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Title **THE RISKS OF NOT DECIDING TO ALLOCATE THE PRECAUTIONARY KRILL CATCH LIMIT AMONG SSMUS AND ALLOWING UNCONTROLLED EXPANSION OF THE KRILL FISHERY UP TO THE TRIGGER LEVEL.**

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ABSTRACT

After the Scientific Committee did not reach consensus and advise the Commission on the risks associated with three options for a Stage-1 allocation of the precautionary krill catch limit among SSMUs in Subareas 48.1-48.3, it was suggested that a comprehensive assessment of the risks that might be incurred by not deciding on such an allocation (i.e., a risk assessment of status quo management) be undertaken. We used the same methods applied by the WG-EMM in 2008, including averaging results provided from multiple parameterizations of the same model, and present such a risk assessment here. Our results demonstrate that i) status quo management may jeopardize the Commission's ability to achieve the objectives specified in Article II, and ii) the current trigger level is not as precautionary as previously presumed. Our work also reiterates the advice that the WG-EMM delivered to the Scientific Committee during 2008, and the caveats associated with that previous advice also apply here. Given the risks of status quo management, we identify three approaches by which the Commission can manage risks to krill-dependent predators in a precautionary manner: i) cap krill catches at recent levels until a feedback approach to management of the krill fishery can be implemented; ii) agree a new trigger level, that is less than the current trigger level, while continuing work to evaluate options for a Stage-1 allocation and feedback management strategies; or iii) eliminate the current trigger level, agree a Stage- 1 allocation, and focus research to design and evaluate a feedback management strategy. We feel that the collective body of scientific work to advise on issues related to the SSMU allocation has met the "burden of proof" that would be required for decision making.

SUMMARY OF FINDINGS AS RELATED TO NOMINATED AGENDA ITEMS

Agenda Item	*Findings*
3.6-3.7	Our results demonstrate that i) *status quo* management of the krill fishery may jeopardize the Commission's ability to achieve the objectives specified in Article II, and ii) the current trigger level is not as precautionary as previously presumed.
3.6-3.7	We identify three approaches by which the Commission can manage risks to krill-dependent predators in a precautionary manner: i) cap krill catches at recent levels until a feedback approach to management of the krill fishery can be implemented; ii) agree a new trigger level, that is less than the current trigger level, while continuing work to evaluate options for a Stage-1 allocation and feedback management strategies; or iii) eliminate the current trigger level, agree a Stage-1 allocation, and focus research to design and evaluate a feedback management strategy.

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The risks of not deciding to allocate the precautionary krill catch limit among SSMUs and allowing uncontrolled expansion of the krill fishery up to the trigger level.

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Abstract

After the Scientific Committee did not reach consensus and advise the Commission on the risks associated with three options for a Stage-1 allocation of the precautionary krill catch limit among SSMUs in Subareas 48.1-48.3, it was suggested that a comprehensive assessment of the risks that might be incurred by not deciding on such an allocation (i.e., a risk assessment of *status quo* management) be undertaken. We used the same methods applied by the WG-EMM in 2008, including averaging results provided from multiple parameterizations of the same model, and present such a risk assessment here. Our results demonstrate that i) *status quo* management may jeopardize the Commission's ability to achieve the objectives specified in Article II, and ii) the current trigger level is not as precautionary as previously presumed. Our work also reiterates the advice that the WG-EMM delivered to the Scientific Committee during 2008, and the caveats associated with that previous advice also apply here. Given the risks of *status quo* management, we identify three approaches by which the Commission can manage risks to krill-dependent predators in a precautionary manner: i) cap krill catches at recent levels until a feedback approach to management of the krill fishery can be implemented; ii) agree a new trigger level, that is less than the current trigger level, while continuing work to evaluate options for a Stage-1 allocation and feedback management strategies; or iii) eliminate the current trigger level, agree a Stage-1 allocation, and focus research to design and evaluate a feedback management strategy. We feel that the collective body of scientific work to advise on issues related to the SSMU allocation has met the "burden of proof" that would be required for decision making.

Introduction

In 2008, the Scientific Committee did not reach consensus and advise the Commission on the risks associated with three options for a Stage-1 allocation of the precautionary krill catch limit among SSMUs in Subareas 48.1-48.3. This situation arose despite the facts that

1. both the WG-EMM and the WG-SAM advised the Scientific Committee that "sufficient" (SC-CAMLR-XXVII, paragraph 3.4) and "adequate" (SC-CAMLR-XXVII, paragraph 3.14) work had been undertaken to assess such risks,
2. the risk assessment was conducted following a multi-year work plan that was previously endorsed by the Scientific Committee (SC-CAMLR-XXVI, paragraph 2.14) and based primarily on three options (Option 2 -- an allocation based on the spatial distribution of predator demand;

Option 3 -- an allocation based on the spatial distribution of standing krill biomass; and Option 4 -- an allocation based on the spatial distribution of the difference between predator demand and standing krill biomass) that were previously endorsed by the Commission (CCAMLR-XXVI, paragraph 4.18),

3. the WG-EMM determined that many of the results from the risk assessment were robust to differences in two separate modeling approaches (e.g., SC-CAMLR-XXVII, Annex 4, paragraphs 2.63, 2.65, 2.66, and 2.70), and
4. the caveats associated with the risk assessment were clearly presented as a component of the work (SC-CAMLR-XXVII, paragraph 3.6).

