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Center for Independent Experts (CIE) independent peer review of an age-based, integrated stock assessment for Antarctic krill (Euphausia superba) with projected catches to 2035

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Representing the Center of Independent Experts

Executive Summary:

The SWFSC Antarctic Ecosystem Research Division (AERD) requested an independent review of an integrated stock assessment it developed for Antarctic krill. The Antarctic krill fishery is managed by the international treaty organization, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), of which the U.S. is a member. The fishery is currently expanding both in total catch and in the number of nations and vessels participating. Current catch limits of 5.61 million tons for the Scotia Sea, where all current krill fishing is conducted, were established using the Generalized Yield Model (GYM), a model developed in the 1990s. A total of 155 thousand tons of this total catch limit has been apportioned to FAO Subarea 48.1, a subregion of the Scotia Sea. This catch limit has been taken in recent years.

The Center for Independent Experts (CIE) organized two reviewers to conduct a peer review. On 18 March 2016, AERD made available at an FTP site, all files required to run and review the integrated model code, as well as background information relating to the model. Additional papers were also supplied by email on the 26th and 30th March 2016 (listed in Appendix). The background information was extensive and included all material required to conduct the review. The CIE reviewers participated in a panel review meeting in La Jolla, California, from 4 April to 6 April 2016 with scientists from AERD. The scientists presented key aspects of their research on the first day. Copies of the presentations were provided to the reviewers (listed in the Appendix, with main points drawn out under TOR 6). The CIE panel queried various aspects of the stock assessment process, model implementation and related research that were presented. All presenters answered questions and expanded on particular key issues. The panel sought additional information from AERD scientists on relationships between the population "health" of predators and prey (krill) biomass, which was then presented and discussed. At the conclusion of day 1, the CIE panel had developed a draft list of requested modifications (subsequently referred to as the "list") to be implemented into the integrated model (IM). The aim of the list was to both help in the model's apparent convergence issues, and to aid in the panels understanding of some of the model's dynamics. The list was provided to AERD scientists for its implementation on the evening of day 1 so the resultant diagnostics could be reviewed on day 2. Presentations on the impacts of the modifications implemented from the list, including the IM's subsequent convergence performance were provided to the panel on day 2. Following discussions of these results, the panel began collaboration with AERD scientists to further modify the IM during the workshop to implement additional items from the list. The remainder of day 2 and the majority of day 3 were spent collaboratively implementing modifications into the IM. On day 3, the panel also held discussions with AERD scientists on decision rules alternatives.

The review specifically addressed the following Terms of References:

1. *Evaluation of the ability of the integrated model for Antarctic krill, combined with the available data, to provide the parameter estimates required to assess the current status and productivity of Antarctic krill in FAO Subarea 48.1.*
2. *Evaluation of the strengths and weaknesses in the use of the integrated modeling approach to assess whether harvest recommendations meet the CCAMLR decision rules.*
3. *Evaluation of the spatial scale over which the model estimates may be applied.*
4. *Evaluation of strengths and weaknesses of a proposed alternative to the current CCAMLR decision rules, which compare spawning biomass under projected levels of fishing catch to initial unfished spawning biomass. The alternative compares spawning biomasses during the period of projected fishing to spawning biomasses with no fishing during the projection period.*
5. *Evaluation of the suitability of the integrated assessment in comparison to the GYM approach to determining precautionary catches.*
    - *(i) Recommendations for further improvements to the assessment model, including frequency of surveys and types of data collection.*
6. *Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations.*

AERD scientists have done a very thorough job of collating a large diverse collection of data on the krill population in FAO Subarea 48.1. To properly incorporate all of the uncertainty associated with this information, an integrated model (IM) has been shown to be advantageous. The IM supplied to the review panel on the 26th of March 2016 was of the appropriate form to conduct such an assessment, was producing biologically sensible parameters and was displaying good replication of the trends in observed data. There was, however, apparent convergence issues associated with the IM. The model required a very specific process to be followed to converge, there were the relatively large gradients associated with some parameters and strong correlations existed between some parameters. There were also a number of processes within the model that were considered by the panel to not have been implemented in the most appropriate fashion (listed in Table 1). After the implementation/examination of all short-term suggestions from the panel (listed in Table 1), it is likely that the model will be capable of providing robust estimates required to confidently assess the current status and productivity of Atlantic Krill in Subarea 48.1.

The great strength of the integrated modelling (IM) approach to assess whether harvest recommendations meet the CCAMLR decision rules is its framework. This allows the necessary calculations to be developed that are needed to assess these decision rules, whilst maintaining a good representation of the uncertainty associated with the input data and incorporating information from a diverse range of sources. This includes the ability to determine spawning biomass (both virgin, current and future) and to compare these in a probabilistic framework after determining the impact of future changes in catch. Specifically, an IM is capable of incorporating a large diverse collection of data, both historical and current, on the krill population in FAO Subarea 48.1 into the one assessment. This allows trends in biological and environmental data to be incorporated into the assessment. This is very valuable when a stock such as krill are located in one of the world's fastest changing environments (King 1994; Murphy *et al*., 1995) and its biological response to the environment are very plastic (Buchholz, 1991; Langdon and Ross, 2003).

Weaknesses of the integrated modelling (IM) approach to assess whether harvest recommendations meet the CCAMLR decision rules include the costs associated with the production and maintenance of the required data sources. The krill fishery in FAO sub area 48.1 is relatively isolated and inhospitable, making data collection issues more pronounced. The IM approach is also relatively new and is constantly evolving, with no current agreed best practice approaches to many aspects of IM construction. This immature nature of IMs means there is not necessarily a right way to implement some components into the IM framework, and the appropriateness of some methods will change in future evolutions. As such, IMs cannot be considered static and should be subject to frequent review.

The spatial scale over which the model estimates are applied is appropriate. Key factors for determining the spatial scale of a model include the locations of fishing activity, regionality of management areas, the availability of data, levels of self-recruitment, the homogeneity of biological processes and the extent to which averaging across the data sources is acceptable. AERD scientists appear to have taken these factors into consideration when determining the scale of their model to be subarea 48.1 as a whole. This choice requires the pooling of some spatial-explicit data which does show within season heterogeneity in size composition and biomass, and should thus be standardised for spatial covariates (see Table 2). Since finer scale modelling was not possible, yet finer scale concentration of fishing is, additional rules could be applied to the fishery to enforce a behavior more consistent with the modelling framework, since the former assumes a spatially homogenous exploitation (i.e. the fishery could be limited to taking no more than ¼ of the quota from any of the four regions within subarea 48.1).

The proposed alternative to the current CCAMLR decision rules is "the median future spawning biomass is compared to 75% of the reference ("predator rule"), and the 0.1 quantile of the future spawning biomass is compared to 20% of the reference (krill rule), with the reference being the future unfished spawning biomass". The strengths of the proposed alternative to the current CCAMLR decision rules is that the use of the future biomass incorporates the current trajectory of the population, and therefore the decision rules are more robust under climate change scenarios. The average future biomass is also temporally closer to the present, and thus, since in recent years data sets are more comprehensive, it is likely future biomasses can be estimated with greater certainty than the historical measure of virgin biomass.

A weakness of the proposed alternative is the "predator rule" component. Future spawning unfished biomass will change over time with climate change (King 1994; Murphy *et al*., 1995) and the proportion of future biomass needed by predators will therefore also change, especially as their population sizes will vary as well. As such, setting a proportion of a future biomass aside to limit impact on predators is unlikely to be robust. In fact, natural variation in the biomass of krill near the Antarctic Peninsula has already been shown to impact the abundance/reproductive success of some predators (Croxall *et al*., 1999; Fach *et al*., 2006). Therefore, based on the objective that fishing krill will not reduce the biomass to levels where predators will be impacted, the only constant proportion that could be set would be zero. Additional work is also needed to determine what components of the krill biomass are important to predators and whether any limits need to be based more specifically on these (i.e. certain cohorts of krill). The "krill rule" component of the proposed alternative should also be based on the outcomes of a stock-recruitment-environment relationship for this area. This is due to the possible scenarios that subarea 48.1 could be a recruitment source for other areas or a recruitment sink, effectively producing little viable recruitment.

An integrated model (IM) is more appropriate for determining precautionary catches than the GYM model, especially given the large amount of diverse time-series data available for this fishery. A production model such as the GYM is more appropriate under the more data-poor scenario. The ability to fit to multiple sources of data allows an IM to constantly improve its estimates as more data becomes available, directly incorporating levels of uncertainty, and progressively changing projections as the population parameters change.

