Center for Independent Experts (CIE) Independent Peer Review of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Toothfish Stock Assessments

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Executive Summary

An online peer review meeting was held on August 3rd, 15th, 16th, and 17th 2023 US East Coast time to discuss toothfish assessments in Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) areas 48.3, 48.4, 58.5.2, and 88. Two species of toothfish were examined *Dissostichus eleginoides* and *Dissostichus mawsoni.* Toothfish in the CCAMLR region are slow-growing, long lived. The general approach in the CCMALR region is to use a statistical catch-at-age modeling approach using the CASAL platform. The assessments of toothfish in the CCMALR region often incorporate catch-at-age data, length sampling, tagging information, and either fishery-dependent or fishery-independent surveys.

Each of the assessments met each of the terms of reference. However, a number of comments were made to help improve the modeling. Chiefly, models tended to fix both natural mortality and steepness outside of the model rather than having them estimated within the model. While this is often the best or only option, the data should be available to estimate either natural mortality or steepness, even if using informative priors. Additionally, some assessments suffered from having relatively short time periods from which to monitor the stock, making the results rather uncertain. Also, the projection periods over which these assessments were providing management advice are very long compared with the period over which the assessments were modeling the stock.

Numerous recommendations were made throughout the report. Importantly, a vision of what the ideal stock assessment structure should be for toothfish in this region should be developed. Ideally, the model structure should incorporate some form of sex specificity to account for the sexual dimorphism seen in the stock (data permitting). A recommendation to use retrospective analysis was suggested, as this type of diagnostic is important to understanding how the model processes the data as well as relating model uncertainty to the managers and stakeholders. There should be more work on documentation and report structure to ease future reviews. And finally, where peer reviews fall in the assessment process was addressed. It is always best if peer reviews are carried out between model formulation/finalization and management advice, with ample time for sensitivity analysis and model testing in collaboration with external reviewers prior to publishing the model's results.

This was an interesting, informative, and enjoyable review. Many of the elements of a good set of assessments are already in place, and the models should be considered the best available science for toothfish stocks in the CCMALR region.

Background

The peer review for Patagonia and Antarctic toothfish was held online on August 3rd, 15th, 16th, and 17th 2023 US East Coast time as part of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) process. In total four stock assessments were reviewed.

i. *Dissostichus eleginoides* in Heard Island and McDonald Islands in Division 58.5.2

ii. *Dissostichus mawsoni* in the Ross Sea in Subarea 88.1 and SSRUs 882A–B
iii. *Dissostichus eleginoides* in South Georgia in Subarea 48.3
iv. *Dissostichus eleginoides* in the South Sandwich Islands in Subarea 48.4.

A map of the areas involved in the CCAMLR is shown below (Figure 1). Notably, the distances between the stocks under review span thousands of kilometers.