At least one Member noted that, should the CCAMLR not follow the advice of the WG-EMM, it would *de facto* select Option 1 (an allocation based on the spatial distribution of historical krill catches) (SC-CAMLR-XXVII, paragraph 3.18). In 2006, the WG-EMM determined that Option 1 "would have relatively greater negative impacts on the ecosystem compared to other fishing options" (SC-CAMLR-XXV, Annex 4, paragraphs 2.4, 5.24, and 5.44). The Scientific Committee advised the Commission of this result (SC-CAMLR-XXV, paragraph 3.28), and the Commission made note of it (CCAMLR-XXV, paragraph 4.8). We continue to agree with the WG-EMM's original assessment; neither the WG-EMM nor the WG-SAM have received new evidence that would change it.

While the Scientific Committee was unable to deliver consensus advice on a Stage-1 allocation in 2008, it was suggested that a more comprehensive risk assessment of Option 1, similar to the risk assessments the WG-EMM had undertaken for Options 2-4, would be an essential piece of future work (SC-CAMLR-XXVII, paragraph 3.18). Such an assessment can address a number of outstanding issues that relate to the allocation problem. In particular, a risk assessment of Option 1 can

1. demonstrate that Members' concerns that "the current trigger level of 620 000 tonnes may not be as precautionary as previously assumed" are legitimate (e.g., CCAMLR-XXVII, paragraph 4.12), and
2. provide advice "on the appropriateness of the current krill catch trigger level" (CCAMLR-XXVII, paragraph 4.18).

In this document our objective is to assess the risks of not deciding to allocate the precautionary krill catch limit among SSMUs and allowing uncontrolled expansion of the krill fishery up to the current trigger level. This is equivalent to assessing the risks of *status quo* management and of allocating the catch limit among SSMUs on the basis of the spatial distribution of historical krill catches (Option 1). We use the same methodological approach reviewed and endorsed at the last meeting of the WG-SAM and applied at the last meeting of the WG-EMM. Using the reference set of parameterizations developed by Watters et al. (2008a), we show that FOOSA simulates minimal impacts by the current krill fishery, but an uncontrolled expansion of the fishery up to the current trigger level is likely to risk depletion of krill-dependent predators. Therefore, the current trigger level may not be sufficiently precautionary to achieve the objectives of Article II. The results of this risk assessment can also be used to help the Commission identify a new, more appropriate trigger level should no decision on a Stage-1 allocation be made in 2009. We conclude this document by recalling the Commission's commitment to acting in a

precautionary manner and its mandate to make decisions on the basis of the "best scientific evidence available" (Article IX of the Convention); we frame our recollection of these points within the context of the "burden of proof." In our opinion, the WG-EMM can readily provide the Scientific Committee with the best scientific evidence available to advise the Commission on the risks associated with not making a decision to allocate the precautionary krill catch limit among SSMUs and/or lower the current trigger level during Stage 1 of the staged development of the krill fishery. By working within the previously agreed, multi-year process of vetting models and results through the WG-SAM and the WG-EMM, we also believe that the work done thus far has met the burden of proof necessary to provide such Stage-1 advice.

Methods

We conducted a risk assessment using the methods described in Watters et al. (2008b) and adapted by the WG-EMM at its 2008 meeting; readers should consult these references for methodological details (further details on FOOSA are provided in Watters et al. 2006 and Watters et al. 2008a). Although our objective is to evaluate the risks of not deciding to allocate the precautionary krill catch limit among SSMUs (e.g., a *de facto* selection of Option 1) and allowing uncontrolled expansion of the krill fishery up to the current trigger level, we repeated and extended the risk assessments for Options 2-4 to provide a basis for comparing Option 1 with the three options that were considered in 2008. Watters et al. (2008a) developed four parameterizations of FOOSA to constitute a "reference set" of parameterizations that explicitly considers uncertainty in krill flux, predator survival rates, and the degrees to which predators respond to variations in krill availability during both the summer and winter. In 2008, the WG-EMM gave these four parameterizations equal weight (SC-CAMLR-XXVII, Annex 4, paragraph 2.53) when averaging the results from each, and, therefore, we adopted this equal weighting scheme here. Last year, the WG-EMM considered yield multipliers in the set { 0.0, 0.15, 0.25, 0.5, 0.75, 1.0, 1.25}. To evaluate the risks of fishery expansion from near present levels of catch up to the trigger level, we extended the range of yield multipliers and considered values in the set {0.0, 0.025, 0.05, 0.075, 0.1 , 0.15, 0.25, 0.50, 0.75, 1.00, 1.25}.

We used data provided in Table 8 of WG-EMM-08/5 to characterize the recent distribution of krill catches throughout the SSMUs in Subareas 48.1-48.3 and parameterize Option 1. We summed the catches reported to have been taken from each SSMU for the last five fishing seasons: 2002/03 through 2006/07. These data were used informally during the 2008 meeting of the WG-EMM and formed the basis for the statement that "preliminary analysis by the Working Group suggested that this [Option 1] would probably involve a higher risk to predators at yield multipliers of 0.15 than the negligible risks identified above for Options 2 and 3" (SC-CAMLR-XXVII, Annex 4, paragraph 2.90). To estimate the proportional allocation of catches among SSMUs for Option 1, we divided the summed catch from each SSMU into the total catch reported from all SSMUs for the five previously identified fishing seasons (Table 1). We note that Watters et al. (2008b, Table 1) reported the proportional allocations for Options 2-4, and we remind readers that, for the purposes of conducting a risk assessment, the proportional allocations used to evaluate these latter three fishing options are specific to each parameterization in the reference set.

Results and Discussion

We present a suite of results that largely parallels those included in the 2008 Report of the Working Group on Ecosystem Monitoring and Management (SC-CAMLR-XXVII, Annex 4) but differs in the following respects:

1. we present the risks of not deciding to allocate the precautionary krill catch limit among SSMUs ("no decision" or Option 1);
2. we include a range of yield multipliers that facilitates the assessment of risks as the fishery expands up to the trigger level; and
3. we illustrate the risks incurred by recent catch levels.