A number of recommendations for improvements to the assessment model were developed (listed in Tables 1 and 2), including the incorporation of additional data sets. The IM framework can incorporate data from a range of sources, with the greater diversity of data being positive for the models robustness. The current IM incorporates data from different surveys, as well as data from the fishery. This consists of both acoustic summarized data and net-tow information. Other data sources which exist and have recently become available should also be incorporated into the IM.

AERD scientists were very knowledgeable, and were willing to provide extensive information on all aspects of the krill fishery and the integrated modelling approach they were developing. The collaborative nature of the review process was very positive and resulted in a pleasant working environment, where ideas and thoughts were discussed freely. Many of the suggested changes to the modelling approach were implemented within the workshop resulting in a very productive process. These changes and future modifications are listed below in two tables, the first for short term and second for longer-term aspects. Key points from these tables include:

- Modify recruitment
- Modify catch removals
- Estimate catchability
- Modify the development of selectivity curves
- Change the development of the maturity schedule
- Standardise data input for spatial and diel variation
- Incorporate a stock-recruitment-environment relationship

Background:

The Center for International Experts (CIE) requested an independent review of an integrated stock assessment it has developed for Antarctic krill fishery. This fishery is managed by the international treaty organization, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), of which the U.S. is a member. The fishery is currently expanding both in total catch and in the number of nations and vessels participating. Current catch limits of 5.61 million tons for the Scotia Sea, where all current krill fishing is conducted, were established using the Generalized Yield Model (GYM), a model developed in the 1990s. A total of 155 thousand tons of this total catch limit has been apportioned to FAO Subarea 48.1, a subregion of the Scotia Sea. This catch limit has been taken in recent years.

Two CIE reviewers conducted the peer review in accordance with the Terms of Reference (ToRs) in Appendix 2. Approximately two weeks before the peer review, AERD made available at an FTP site all necessary background information and reports for the peer review. The CIE reviewers participated in a panel review meeting in La Jolla, California from 2 April to 4 April 2016 to conduct a peer review of the stock assessment with the authors of the krill assessment. The reviewers met with scientists involved in the Krill fishery. The meeting was chaired by Dr George Watters. The scientists presented the key aspects of their research on the first day according to the agenda in Appendix 2. Copies of the presentations were provided to the reviewers. Throughout the presentations the CIE panel and other scientists present asked questions on issues of the stock assessment and related research that was presented. All presenters answered questions and expanded on aspects of the stock assessment and research. On the second and third day the CIE panel met to determine the key issues in the stock assessment modeling that would require some additional modification. They also, collectively with AERD scientists, modified the models code to implement aspects the panel thought were essential. They sought additional analyses from the authors of the stock assessment and additional information on krill predator indices. The reviewers then prepared their individual reports.

The report generated by reviewers addressed the following TORs:

1. *Evaluation of the ability of the integrated model for Antarctic krill, combined with the available data, to provide the parameter estimates required to assess the current status and productivity of Antarctic krill in FAO Subarea 48.1.*
2. *Evaluation of the strengths and weaknesses in the use of the integrated modeling approach to assess whether harvest recommendations meet the CCAMLR decision rules.*
3. *Evaluation of the spatial scale over which the model estimates may be applied.*
4. *Evaluation of strengths and weaknesses of a proposed alternative to the current CCAMLR decision rules, which compare spawning biomass under projected levels of fishing catch to initial unfished spawning biomass. The alternative*

compares spawning biomasses during the period of projected fishing to spawning biomasses with no fishing during the projection period.

5. *Evaluation of the suitability of the integrated assessment in comparison to the GYM approach to determining precautionary catches.*
    a. *Recommendations for further improvements to the assessment model, **i**ncluding frequency of surveys and types of data collection.*
6. *Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations.*

Summary of Findings

The findings of the review have been presented based according to the terms of reference set of the panel:

1. *Evaluation of the ability of the integrated model for Antarctic krill, combined with the available data, to provide the parameter estimates required to assess the current status and productivity of Antarctic krill in FAO Subarea 48.1;*

AERD scientists have done a very thorough job of collating a large diverse collection of data on the krill population in FAO Subarea 48.1, which collectively contains the necessary information required to assess the current status of this area's krill stocks. Many consider the current best practice approach for utilizing such a diverse array of data to quantify the performance of a dynamic stock such as krill, is through the use of an integrated model (IM). The IM supplied to the review panel on the 26th March 2016 was a comprehensive and well-developed model that was able to converge (produce an invertible hessian matrix) and implement MCMC sampling. Its estimated parameters generally made biological sense and the diagnostics of the models fit to the data were very good.

The IM however, required a very specific parameter process order to be followed for convergence to be achieved (the order the panel was provided to run the IM was determined following a process of randomizing the parameter phases). Although this technique of randomizing the phases until convergence is achieved has been published by AERD scientists (Kinzey *et al*., 2015), its requirement still suggests problems in the IM consistently reaching an optimal likelihood. Adding to these concerns were the relatively large gradients associated with many of the parameters in the converged model and the strong correlations between some parameters in the covariance matrix. Collectively, this indicated that the likelihood profile of the model may contain areas of localized minima and may therefore have trouble finding an optimal solution. There were also a number of processes within the model that were considered by the panel to not have been implemented in the most appropriate fashion. These included processes such as the estimation of recruitment and the implementation of selectivity relationships (see Tables 1 and 2 for a complete list).

Based on an extensive examination of the model code and discussions with AERD scientists, two lists (Tables 1 and 2) were developed that contain short-term and long-term objectives, respectively. It was the opinion of the panel that after the investigation / implementation and achievement of short-term objectives (Table 1) that the model would be in a condition that it should be capable of providing the estimates required to assess the current status and productivity of Atlantic Krill in Subarea 48.1.

Table 1. List of short-term objectives for implementation into the integrated krill model. In the table "#" represents a point where the model is robustly converging, large correlations are no longer present between parameters and the maximum gradient is below 1e-3. The terms "model" and "IM" are used throughout the table and refer to the version of the integrated model supplied to the panel on the 26th March 2016.

Modification	Description
Fix F and F_devs_y and directly remove the catches as known values.	The fishery is currently taking out a relatively small proportion of the stock and therefore catches do not markedly impact the biomass. As such they provide little contrast in the model and are hard to estimate. F can attempted to be estimated in the longer-term after #. There are also techniques to calculate F. One such implementation has been provided to AERD scientists.
Fix M and use sensitivity analysis to examine sensible ranges	Until # is reached, the model needs simplification. Estimating M should be tried in the longer-term after #.
Modify the parameters used for selectivity. Use common parameters for: 1. Summer$_{nets}$, Winter$_{nets}$, Summer$_{acou}$, Winter$_{acou}$, Summer$_{fish}$, Winter$_{fish}$. 2. RMT8, IKMT, Acou. and Fish. 3. Other possible reduced parameter options.	There are currently seven separate equations for selectivity being used in the model, some of the parameters of which are highly correlated. Combining parameters to use common values for multiple scenarios will remove these correlations and aid in #. This should not be done by aggregating the data from different surveys, rather keep all seven equations and derive their respective relationships from common parameter sets. This allows the fit to each data source to be individually assessed. It is also important to ensure the selectivity-at-age used in the model always ranges between 0 and 1. Dividing the series by its maximum value may not be the best / complete solution. Under this modification the parameters can still "wander off" as their result can be re-scaled. This will result in large parameter gradients. A solution, if little contrast exists across the age classes, is to fix the selectivity to 1.0 and adjust catchability with q (see below). If contrast exists across age classes then possibly employ small penalties or bound the parameters. The review panel in collaboration with AERD scientists initiated a "quick fix" for the selectivity component; however, this proved quite convoluted and a complete re-structuring of this component would be a more efficient solution and would make future review of the model easier.
Estimate catchability (q_y)	Once the selectivity equations have been modified (see above), catchability (q_y) parameters should be estimated