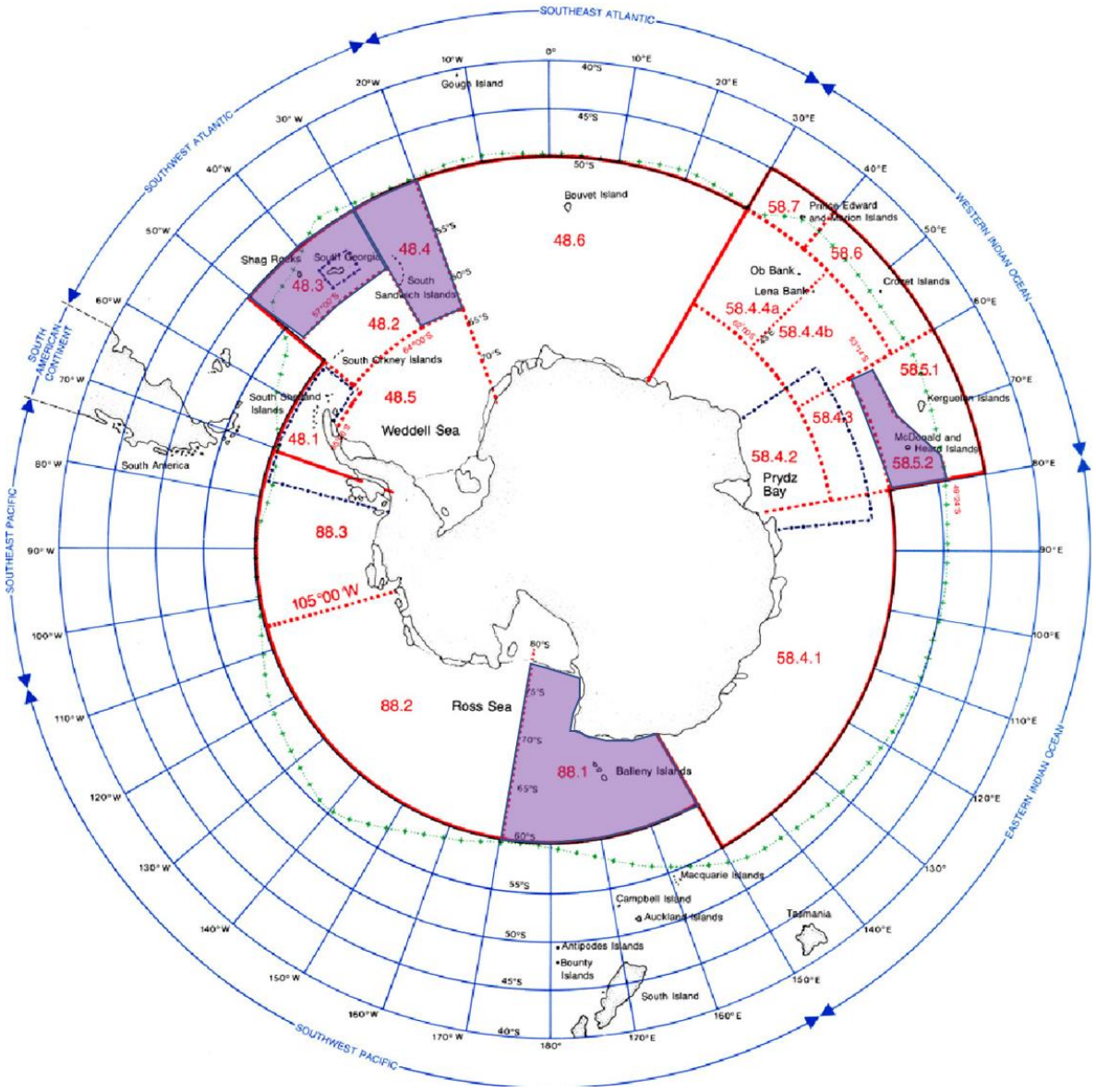

Figure 1: CCAMLR areass pertaining to the stocks under review. Areas for te review are shaded in purple.

The basic biology of both Patagonia (*Dissostichus eleginoides*) and Antarctic (*Dissostichus mawsoni*) toothfish is very similar. Spawning takes place in deep waters (~1,000 m) during the austral winter and the pelagic eggs and larvae drift to suitable shallow water areas (< 300 m) either near the

Antarctic shelf (in the case of Antarctic toothfish) or to seamounts or shelf fragments (in the case of Patagonia toothfish). Juveniles spend the next 6-8 years in these shallow areas before migrating to deeper waters prior to maturing. Maturation is generally at between 6-10 years with males becoming mature earlier than females. Additionally, there is some sexual dimorphism, with females achieving a larger size than males. The fishery for toothfish tends to take place in shallower areas, and so often targets immature fish before their first spawning. Likewise, most of the tagging and survey information is also taken from toothfish during their juvenile stages, when they are more vulnerable to fishing and survey gear. The maximum age is thought to be around 50+ years.

The models under review all used CASAL; an age or length-based approach usually configured for toothfish in a statistical catch-at-age approach similar to ASAP or SS3 with some minor differences. Major data elements across assessments include catch, length information, tagging data, Catch per Unit Effort (CPUE), or fishery-independent surveys of abundance. Currently, CASAL 2, a more flexible and powerful form of CASAL software, is undergoing testing and implementation for other stocks in the CCAMLR region. It was indicated during the review meeting that CASAL 2 would be used for the next round of toothfish assessments.

In general stock assessments feed into the process as outlined in Figure 2 (below) between the WG-FSA and SC-CAMLR.

