide 18 to a simulation in which krill are less available to predation and fishing. All other conditions are the same in each simulation.