$N_{1,y} = R_y e^{rec\_devs_y}$ where R_y : Beverton-Holt (BH) and Rzero is estimated	The current implementation of recruitment in the model is not common. It appears that recruitment (mean and deviations) is estimated for the entire data time series before the breeding biomass is estimated. Furthermore, recruitment is currently re-played into the future. The result of this is that when catches are increased in the future (for scenario testing against decision rules), the future recruitment will not be impacted by the reduced biomass (as should happen based on the BH). This could, in the panels opinion, be improved if the recruitment was changed to a standard implementation (as shown left), whereby each year's mean recruitment is estimated iteratively, i.e. from the previous year's spawning stock measure using a BH. Recruitment deviations (*r_devs*) are estimated only for years when data is available. This was implemented into a modified model by collaboration between the panel and AERD scientists. Future versions of the model should maintain this general form of implementation.
$0 = \sum \log\left(rec\_devs_y\right)$	Currently, the *rec_devs* do not sum to zero. As such the mean recruitment (derived from the BH) will not be the mean recruitment. This was rectified in a modified model by collaboration between the panel and AERD scientists. Future versions of the model should maintain this general form of implementation.
Projected recruitment	The current method of projecting recruitment is to copy the historically estimated recruitment and replay this in full into the future. This does not allow future catches to impact on future recruitment. The BH should be used to project mean future recruitment in the same iterative manner as described above. The *r_devs* estimated from the period with data can then be used to add variability for future projections. How they are drawn from the estimated values (i.e. from the period with size composition data) can occur in a multitude of ways. Two possible suggestions are: short-term easy solution (a) and a longer-term more difficult solution (but conceptually better) (b). Future *r_devs* can be chosen based on a weighting of the inverse of the time since that *r_dev* was estimated (a) or using an auto-regressive function can be used to produce future *r_devs* from historically estimated ones (b). The benefit of these two methods is that more recent trends in *rec_devs*, due for example if increasing sea temperatures trends started to effect

	recruitment, would be introduced into future projections. Option b can be considered a longer-term implementation.
Fix steepness (*h*) in BH and use sensitivity analysis to examine (start with 0.85).	It is possible that the current implementation of recruitment in the IM is biasing *h* towards 1. (The model curvature in mean recruitment from a low biomass would be implemented via increasingly negative *rec_devs*. At the same time the *rec_devs* are forced via a penalty to be close to 0. The apparent outcome of this therefore is that the penality on *rec_devs* will force *h* towards 1). After the successful implementation of the recruitment modifications (see above) *h* might prove less problematic (see also stock-recruitment-environment relationship below). *h* can attempted to be estimated in the longer-term after #.
Growth, fix/modify σ and solve for L^{∞} and K	The model contains large amounts of very good length composition data, and the first cohort appears to be well represented and isolated from the older age classes. The IM should be able to estimate all growth parameters. Initially however, it might help in the development of the model to reach # if σ is not estimated in the short-term. The current implementation of the age-length key may be making the estimation of σ difficult and when this is modified, its estimation may become easier (see below).
Model Tuning	The likelihood components resulting from the model are very unbalanced (size composition values 1000 * larger than those for biomass measures). This will cause the model to fit far better to the size composition data than the survey biomass data – which can be fine but may be making it hard for the model to fit some parameters associated only with biomass data. Investigation (sensitivity tests) into the impact of these unbalanced likelihoods on the overall model fit has been undertaken by the AERD scientists prior to this review. I would like to highlight the need for these trials to continue as the model is developed further. Furthermore, if the down weighting of the likelihoods associated with the size composition data does not prove adverse to the overall model's fit, then these likelihoods could be reduced in order for the magnitude of the various likelihoods to be on a more comparable scale. In concert with these trials are continued examinations of the impact of removals of individual data sets from the IM (as have also been done prior to the review by AERD scientists).

	In the longer term, it may prove valuable to modify the likelihood equations (replace the multinomial form) to effectively standardise the size composition data (see Francis, 2014; Thorson 2014).
Maturity schedule	Assigning maturity within the IM is very important since the decision rules for this fishery are based on estimates of spawning biomass (Constable et al., 2000) and this measure is used to estimate recruitment (see above). Currently, the maturity schedule is hard-wired into the model (age-maturity vector brought in via the .dat file). This does not allow the maturity schedule to vary in the model as growth parameters are estimated. Furthermore, the current schedule assigns about 47% of 1+ krill as being mature, which is at odds with what has been reported in journal articles (Cuzin-Roudy 1987a, b; Siegel & Loeb 1994; Ross & Quetin 2000), and with patterns shown in the IKMT data which is used in the model (Fig. 1). It is suggested that the maturity schedule be derived within the model using the age-length key already present and the length maturity information associated with the size composition data. Because an age-length key, will smooth the fine scale (1 mm) length-maturity data into broader age categories (encompass ca. 25 mm), it may be necessary to apply a business rule that all 1+ krill are immature. An alternative to spawning biomass, which is currently determined within the model, is to determine a total fecundity. The two measures only differ if rates of change of the length-weight and length-fecundity relationships differ from each other. In the case of krill, a preliminary examination (Fig. 2) does indicate a difference in rate-of-change. The IM was modified to implement this additional reproductive index (total egg production) during the workshop. The two reproductive indices showed different timing in peaks and troughs (Fig. 3). Future versions of the model should maintain these two measures and investigate the pros and cons of each index for use in the BH.
Age-length key	There is currently a mistake in the way the age-length key is developed in the IM, with the final length bin (the 60+, plus group bin) not being filled. Modifications to the code to correct this have been provided to AERD scientists and this should be implemented into the IM.

Table 2. List of long-term objectives for implementation into the integrated model for krill. In the table "#" represents a point where the model is robustly converging, large correlations are no longer present between parameters and the maximum gradients are below 1e-3. The terms "model" and "IM" are used throughout the table and refer to the version of the integrated model supplied to the panel on the 26th March 2016.

Modification	Description
Pre-standardize spatial data	The spatial scale of the IM encompasses data from a range of locations, both on and off the continental shelf. Previous publications (Siegel, 1988; Siegel *et al*., 1997) and analysis of IKMT survey data used in the model indicates spatial heterogeneity (Fig. 4). When the sampling design is not balanced, as in the case of this data, any consistent spatial variability should be adjusted for. A common technique employed is to use the GLM framework to standardise the data, and in this situation factors of longitude / latitude or depth may be appropriate.
Pre-standardize temporal data	Krill have been shown to display diel activity (Miller and Hampton, 1989). It is therefore possible that changes in the depth distribution of krill between day and night could be increasing the variability of survey samples, and this could occur to different extents for the two different survey types. Standardising for krill diel activity may reduce the variability of survey estimates and make the two survey types more consistent with each other. Again a common technique employed is to use the GLM framework.
Variable growth	The diagnostics provided to the panel from both the current and previous IMs, all show a very good fit to the size composition data. This indicates that the IM is doing a very good job at estimating recruitment size and replicating subsequent growth. It is noticeable in some years that the cohort of 1+ krill has a shifted mode which is also apparent in the following year, i.e. in some years the 1+ cohort appears to be smaller and this continues into the following year when they are 2+. This is not surprising since work has shown that the growth rates of krill are significantly affected by variation in factors such as food sources and water temperature (e.g. Buchholz, 1991). The IM could account for this variability by allowing for a size-at-recruitment deviation that can be carried through into at least the 2+ cohort. If implemented, this deviation should be forced to sum to zero.
Reduce code / input complexity	The current model code and .dat file contain extensive legacy (e.g. area loops, unused selectivity

	function/parameters, movement functions/parameters etc.), which is not erroneous. They do, however, make comprehending the code and its intended processes quite difficult. Removing some of this legacy is recommended. All IMs benefit from the constructive input from a biologist with a strong understanding of the life processes being replicated within the modelling framework. Clear code can make this collaboration easier. Removing legacy can also often identify typographic errors in the code.
Stock-recruitment environment relationship	Previous work has shown links between recruitment and sea-ice cover / ENSO (e.g. Loeb *et al*., 1997; Langdon and Ross, 2003) and Chlorophyll-a (Figs 5 and 6; Chlorophyll-a concentrations in an area just north-west of sub area 48.1 in November/December of year *t* explains almost 75% of the variation in krill recruitment in Subarea 48.1 in year *t+2*). The strength of the Chlorophyll-a relationship indicates that any stock-recruitment relationship (SRR) that exists will be very hard to determine due to the overwhelming influence of environmental drivers. Moreover, a driver such as Chlorophyll-a can inform recruitment two-years in advance, thus improving the model's ability in projecting. Environmental drivers of recruitment in this area should be further examined and significant factors should be added into the IM as data. This will improve the ability of the model to estimate difficult parameters associated with the SRR, such as steepness (*h*), and reduce the magnitude of *rec_devs*.
Model structure	The model's structure is age-based which is a very common form of an IM when age information is known. When, however, ages are unknown and all information is known relative to length and not age, a length-based model is far more commonly used. A reason for this is that all information is known relative to length, so it is directly implemented into the IM without first having to be converted (pooling) into age groups. This therefore maintains a greater amount of information from the raw data. Currently, no age data exist for krill and although this data is presently unobtainable (as krill currently cannot be aged), scientists at AERD are investigating the presence of bands in krill eye stalks. These bands have been reported in a number of crustacean body parts (Leland *et al*., 2011, Kilada *et al*., 2012) and may provide a direct aging technique in the future. Data of