We also present model-averaged results of the risks that krill densities fall below a threshold of 15 g m^{-2}. In 2008, the WG-EMM presented similar results for three different thresholds (10, 15, and 20 g m^{-2}) to the Scientific Committee and did not average across parameterizations in the reference set. Model-averaged results for other thresholds can be illustrated, but in general the risks that krill densities will fall below such thresholds increase as the thresholds increase (and decrease as the thresholds decrease). Readers should note that the results presented for Options 2-4 and yield multipliers greater than or equal to 0.15 are, except for the model-averaged risks of falling below a specific krill-density threshold, exactly the same results that the WG-EMM presented to the Scientific Committee last year. Thus, much of the text that follows is copied or paraphrased from the 2008 Report of the WG-EMM.

Krill

Figure 1 presents effects on the krill population; as in the last Report of the WG-EMM, these results are displayed by subarea and for Subareas 48.1-48.3 combined.

We considered risks to the krill population within the context of two decision rules. There was zero probability that minimum krill abundance during the fishing period would be reduced to less than 20% of the abundances from comparable no-fishing trials (a derivative of the first decision rule for krill). The absence of such risk was predicted for all yield multipliers (including that consistent with recent catches) and all fishing options, including the option of *status quo* management ("no decision" regarding a Stage-1 allocation) (Figure 1, panels marked "rule 1"). We predicted that no decision regarding a Stage-1 allocation would incur negligible risk that krill abundance measured at the end of the fishing period would be less than 75% of the median abundances from comparable no-fishing trials (a derivative of the second decision rule for krill) (Figure 1, first panel marked "rule 2"). In contrast, for Options 2-4, this risk did increase as the yield multiplier increased beyond 0.15 (a level consistent with the current trigger level) (Figure 1, remaining panels marked "rule 2"). Note, however, that increases in the risk that krill abundance measured at the end of the fishing period would be less than 75% of the median abundances from comparable no-fishing trials were generally less for Subareas 48.1 and 48.2 and all three subareas combined than for Subarea 48.3 (particularly for Option 4). Regardless of fishing option, a yield multiplier consistent with recent catches was estimated to incur almost no risk to the krill population.

Predators

Figures 2 and 3 present effects on predators, with Figure 3 simply providing a magnified view of results from Figure 2 within the region bounded by recent catches (yield multiplier ≈ 0.026) and the trigger level (yield multiplier = 0.15).

Our results demonstrated that no decision regarding a Stage-1 allocation would, of the options considered here, be the most likely to risk depleting predator populations to 75% or less than the abundances that might occur in the absence of fishing (Figure 2) -- thus, *status quo* management may jeopardize the Commission's ability to achieve the objectives specified in Article II of the Convention. These risks applied to modeled populations of penguins, fish, and seals. Furthermore, the risks to predators, while near zero at recent catch levels, were predicted to increase as catches approach the trigger level, with catches at the trigger level incurring significant risks to some predator populations (Figure 3). Thus, the current trigger level is likely not as precautionary as previously presumed. This result legitimizes the concerns that most Members expressed at the last meeting of the Commission (CCAMLR-XXVII, paragraph 4.12), and we note that the current trigger level was not agreed on the basis of a fully-vetted scientific analysis such as that conducted to provide advice on a Stage-1 allocation.

Of the three options that would require a change from the *status quo*, Option 4 was most likely to risk depleting predator populations to 75% or less than the abundances that might occur in the absence of fishing (Figure 2). We predicted that Option 2 was least likely to risk depleting predator populations and that the risks incurred by Option 3 would be intermediate to those of Options 2 and 4 (Figure 3). Furthermore, we predicted that Option 4, but not Options 2 and 3, would incur risks as catches increase from recent levels up to the trigger level (Figure 3). We note that a completely separate model (SMOM, Plagányi and Butterworth 2008) also predicts that Option 4 will incur greater risks than Options 2 and 3 (SC-CAMLR-XXVII, Annex 4, paragraph 2.66). In 2008, the WG-EMM noted that the increased risks of Option 4 arise from limiting the spatial distribution of the fishery to coastal SSMUs; the proportion of the total catch allocated to coastal SSMUs in Options 2, 3, and 4 of FOOSA were about 30%, 38%, and 66% respectively (Watters et al. 2008b).

The fishery

Figures 4-6 present model-averaged effects on the fishery using three performance measures: log of the mean catch, the proportion of the allocation that was caught, and the probability that krill density fell below a threshold which might cause an involuntary change in the behavior of the fleet.

In general, Options 2 and 3 resulted in greater catches than Options 1 (no decision) and 4, with Option 2 predicted to have slightly better average performance than Option 3 and Option 4 predicted to have the lowest average performance (Figure 4). Catches predicted from the implementation of Fishing Option 4 were biased low because all of the parameterizations in the reference set implicitly describe initial conditions that would prohibit fishing in many SSMUs (see Table 1 in Watters et al 2008b). It is worth noting that the WG-EMM has acknowledged "that the SSMU allocation within the model trials would result in allocations different to that arising in reality" (SC-CAMLR-XXVII, Annex 4, paragraph 2.71). Absolute catches were predicted to increase as the yield multiplier increased (Figure 4), but the

relative performance of the fishery (catches as proportions of allocations) usually decreased as the yield multiplier increased (Figure 5). In 2008, it was noted that the fishery "may not be able to achieve its catch levels even when these are very low " (SC-CAMLR-XXVII, Annex 4, paragraph 2.72). In FOOSA, the performance of the fishery could potentially be increased by mechanisms that include increasing the mean krill recruitment, decreasing the variation in krill recruitment, and establishing the fishery as a superior (relative to predators) competitor for krill. We note, however, that the WG-EMM has advised the Scientific Committee that, because the fishery and predators are currently treated as equal competitors within the reference set of parameterizations for FOOSA, estimates of risk to the ecosystem are negatively biased (SC-CAMLR-XXVII, Annex 4, paragraphs 2.54 and 2.97).