	this form would be invaluable to the IM in its current structure (age-based) and should be incorporated if available.
Acoustic data	During the workshop it was described to the panel that the acoustic surveys cover large expanses of krill habitat, and therefore their biomass estimates do not suffer from the heterogeneous nature of the krill swarms. The acoustic survey data are currently based on three frequencies (38, 120 and 200 kHz), but historically (data not currently included in the model) they were based on only two frequencies (38 and 120 kHz). If possible, these historical data should be included into the model. Furthermore, it may be possible to incorporate the raw acoustic data from each frequency into the model and produce the biomass indices within the model framework. This will allow some of the uncertainty associated with this calculation to be directly incorporated in to the model.
Net data (IKMT and LTER)	Net-based surveys were described to the panel to be less precise than the acoustic surveys due to the patchiness of krill swarms. A useful process may therefore be to conduct a power analysis on the net-based biomass estimates to examine how the variance of the data reduces with increased samples. This may provide further insight into the accuracy of these surveys and how they may be modified to improve accuracy (e.g. increase samples, focus in certain locations).

2. *Evaluation of the strengths and weaknesses in the use of the integrated modeling approach to assess whether harvest recommendations meet the CCAMLR decision rules.*

The strengths of the integrated modelling approach to assess whether harvest recommendations meet the CCAMLR decision rules include:

- The mechanics needed to assess the CCAMLR decision rules (determine spawning biomass (both virgin, current and future) and compare these in a probabilistic framework after determining the impact of future changes in catch are all within the constraints of the integrated modelling framework.
- A large diverse collection of data, both historical and current, on the krill population in FAO Subarea 48.1 has been collated. Incorporating and balancing the trends of these data into a single measure is a complicated process. The current best practice approach for utilizing so much diverse data to quantify the

dynamic state of a stock and compare this to decision rules is through the use of an integrated model (IM).

- Since the IM approach can incorporate information from a range of data sources, including trends in biological and environmental data, this approach is very robust to progressive changes due to factors such as climate change. This is very important when a stock is located in one of the world's fastest changing environments (King 1994; Murphy *et al*., 1995) and its biological response to the environment is very plastic (Buchholz, 1991; Langdon and Ross, 2003).
- IM models incorporate a number of different data sources. Therefore, they are far less likely to be overly biased by one data source over another. Rather, they provide an "average" view of the population that agrees with all data sources.
- Through the process of estimating all multi-year parameters based on their performance over a relatively long time series (e.g. average recruitment and growth), an IM model can be utilized to project estimates forwards and backwards from the time series of data. Therefore, estimates of virgin biomass (i.e. biomass prior to exploitation) can be estimated with associated levels of uncertainty. This is an essential ability that allows an IM to be used to assess whether harvest recommendations meet the CCAMLR decision rules.

The weaknesses of the integrated modelling approach to assess whether harvest recommendations meet the CCAMLR decision rules include:

- The IM approach benefits greatly from its use of a diverse range of data sources. The collection and maintenance of these data sources can be expensive and time consuming. In the case of the krill fishery in FAO sub area 48.1, which is relatively isolated and unhospitable, these data issues are magnified.
- The IM approach requires a good understanding of the biological processes being modelled and benefits from the incorporation of environmental factors. Determining and understanding the causation behind these processes are required before they can be incorporated into the IM framework and can be difficult to develop.
- In fisheries modelling the IM approach is relatively new and constantly evolving, with no current agreed best practice approaches to many aspects of IM construction. For example, there are a number of approaches used to balance the likelihood components of an IM, with much discussion as to the most appropriate (see Francis, 2014). The immature nature of IMs means there is not necessarily a right way to implement some components into the IM framework, and the appropriateness of some methods will change in future evolutions. As such, IMs cannot be considered static and should be subject to frequent review.

3. Evaluation of the spatial scale over which the model estimates may be applied.

Krill are a circumpolar species (Atkinson et al., 2008), yet over this range there is great diversity in biological processes, stock abundance and oceanography. It is therefore very difficult to encompass the entire distribution of krill in a single model and a decision is needed as to what reduced spatial scale is most appropriate for assessment. Key factors in such a decision include the spatial extent of fishing activity, regionality of management, the availability of data, levels of self-recruitment, the homogeneity of biological processes and the extent to which averaging across the data sources is acceptable.

AERD scientists have taken many of these factors into consideration and determined the spatial scale of encompassing FAO Subarea 48.1, with internal regionality (four regions), is the appropriate. This was a sensible approach, since much of the fishing effort occurs within subarea 48.1, it is spatially isolated from other fishing grounds and the extent of population connectivity among regions around Antarctica is unknown. The AMLR Survey sampling grid, the most expansive data source for this area, is also derived from inside Subarea 48.1.

Initial investigations in modelling the krill fishery in subarea 48.1 with four internal regions proved troublesome, and since each of the four regions in the subarea showed similar inter-annual variation in size composition and biomass (Kinzey et al., 2011), it was decided to remove the regionality from within the model. Though it would be marginally beneficial to represent the various regions within the model, the complexity of the movement of krill between regions made this very difficult. The choice of pooling spatial data into a global model is very common and should be associated with the standardization of all spatial data for covariates (in the case of these data inputs covariates such as Longitude, Latitude, depth or distance from continental shelf may be appropriate).

Encompassing subarea 48.1 in an integrated model without internal regionality appears to be the most appropriate spatial scale for the model; however, it does have the problem that its assessment is at a regional scale and localized behavior by the fishing fleet cannot be replicated. In this case, it may be sensible to try to modify the fishery to match the model. For example, because of the potential for localized depletion, conservative catch limits from the modelling may need to be applied. However, if the fishery modified its behavior to more closely replicate the modelling framework, i.e. limiting no more than ¼ of the quota to be taken in any of the four regions, the model-derived catch limits need not to be as conservative, and the fishery benefits.

4. Evaluation of strengths and weaknesses of a proposed alternative to the current CCAMLR decision rules, *which compare spawning biomass under projected levels of fishing catch to initial unfished spawning biomass. The alternative compares spawning biomasses during the period of projected fishing to spawning biomasses with no fishing during the projection period.*

The proposed alternative to the current CCAMLR decision rules is "the median future spawning biomass is compared to 75% of the reference ("predator rule"), and the 0.1 quantile of the future spawning biomass is compared to 20% of the reference (krill rule), with the reference being the future unfished spawning biomass".

The main strength of the proposed alternative to the current CCAMLR decision rules is the use of an estimate of future spawning biomass rather than historical spawning biomass. This is a more appropriate reference level because it incorporates the current trajectory of the fishery. This results in the reference level and index to which it is compared to being on the same scale, future unfished vs future fished, both influenced by the same environmental drivers. Climate change may lead to changes in average krill biomass, and it is these future biomasses that will be relevant to future krill recruitment and to future populations of krill predators. The average future biomass is also temporally closer to the present, and since in recent years data sets are more comprehensive, is likely future biomasses will be estimated with greater accuracy than the historical measure of virgin biomass.

The weaknesses of the proposed alternative to the current CCAMLR decision rules include the dynamic nature of future spawning unfished biomass due to factors such as changing water temperatures, ice coverage, and upwelling, all of which have been shown to be evolving under climate change (King 1994; Murphy *et al*., 1995). The proportion of future biomass needed by future predators will therefore also be quite variable, especially as their population sizes will vary. As such, setting a constant proportion of this biomass aside to limit impact on predators is unlikely to be robust, or if it is to be, this proportion will have to be extremely conservative. In fact, natural variation in the biomass of krill near the Antarctic Peninsula has already been shown to impact the abundance/reproductive success of some predators (Croxall *et al*., 1999; Fach *et al*., 2006), presumably without fishing significantly reducing the biomass. Based on this work, only a constant proportion of zero could be used to assign future fishery catches.

The use of the spawning biomass as a measure by which to determine commercial catch levels that will not impact predators seems limited. The spawning biomass does not directly represent the entire prey composition of many of the krill's predators as they eat both juvenile and adult krill (as well as other species). Specifically for krill, additional work is needed to determine the relationship between krill size and its importance to predators, which then needs to be implemented when determining what proportion of the stock should be used as a biomass measure for predators.

Another weakness is relatively arbitrary setting of the krill reference levels (0.1 quantile of the future spawning biomass is compared to 20% of the reference). This may be overly conservative or not conservative enough. This reference could be more quantitatively based on results from a stock-recruitment-environment relationship for subarea 48.1. This would incorporate factors such as levels of self-recruitment and whether there exist areas of recruitment source (i.e. is subarea 48.1 a recruitment sink). The plot provided to AERD scientists showing spatial correlations between SeaWifs Chlorophyll-a (mg/L) concentration and an empirical index of recruitment derived from the IKMT data (Fig. 5) indicated that locations north-west of subarea 48.1 are related to the recruitment success in this subarea. This relationship may be between an area correlated with production processes within subarea 48.1, or may be a direct measurement and therefore highlights the area where successful larval production is produced. In the case of the latter, no direct stock-recruitment relationship may exist with subarea 48.1 and the krill rule is overly conservative.

Possible modifications to the proposed alternative to the current CCAMLR decision rules may include modifying the predator rule to include directly monitoring indicator predator population health parameters (i.e. age at crèche) and having feedback mechanisms into the catch setting process that ensure, irrespective of the estimated future krill biomass estimates, that fishing does not negatively impact on predators. Since this removes the proportion approach to the future biomass, in some years, following periods of low recruitment and thus low overall biomass levels, it could result in no fishing occurring in certain areas.

5. Evaluation of the suitability of the integrated assessment in comparison to the GYM approach to determining precautionary catches.

*(i) Recommendations for further improvements to the assessment model, **i**ncluding frequency of surveys and types of data collection.*

An integrated model (IM) is more appropriate for determining precautionary catches than the GYM model, given the large amount of diverse time-series data available for this fishery. A production model such as the GYM is more appropriate under a more data-poor scenario. This is because the GYM is a simulation model that utilizes pre-specified values to represent the processes of Antarctic krill. Unlike an IM the GYM model does not statistically estimate parameters directly from data through likelihood functions; rather, its uncertainty is incorporated from uncertainty determined around the input values. The ability to re-fit to multiple sources of data allows an IM to constantly improve its estimates as more data becomes available, directly incorporate levels of uncertainty, and progressively change projections as the population parameters change due to factors such as climate change.

An example of the limitations of the use of pre-specified values in the GYM was the recruitment variability used, which was derived from a Beta distribution with a predetermined mean and standard deviation (SC-CAMLR, 2012). This recruitment variability was shown by Kinzey et al. (2013; 2015) to be far too limited, well below that shown by empirical measures of variability based on size compositions and predator diets. As such the projections produced by the GYM would have been overly optimistic. This outcome would not have occurred under the IM framework since a good time series of size composition data exists, and the IM determines recruitment directly from this data set (and others). Moreover, progressive changes that occur in recruitment will be included as they occur and they will be implemented into future projections by the IM.

A number of recommendations for improvements to the assessment model are listed in Tables 1 and 2, including the incorporation of additional data sets associated with certain improvements. The IM framework can incorporate data from multiple sources, with the greater diversity of data being positive for the model's robustness. The current IM incorporates data from different surveys, as well as data from the fishery. This consists of both acoustic summarized data and net-tow information. Other data sources do exist and these should be incorporated into the IM as a priority. These include:

- If available, age composition data (possibly from eye stalk sectioning).
- Environmental data associated with krill recruitment, growth and movement.
- Size composition data derived from the sampling of predator diets.
- NSF LTER data has just become available for part of subarea 48.1.
- Do multiple net catches exist from the same time/location? These do not have to have occurred within subarea 48.1. Direct comparisons of nets within the model could help with the determination of parameters associated with selectivity.
- Ensure fishery-based statistics are produced in a standardised fashion. Fishery statistics from different jurisdictions are often recorded in different formats and sometimes under different measures (i.e. green vs processed). It is important that all data sources are collected in a standard fashion.

In addition to modifications to the model suggested in Tables 1 and 2, AERD scientists could consider:

- Diagnostics fits to empirical data sets. Currently, the modelling work produces very useful diagnostic plots. These, however, could be augmented by diagnostics between modelled and empirical data sets. For example, it is relatively simple to develop empirical time series of recruitment, spawning biomass and egg production. These could be compared to model estimates of these indices to ensure that the general trends are replicated. Any significant differences between indices provide useful information for understanding what processes are occurring within the model.
- The use of an external .pin file (with or without randomised starting values) is very useful, especially in the developmental phase of an IM. It makes the input parameters easy to assign and to determine their values for de-bugging. It is suggested that AERD scientists use this technique.

6. Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations.

The panel review proceedings consisted of a three day workshop from the 2nd to 4th of April 2016. A large number of outcomes and future objectives were developed during the workshop. These are listed in Tables 1 and 2. The collaborative nature of this process was very positive and resulted in a pleasant working environment, where ideas and thoughts were discussed freely.

2 April 2016.
The meeting convened at the South West Fisheries Centre at 9 am, and was attended by the two reviewers (Simon de Lestang and Robin Thomson) and four staff members from SWFC (Christian Reiss, George Watters, Doug Kinzey and Jeremy Rusin).

A number of presentations were provided to the panel (reproduced in the Appendix) in an informal setting allowing for discussions on key points to occur throughout the presentations.

Key discussion points included:

- The ageing of krill
- Alternate decision rules to those of CCAMLR
- Predator-based indices to use for decision rules
- Modifications to the IM

3 April 2016.
The meeting convened at the South West Fisheries Centre at 9 am, and was attended by the two reviewers (Simon de Lestang and Robin Thomson) and three staff members from SWFC (George Watters, Doug Kinzey and Jeremy Rusin).

Dr Kinzey provided a number of presentations on the changes implemented into the IM. Following from this, the panel and AERD scientist began collectively modifying the IM code to implement a modified recruitment process (outlined in Table 1).

4 April 2016.
The meeting convened at the South West Fisheries Centre at 9 am, and was attended by the two reviewers (Simon de Lestang and Robin Thomson) and three staff members from SWFC (George Watters, Doug Kinzey and Jeremy Rusin).

The panel and AERD scientist continued to collectively modify the IM code to implement the production of an index of fecundity, and to change the process selectivity curves are developed within the model (outlined in Table 1).

Figures:

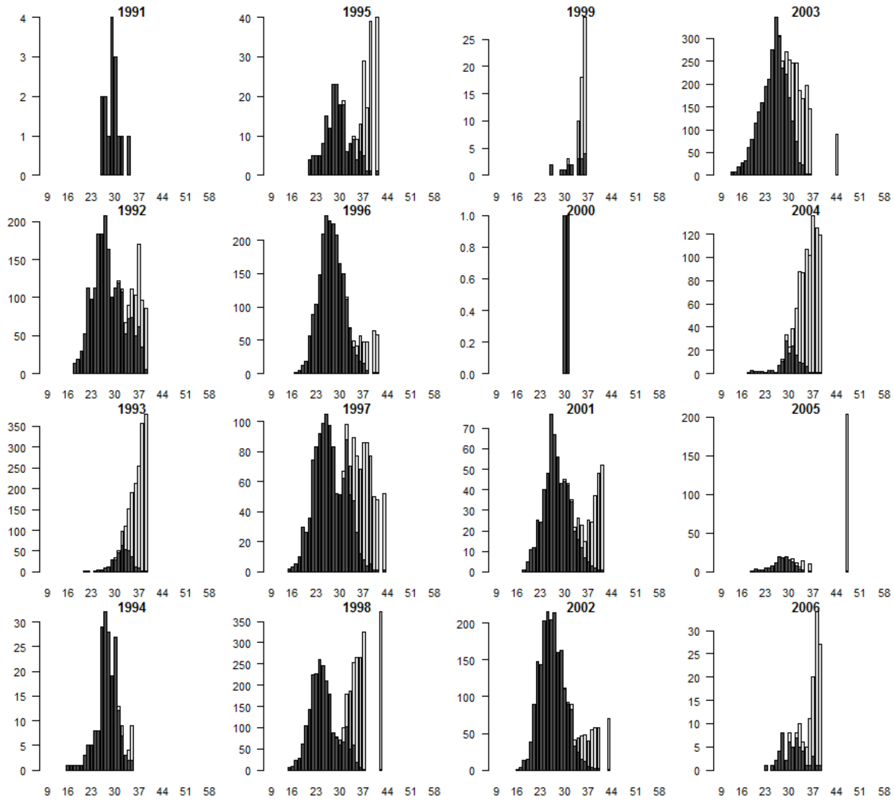

Figure 1. Annual size-composition data from AMLR IKMT surveys between 1991 and 2006 showing juvenile krill (dark grey) and mature female krill (light grey).