Implementation of Options 2 and 3 would require that the fishery mostly operate away from coastal areas, with about 70% and 62% of the catch respectively being allocated, within FOOSA, to pelagic SSMUs. Although the available biomass of krill may be higher in pelagic SSMUs (because the total area of these SSMUs is substantially greater than the area of coastal SSMUs), the risk that krill densities will fall below thresholds which necessitate involuntary changes in the behavior of the fishing fleet was predicted to be greater in pelagic SSMUs than in coastal SSMUs (Figure 6). Nevertheless, we did predict that absolute catches could be greatest (Figure 4) and that the relative performance of the fishery is not necessarily worst (Figure 5) in pelagic SSMUs.

Caveats and cautionary notes

Last year's report of the Scientific Committee provides a succinct description of the caveats associated with the risk assessment conducted in 2008 (SC-CAMLR-XXVII, paragraph 3.6). These caveats still apply, and we repeat them here. Our risk assessment was drawn from results that:

1. predicted that the krill fishery (SC-CAMLR, Annex 4, paragraphs 2.70 to 2.74) –
    a. may be forced to change its behavior in pelagic areas where total krill biomasses are relatively high but where average densities are relatively low;
    b. may not be able to catch its allocated catch limit in some SSMUs due to the assumed nature of competition between itself and krill predators;
    c. may be prohibited from fishing in some SSMUs because the model simulates the estimation of krill biomass or predator demand to represent the process that would be undertaken in reality (but may provide results that are different to those that would be obtained in reality);
2. may be negatively biased and lead to advice on SSMU allocations that was not as precautionary as intended, in which case the risk assessment should be considered as indicating minimum risks to the ecosystem for any given harvest rate (SC-CAMLR, Annex 4, paragraphs 2.54 and 2.55);
3. were conditioned on a calendar of events which specifies a step-change in krill abundance that was likely to have occurred with an uncertain magnitude and does not describe the dynamics of fish populations whose role in the ecosystem is an important source of uncertainty (SC-CAMLR, Annex 4, paragraphs 2.76 to 2.83);
4. were initialized by extrapolating results from the CCAMLR-2000 Survey (SC-CAMLR, Annex 4, paragraphs 2.84 and 2.85).

We also note the WG-EMM's previous acknowledgement that estimates of predator consumption are uncertain primarily as a result of incomplete estimates of abundance of predators and also that SSMU-scale krill densities are not adequately estimated in available analyses of the CCAMLR-2000 Survey (these will remain uncertain until the issues surrounding methods for estimating krill abundance from the acoustic data are resolved) (SC-CAMLR-XXVII, Annex 4, paragraph 2.102).

Watters et al. (2008b) provided a cautionary note that is also worth repeating here. Although many management strategies (i.e., combinations of a yield multiplier and a fishing option) are not likely to increase the risks that predator populations will be reduced to 75% (or less) of the abundances that might occur in the absence of fishing, fishing can nevertheless push some populations, particularly penguins, into states where there is some risk that recovery will not occur, even after a period of 20 years without fishing (Watters et al. 2008b). Furthermore, the risks that some populations may not recover can increase rapidly as catches increase past the current trigger level (see Figure 7 in Watters et al. 2008b). These risks result from the depensatory recruitment dynamics (for all predator populations except fishes) characterized in the reference set of parameterizations we used to run FOOSA (Watters et al. 2008a).

Summary and next steps

Given that the our results simply confirm and extend those agreed by the WG-EMM in 2008, we present summary conclusions that are mostly copied verbatim from the last Report of the WG-EMM. We indicate new conclusions with ***bold italic*** font.

1. ***Option 1 (status quo management) may jeopardize the Commission's ability to achieve the objectives specified in Article II.***
2. ***The current trigger level is not as precautionary as previously presumed.***
3. Option 4 performs significantly worse than Options 2 and 3 across all performance indicators.
4. Options 2 and 3 appeared to perform equally well under a number of scenarios.
5. Under Options 2 and 3 the risk of negative impacts on predators was negligible at yield multipliers of 0.15 (the harvest rate consistent with the trigger level).
6. Under Options 2 and 3 the risk of negative impacts on predators increased at yield multipliers greater than 0.25 to 0.5 with penguins and fish being most significantly affected, seals affected to a minor degree and whales unaffected.
7. Options 2 and 3 include allocations of 70 and 62% respectively of total catch to pelagic SSMUs, where indications from the models and from paragraphs 2.32 to 2.39 [from the 2008 Report of the WG-EMM] suggest that fishery performance will be significantly negatively impacted.

Some Members have indicated that it is not yet necessary to agree on a Stage-1 allocation of the precautionary catch limit for krill (CCAMLR-XXVII, paragraph 4.12). This position may be defensible if catch levels do not change, but Members have not agreed to cap krill catches near recent levels. Our results suggest that the objectives of Article II may be jeopardized by a lack of decision making and *status quo* management. Fortunately, our risk assessment does suggest a number of possibilities for

managing future risk; we present some of these in the following list, from most draconian to most permissive in terms of future catches. The risks to krill-dependent predators can be managed by

1. capping krill catches at recent levels until a feedback approach to management of the krill fishery can be implemented;
2. agreeing a new trigger level, that is less than the current trigger level, while continuing work to evaluate options for a Stage-1 allocation and feedback management strategies;
3. eliminating the current trigger level, agreeing a Stage-1 allocation, and focusing research to design and evaluate a feedback management strategy.