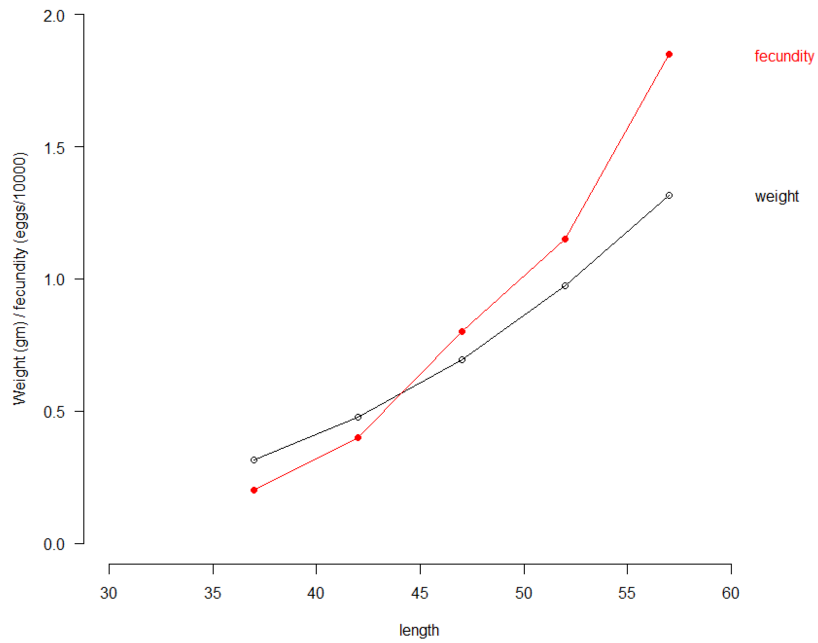

Figure 2. Relationships for krill between length and weight (black, data from .dat file) and length – fecundity (red, derived from Tarling *et al*., 2007).

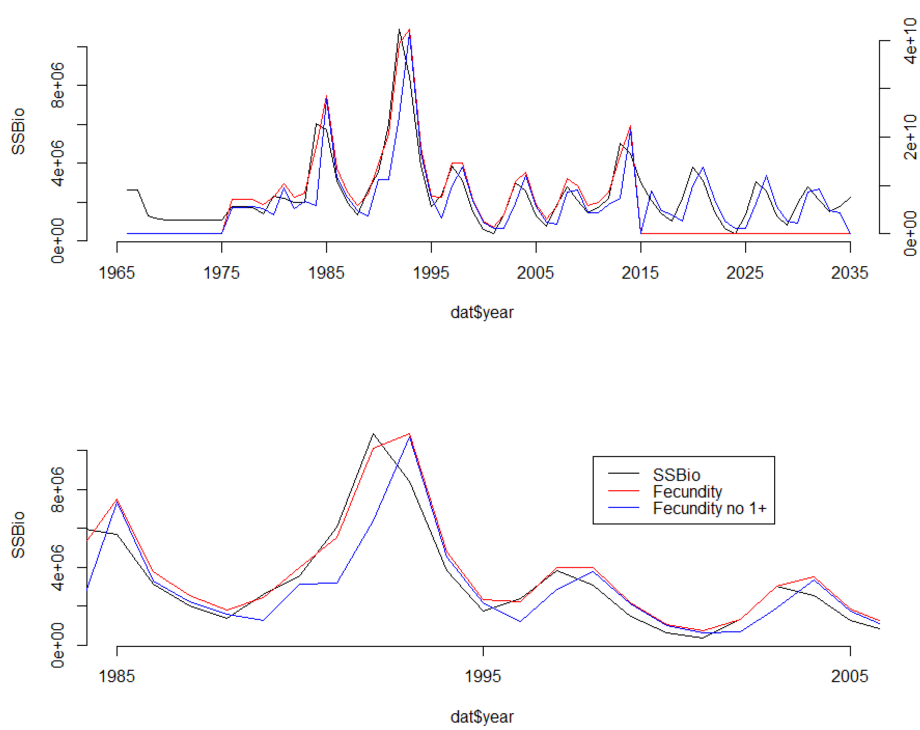

Figure 3. Model estimates of spawning stock biomass (black, SSBio), total fecundity (red, Fecundity) and total fecundity with the business rule of all 1+ krill are immature (blue, Fecundity no 1+). The top panel is

the entire time series and the bottom panel highlights a section of the time series to better examine differences.

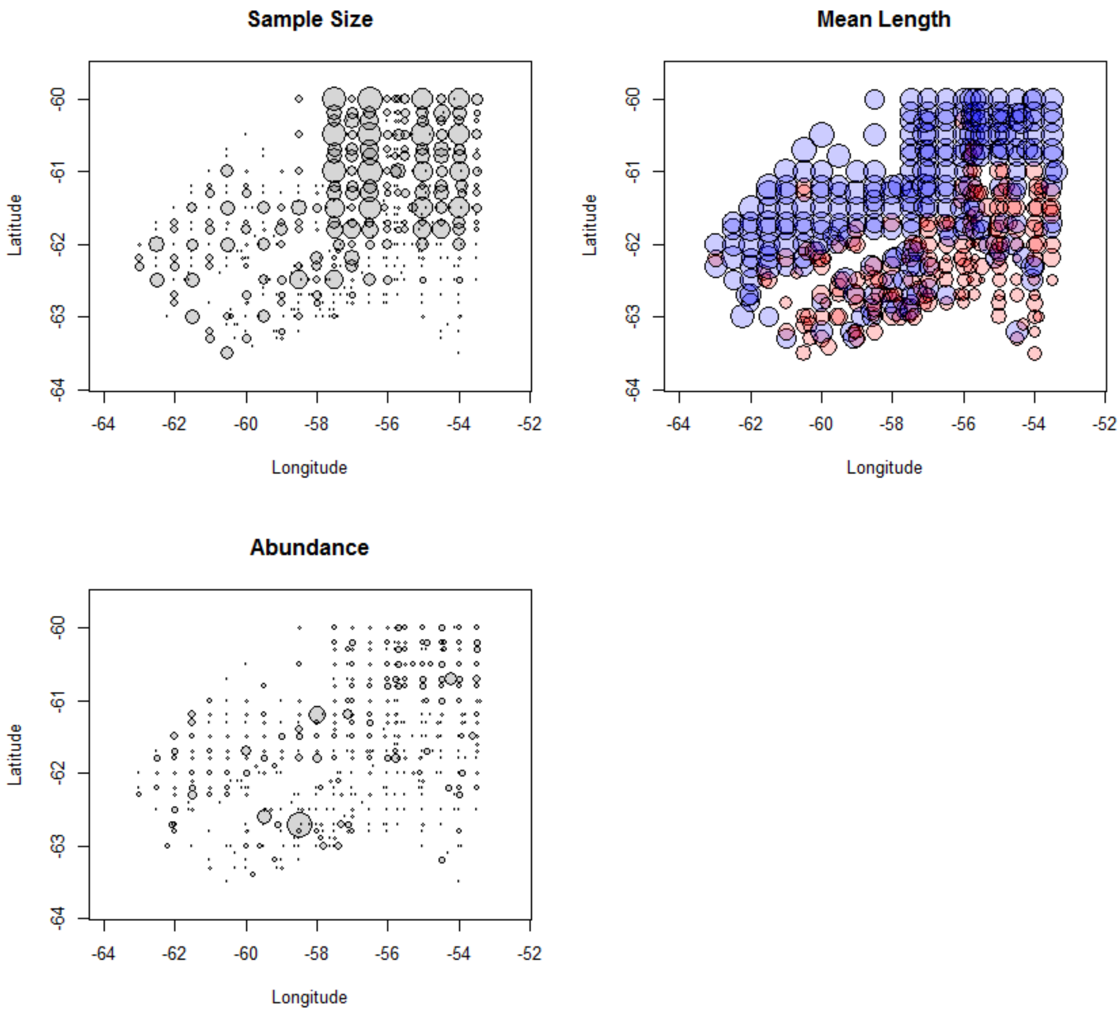

Figure 4. Spatial magnitude plots for krill showing the sampling intensity (top left), relative variation in mean krill length (means smaller than 70% of the maximum mean krill length are red, otherwise they are blue) (top right) and relative variation in mean krill abundance (bottom left).

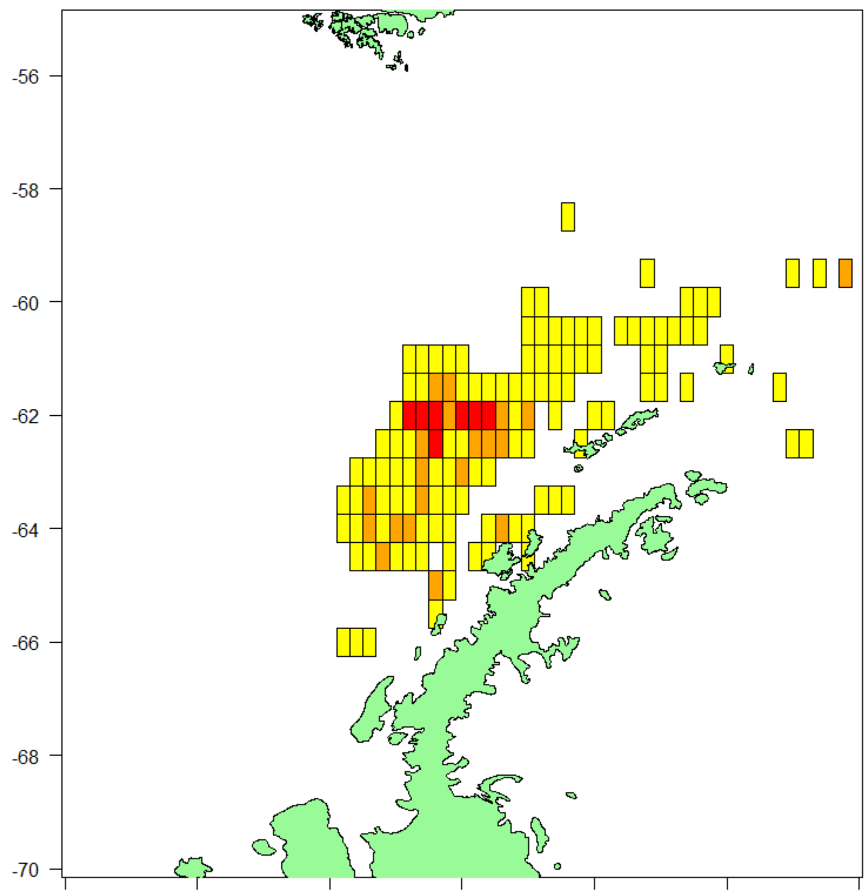

Figure 5. Spatial plot showing the correlation between SeaWifs Chlorophyll-a (mg/L) concentrations in November/December of year t and an empiric index of recruitment derived from the IKMT data in year t+2 (all krill <= 30 mm length). Correlations above 0.6, 0.7 and 0.8 are shown in yellow, orange and red, respectively.

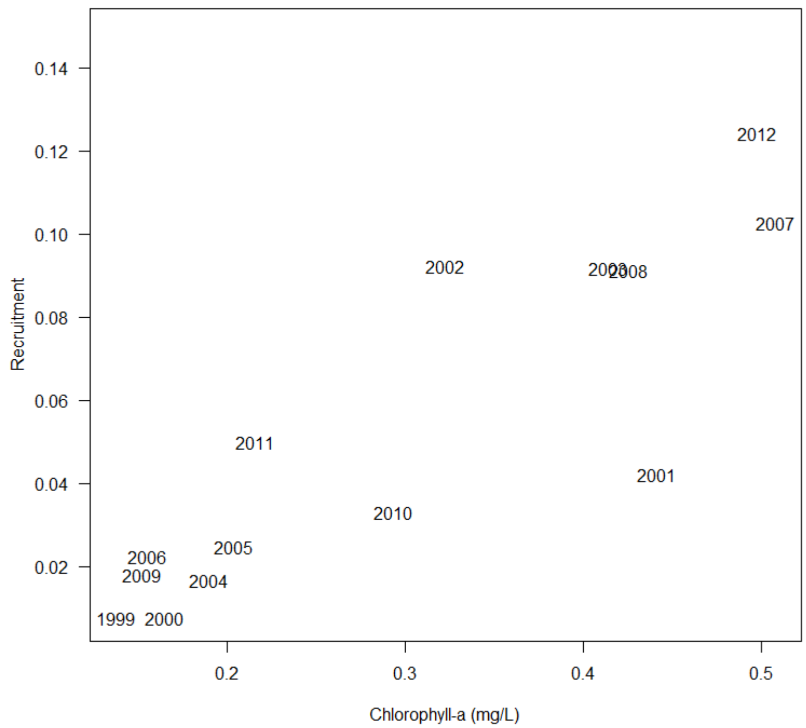

Figure 6. Relationship between SeaWifs Chlorophyll-a concentrations (mg/L) in the red blocks shown in Figure 8 and an empiric index of recruitment two years later derived from the IKMT data (all krill <= 30 mm length). Year show is the recruitment year.

References:

Atkinson, A., Siegel, V., Pakhomov, E. A., Rothery, P., Loeb, V., Ross, R. M. & Tarling, G. A. 2008. Oceanic circumpolar habitats of Antarctic krill. *Marine Ecology Progress Series*, *362*, 1-23.

Croxall, J.P, Prince, P.A. and Reid, K. 1999. Diet, provisioning and productivity responses of marine predators to difference in availability of Atlantic Krill. *Mar Ecol Prog Ser*. 177, 115-131.

Fach, Bettina A., Eileen E. Hofmann, and Eugene J. Murphy. "Transport of Antarctic krill (Euphausia superba) across the Scotia Sea. Part II: Krill growth and survival." *Deep Sea Research Part I: Oceanographic Research Papers* 53.6 (2006): 1011-1043

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King J.C. 1994 Recent climate variability in the vicinity of the Antarctic Peninsula. *International Journal of Climatology*. 14 357-369

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Siegel, V., W. K. De la Mare, and V. Loeb. 1997 "Long-term monitoring of krill recruitment and abundance indices in the Elephant Island area (Antarctic Peninsula)." CCAMLR Science 4: 19-35.).

Tarling, G. A., Cuzin-Roudy, J., Thorpe, S. E., Shreeve, R. S., Ward, P., & Murphy, E. J. (2007). Recruitment of Antarctic krill *Euphausia superba* in the South Georgia region: adult fecundity and the fate of larvae. *Marine Ecology Progress Series*, 331, 161-179.

Thorson, J.T. 2014. Standardizing compositional data for stock assessment. *ICES Journal of Marine Science*. doi:10.1093/icesjms/fst224

Appendix 1: Bibliography of materials provided for review

Model files:
- krill.exe
- krill.tpl
- krill.dat

Documents (pdf and word):
- Constable et al., 2000
- Kinzey et al., 2011
- Kinzey et al., 2013
- Kinzey et al., 2014
- Kinzey et al., 2015a
- Kinzey et al., 2015b
- Krill Fishery Report 2015
- Nicol et al., 2012
- Siegel 2005
- Siegel et al., 2013

Presentations (ppt files):
- 1_Overview
- 2_SpatialTemporal aspects
- 3_CCAMLR Recommendations
- 4_Diagnostics
- 5_Projections
- 6_Alternatives
- Opening CIE talk

Appendix 2: Statement of Work

National Oceanic and Atmospheric Administration (NOAA)
National Marine Fisheries Service (NMFS)
Center for Independent Experts (CIE) Program
External Independent Peer Review

An age-based, integrated stock assessment
for Antarctic krill (Euphausia superba)
with projected catches to 2035

Background

The National Marine Fisheries Service (NMFS) is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). NMFS science products, including scientific advice, are often controversial and may require timely scientific peer reviews that are strictly independent of all outside influences. A formal external process for independent expert reviews of the agency's scientific products and programs ensures their credibility. Therefore, external scientific peer reviews have been and continue to be essential to strengthening scientific quality assurance for fishery conservation and management actions.