Although the Commission has not provided guidance on what levels of risk may be acceptably precautionary, committing to Item 2 or 3 from the above list would, at least implicitly, require that an acceptable level of risk be articulated. Therefore, it would seem useful for the WG-EMM and the Scientific Committee to discuss the implications of defining acceptable risk levels for krill-dependent predators (as was done to develop the existing decision rules for krill). For example, the WG-EMM and Scientific Committee could discuss whether a 50:50 chance of depleting predators to 75% of the abundances that might occur in the absence of fishing is suitably precautionary given the possibility of depensatory recruitment dynamics (see above). We conclude this point of discussion by noting that Item 3 from the above list will also require i) "use of the best available data to estimate SSMU allocation proportions" and ii) "calculation of the SSMU allocations using the proportions determined in i)... multiplied by the yield multiplier...multiplied by the yield (from the GYM)" (SC-CAMLR-XXVII, paragraph 3.3).

The burden of proof

The role of the Scientific Committee and its working groups is to provide relevant and timely scientific advice to the Commission. However, it is the Commission's prerogative to decide how to respond to this advice. The development of advice on SSMU allocations contained in this paper and previous papers, as well as the 2008 Report of the WG-EMM, was based on one of the most rigorous scientific evaluations devised within CCAMLR, which is documented in the WG-EMM reports of 2005 through 2008 as well as the WG-SAM reports of 2007 and 2008. We therefore feel that the collective body of work to address this issue has met the "burden of proof" which should be required for decision making. Our results and the previous advice of the WG-EMM provide compelling information about the risks associated with *status quo* management, including the current trigger level, and various other SSMU allocations. The Commission is committed to applying the precautionary approach to management and so relies on the Scientific Committee to provide this sort of advice when it becomes available. We therefore suggest that it is incumbent on the Scientific Committee to advise the Commission on this issue without further delay.

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Table 1. Proportional subdivision of the precautionary krill catch limit among the 15 SSMUs in Statistical Areas 48.1-48.3. Values are derived from catches for the last five fishing seasons reported in Table 8 of WG-EMM-08/5. Pelagic SSMUs are highlighted with bold type, and the total subdivision to these SSMUs is reported in the row marked "pelagic." The total subdivision to coastal SSMUs is reported in the row marked "coastal." Dashes indicate subdivisions of zero.

SSMU	Option 1
1	**0.0007**
2	0.0007
3	0.1669
4	0.0292
5	0.0273
6	0.0413
7	0.0179
8	-
9	**0.0042**
10	0.3401
11	0.0097
12	0.0002
13	**0.0020**
14	0.1039
15	0.2558
pelagic	**0.0069**
coastal	0.9931

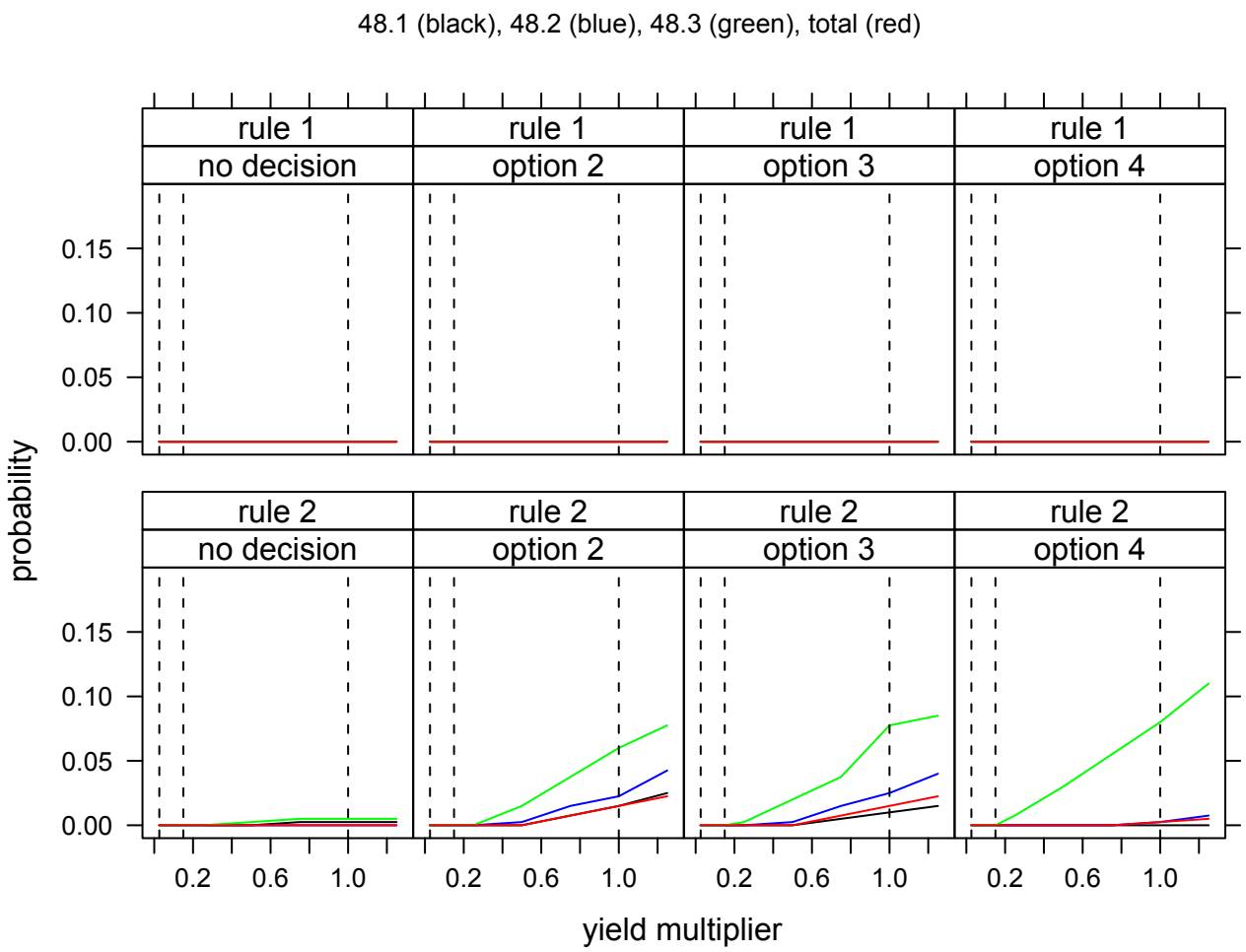

Figure 1. Effects on the krill population. Model-averaged, fishing-option-specific probabilities that minimum krill abundance during the fishing period is <20% of the abundances from comparable no-fishing trials (krill decision rule 1; upper panels) and that krill abundance measured at the end of the fishing period is <75% of the abundances from comparable no-fishing trials (krill decision rule 2; lower panels). Probabilities are averaged across parameterisations in the reference set using equal weights. Results in each panel are aggregated across relevant SSMUs. The x axis is harvest rate, labelled "yield multiplier." "No decision" is status quo management; Option 2 is the SSMU allocation proportional to predator abundance; Option 3 is the SSMU allocation proportional to the CCAMLR-2000 Survey krill abundance; and Option 4 is the SSMU allocation proportional to predator abundance minus krill abundance. The vertical dotted lines mark yield multiplier values of 0.026 (indicating the harvest rate at recent catch levels), 0.15 (indicating the harvest rate at the trigger level), and 1.0 (indicating the harvest rate at the full precautionary catch limit).

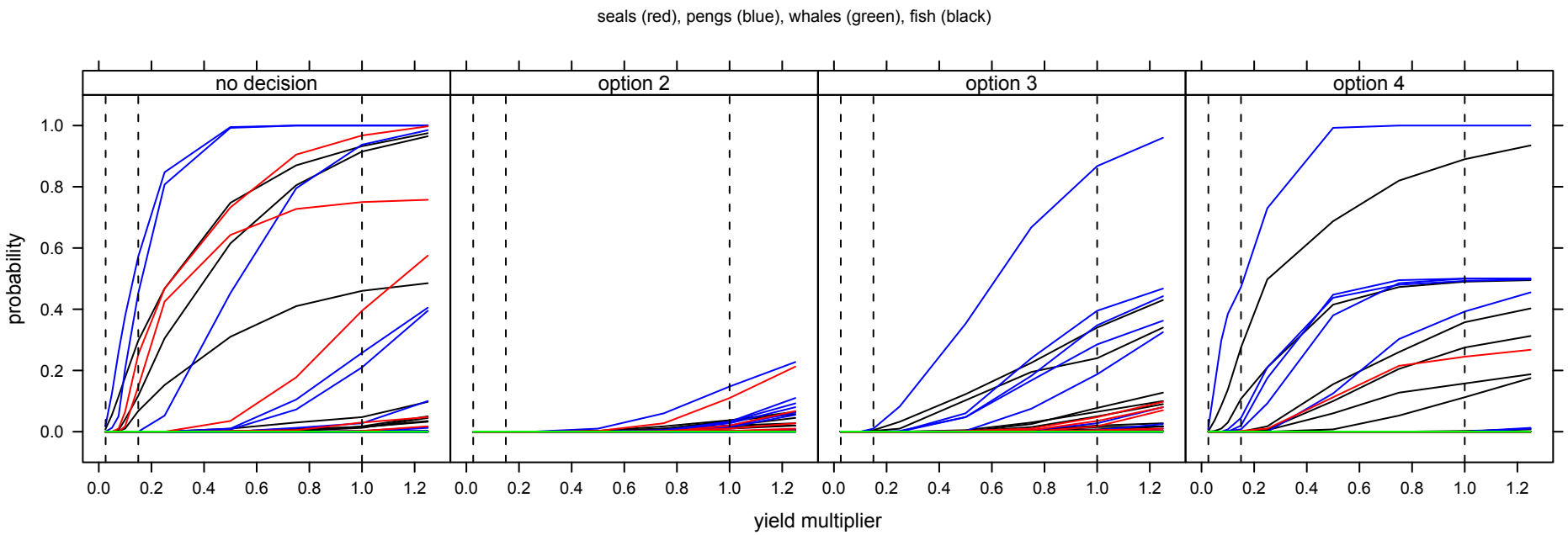

Figure 2. Effects on predators. Model-averaged, fishing-option-specific probabilities that, at the end of the fishing period, the abundances of predators will be reduced to values less than 75% of abundances from comparable no-fishing trials. Other details as in Figure 1.