Scientific peer review is defined as the organized review process where one or more qualified experts review scientific information to ensure quality and credibility. These expert(s) must conduct their peer review impartially, objectively, and without conflicts of interest. Each reviewer must also be independent from the development of the science, without influence from any position that the agency or constituent groups may have. Furthermore, the Office of Management and Budget (OMB), authorized by the Information Quality Act, requires all federal agencies to conduct peer reviews of highly influential and controversial science before dissemination, and that peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards.
(http://www.cio.noaa.gov/services_programs/pdfs/OMB_Peer_Review_Bulletin_m05-03.pdf).
Further information on the CIE program may be obtained from www.ciereviews.org.

Scope

The SWFSC Antarctic Ecosystem Research Division (AERD) requests an independent review of the integrated stock assessment it has developed for Antarctic krill. The Antarctic krill fishery is managed by the international treaty organization, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), of which the U.S. is a member. The fishery is currently expanding both in total catch and in the number of nations and vessels participating. Current catch limits of 5.61 million tons for the Scotia Sea, where all current krill fishing is conducted, were established using the

Generalized Yield Model (GYM), a model developed in the 1990s. 155 thousand tons of this total catch limit has been apportioned to FAO Subarea 48.1, a subregion of the Scotia Sea.

The GYM is a simulation model rather than a statistical model and relies heavily on data from a single multination survey conducted in 2000. The integrated model developed by AERD is a statistical model that uses annual survey (1981-2014) and fishery data (1976-2014) from FAO Subarea 48.1, where available, and will continue to use new data as it becomes available. AERD in conjunction with the U.S. Department of State intends to propose to CCAMLR that the model developed by AERD be used to establish catch limits for the krill fishery rather than the GYM. Having the model framework scientifically vetted outside of AERD or CCAMLR will be an important step in this process. The Terms of Reference (TORs) of the peer review and the tentative agenda of the meeting are below.

Requirements
NMFS requires two reviewers to conduct an impartial and independent peer review in accordance with the SOW, OMB Guidelines, and the TORs below. The reviewers shall have working knowledge and recent experience in the application of fisheries stock assessment processes and results, including population dynamics, separable age-structured models, harvest strategies, survey methodology, ecosystem-based fishery management, and the AD Model Builder programming language. They should also have experience conducting stock assessments for fisheries management.

Tasks for reviewers

- Review the following background materials and reports prior to the review meeting:

  Kinzey, D., G. Watters, and C. Reiss. 2015. An age-based, integrated stock assessment for Antarctic krill (Euphausia superba) with projected catches to 2035. 30 pp (estimated page number, document to be developed)

  Kinzey, D., G. Watters, and C. Reiss. 2015. Selectivity and two biomass measures in an age-based assessment of Antarctic krill (Euphausia superba). Fisheries Research 168:72-84.

  Kinzey, D., G. Watters, and C. Reiss. 2014. Integrated models for Antarctic krill (Euphausia superba) using survey data from 1981–2014 in Subarea 48.1. CCCAMLR WG-SAM-14/32. 30 pp

  Kinzey, D., G. Watters, and C. Reiss. 2013. Effects of recruitment variability and natural mortality on Generalised Yield Model projections and the CCAMLR Decision Rules for Antarctic krill. CCAMLR Science 20:81-96.

Kinzey, D., G. Watters, and C. Reiss. 2011. Modeling Antarctic krill: scale, movement and age-structure. CCAMLR WG-EMM-11/43 Rev.1. 37 pp

Constable, A.J., W.K. de la Mare, D.J. Agnew, I. Everson,and D. Miller. 2000. Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). ICES Journal of Marine Science. 57: 778-791.

- Attend and participate in the panel review meeting
    - The meeting will consist of presentations by NOAA and other scientists, stock assessment authors and others to facilitate the review, to provide any additional information required by the reviewers, and to answer any questions from reviewers
- After the review meeting, reviewers shall conduct an independent peer review in accordance with the requirements specified in this SOW, OMB guidelines, and TORs, in adherence with the required formatting and content guidelines; reviewers are not required to reach a consensus
- Each reviewer may assist the Chair of the meeting with contributions to the summary report, if required by the TORs
- Deliver their reports to the Government according to the specified milestone dates

Foreign National Security Clearance

When reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for reviewers who are non-US citizens. For this reason, the reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/ and http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national-registration-system.html. The contractor is required to use all appropriate methods to safeguard Personally Identifiable Information (PII).

Place of Performance

The place of performance shall be at the contractor's facilities, and at the Southwest Fisheries Science Center in La Jolla, California.

Period of Performance

The period of performance shall be from the time of award through May 31, 2016. Each reviewer's duties shall not exceed 14 days to complete all required tasks.

Schedule of Milestones and Deliverables: The contractor shall complete the tasks and deliverables in accordance with the following schedule.

Within two weeks of award	Contractor selects and confirms reviewers
No later than March 14, 2016	Contractor provides the pre-review documents to the reviewers
March 4-6, 2016	Panel review meeting
April 21, 2016	Contractor receives draft reports
May 15, 2016	Contractor submits final reports to the Government

Applicable Performance Standards
The acceptance of the contract deliverables shall be based on three performance standards:
(1) The reports shall be completed in accordance with the required formatting and content (2) The reports shall address each TOR as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel
All travel expenses shall be reimbursable in accordance with Federal Travel Regulations (http://www.gsa.gov/portal/content/104790). International travel is authorized for this contract. Travel is not to exceed $16,000.

Restricted or Limited Use of Data
The contractors may be required to sign and adhere to a non-disclosure agreement.

Peer Review Report Requirements

1. The report must be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether or not the science reviewed is the best scientific information available.

2. The report must contain a background section, description of the individual reviewers' roles in the review activities, summary of findings for each TOR in which the weaknesses and strengths are described, and conclusions and recommendations in accordance with the TORs.

   a. Reviewers must describe in their own words the review activities completed during the panel review meeting, including a brief summary of findings, of the science, conclusions, and recommendations.

   b. Reviewers should discuss their independent views on each TOR even if these were consistent with those of other panelists, but especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the summary report that they believe might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The report shall be a stand-alone document for others to understand the weaknesses and strengths of the science reviewed, regardless of whether or not they read the summary report. The report shall represent the peer review of each TOR, and shall not simply repeat the contents of the summary report.

3. The report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of this Statement of Work
   Appendix 3: Panel membership or other pertinent information from the panel review meeting.

Terms of Reference for the Peer Review

An age-based, integrated stock assessment for Antarctic krill (Euphausia superba) with projected catches to 2035

1. Evaluation of the ability of the integrated model for Antarctic krill, combined with the available data, to provide the parameter estimates required to assess the current status and productivity of Antarctic krill in FAO Subarea 48.1.
2. Evaluation of the strengths and weaknesses in the use of the integrated modeling approach to assess whether harvest recommendations meet the CCAMLR decision rules.
3. Evaluation of the spatial scale over which the model estimates may be applied.
4. Evaluation of strengths and weaknesses of a proposed alternative to the current CCAMLR decision rules, which compare spawning biomass under projected levels of fishing catch to initial unfished spawning biomass. The alternative compares spawning biomasses during the period of projected fishing to spawning biomasses with no fishing during the projection period.
5. Evaluation of the suitability of the integrated assessment in comparison to the GYM approach to determining precautionary catches.
    (i) Recommendations for further improvements to the assessment model, **i**ncluding frequency of surveys and types of data collection.

6. Brief description on panel review proceedings highlighting pertinent discussions, issues, effectiveness, and recommendations.

Tentative Agenda

An age-based, integrated stock assessment for Antarctic krill (Euphausia superba) with projected catches to 2035

TBD

Southwest Fisheries Science Center

8901 La Jolla Shores Drive

La Jolla, CA 92037-7000

March 28-30, 2016 9AM - 5PM

Point of contact: Front Desk

Appendix 3: Panel membership or other pertinent information from the panel review meeting.

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