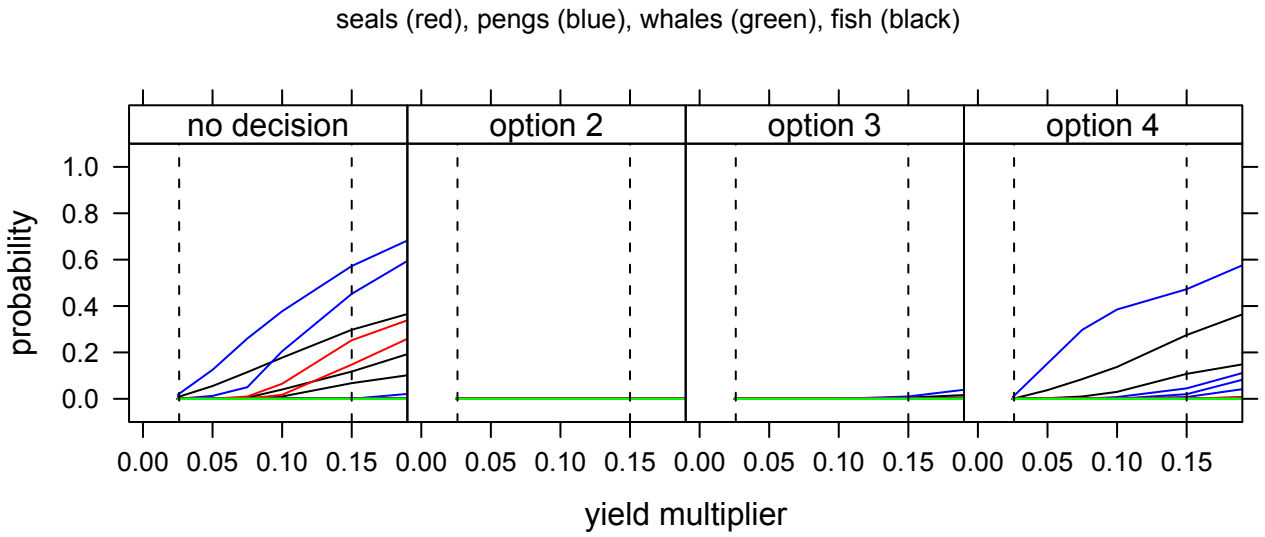

Figure 3. Effects on predators. Model-averaged, fishing-option-specific probabilities that, at the end of the fishing period, the abundances of predators will be reduced to values less than 75% of abundances from comparable no-fishing trials. The view is a magnified version of Figure 2, focusing on the region between yield multipliers consistent with recent catches and the current trigger level. Other details as in Figure 1.

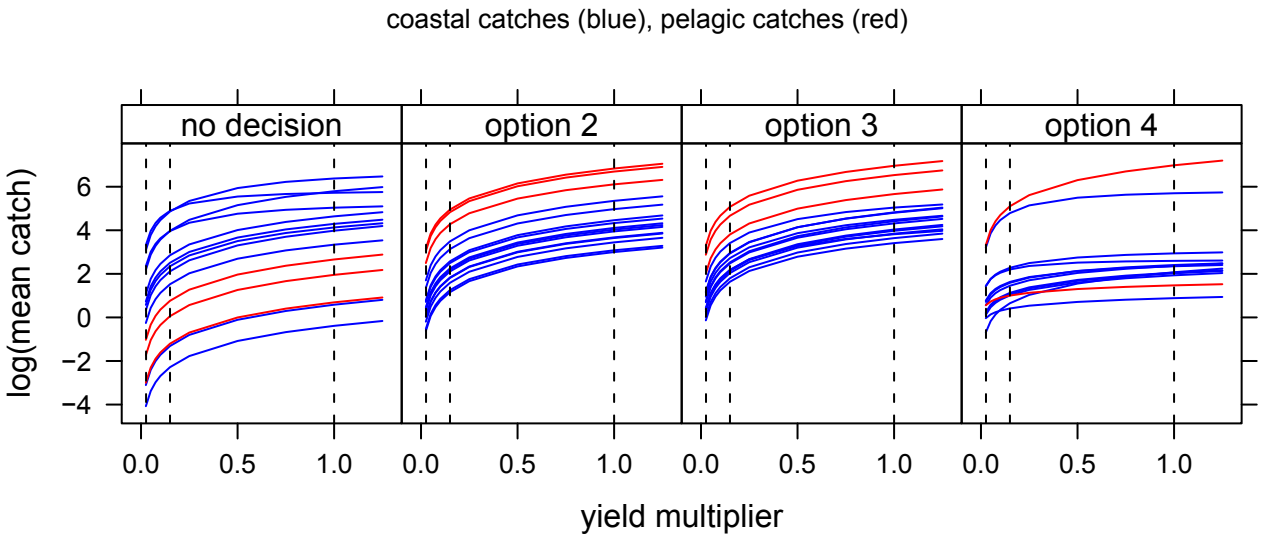

Figure 4. Effects on the fishery. Model-averaged, fishing-option-specific log of mean catches. Performance was averaged across parameterisations in the reference set using equal weights. The trend lines are SSMU-specific. Note, many SSMU-specific, model-averaged catches predicted from the implementation of Fishing Option 4 were low compared to other options because all the parameterisations in the reference set implicitly describe initial conditions that would prohibit fishing in many SSMUs. Other details as in Figure 1.

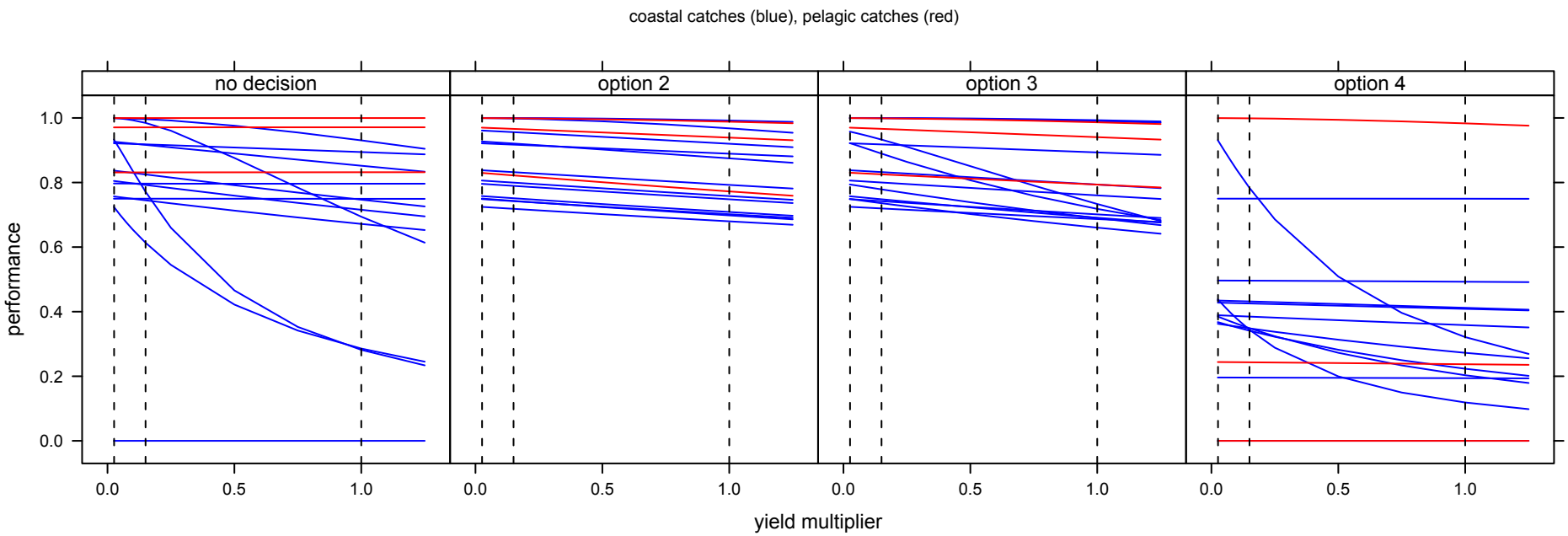

Figure 5. Effects on the fishery. Fishery performance expressed as the proportion of the total allocation taken by the fishery. Performance metrics are averaged across parameterisations in the reference set using the equal weights. The trend lines are SSMU-specific. Other details as in Figure 1.

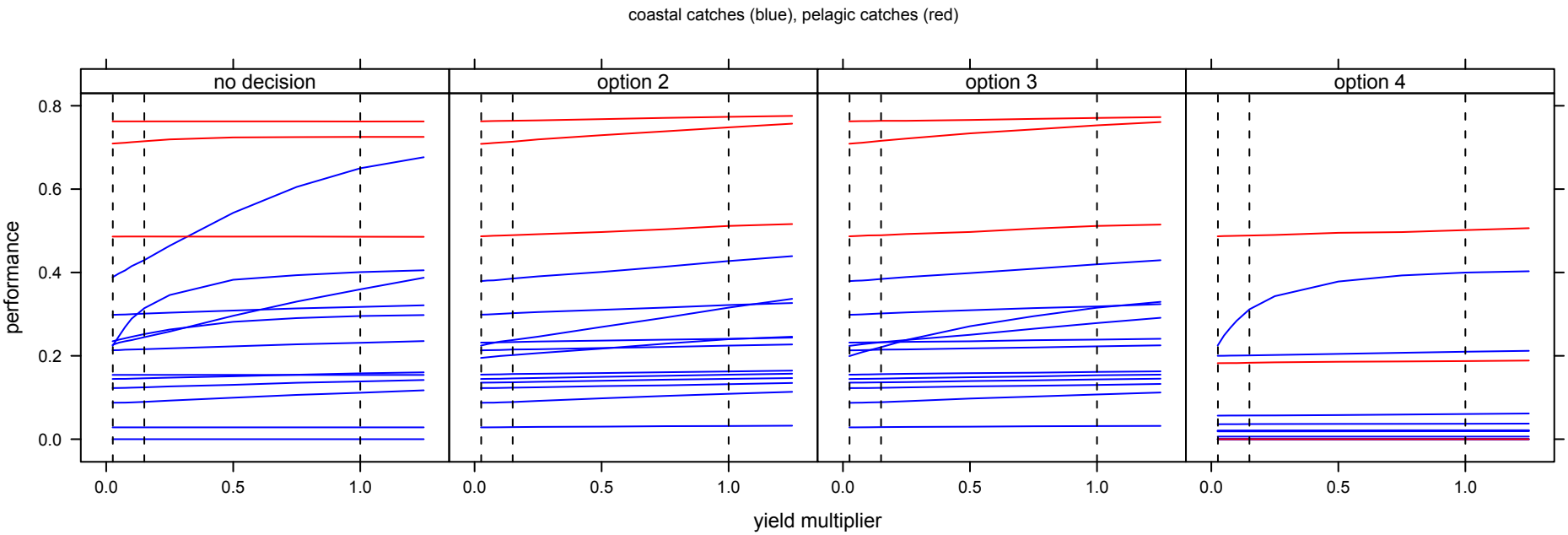

Figure 6. Effects on the fishery. Fishery performance expressed as probabilities that krill density falls below 15 g m^{-2} during fishing period. Performance metrics are averaged across parameterisations in the reference set using the equal weights. The trend lines are SSMU-specific. Other details as in Figure 1.