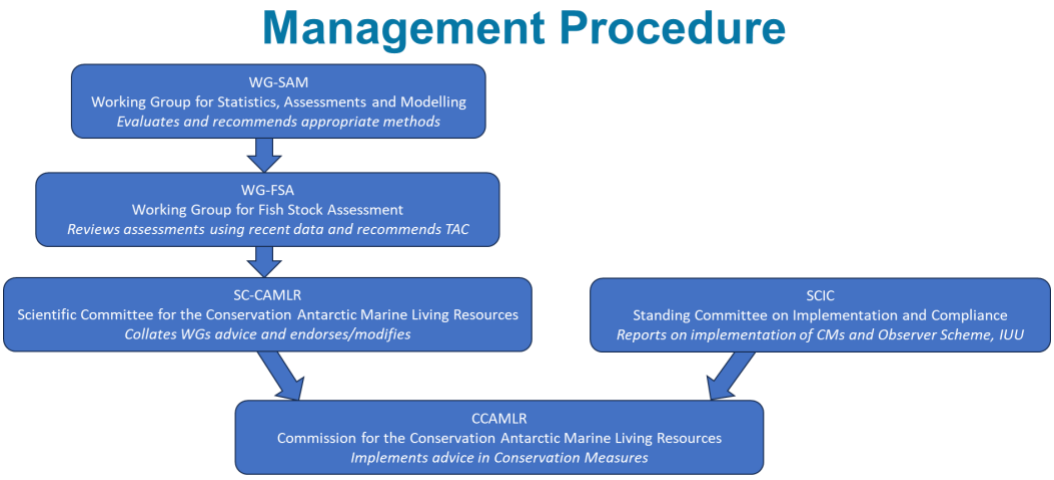

Figure 2: Flow of scientific advice in the CCAMLR process

For toothfish, CCAMLR uses depletion from B_0 rather than MSY-based reference points. In this scheme, B50% is considered the target biomass reference point, with B25% a threshold where management measures may be taken should the stock fall below this value. Fishing mortality or exploitation-based reference points don't seem to be used in this region to supplement the biomass reference points, unlike other areas around the world.

In contrast to other peer review processes, this review took place on assessments that have already been released and have already been used for management purposes. As such it was not possible to request sensitivity analysis or other diagnostics as the materials under review had already been used to provide management advice and set quotas. Rather this review is a retrospective examination to determine if the best scientific information and analysis was used to craft that advice.

Throughout the document, a number of key recommendations highlighted in bold are made.

Description of Reviewer's Role

For this Review, the role of the reviewer assigned to read the materials provided and complete a review of the toothfish assessments in CCAMLR regions outlined in Figure 1 and report organization and process in accordance with the TORs. The Review is independent of the other Review panel members and serves as a standalone document separate from any consensus document created during the review process.

Summary of Findings

TOR 1: Reviewing the status and report on the implementation of the recommendations arising from the CCAMLR Independent Stock Assessment Review for Toothfish in 2018 (SC-CAMLR-XXXVII/02 Rev. 1, and SC-CAMLR-XXXVII, Annex 9, Table 3).

Examination of all of the recommendations by assessment would be needlessly burdensome and lengthy. Most of this information is contained in each of the specific assessment reports or the supporting documents for this review. Overall, each of the assessments examined made satisfactory progress on the recommendations outlined in Table 1. Three issues from that review, however, are commented upon here.

The first is the documentation comment found in Table 1. During this review, it was found that documentation was still an issue. Often the documents were not as standard as recommended, with various groups utilizing the template differently. Additionally, the current document structure made it very difficult to find the information necessary to fully conduct the review. In some cases, methods and assumptions of the various assessments referred to other previous years, only to have that document refer to previous years. Also, there was no full document that contained a full treatment of all aspects of the assessment in one place. Instead, information, diagnostics, and model descriptions were spaced out over many different documents with similar naming conventions. A full recommendation in the Other Comments and Recommendations section will help to clarify what document structure could be used. **In short, there should be one document with all the needed information, including model description, data treatment, and diagnostics**. A separate, much shorter document should summarize the findings for stakeholders and the public.

Table 1: Review Panel recommendations per SC-CAMLR-XXXVII, Annex 9, Table 3

Review panel comments	Target	Evaluation	Priority	Timeline
Documentation				
1. It is recommended that a standardised format be developed by CCAMLR for the presentation of details of assessments to facilitate understanding of the assumptions, data preparation and inputs, parameter estimation and results across the assessments performed by the CCAMLR, and that a public summary document with these details be developed and updated at a fixed period (e.g. five years).	WG-SAM WG-FSA	Summary	High	2019/20
Stock hypotheses				
2. A number of assessments described the proposed stock hypotheses and described ideas for future work. The RP suggests that appropriate experts be consulted, and a review be planned if these assessments or CCAMLR require evaluation of the hypotheses.	SC WG-SAM WG-FSA	Area dependent data review	High / Medium	Ongoing
Surveys				
3. Where possible, such surveys should be continued and optimised to ensure recruitment variability can be detected.	SC WG-FSA	Assessment	High	Ongoing
4. Subareas 88.1/88.2 – Consideration should be given to restricting the data from the survey to be more representative of recruitment.	WG-SAM WG-FSA	Sensitivity	High	2019
5. Subareas 88.1/88.2 – Consideration should be given to designing the survey to take this into consideration or increasing the catch limit, so that the unused catch limit can be released after the survey, or by releasing excess fish, etc.?	SC WG-FSA	Review	Medium	Ongoing
6. Division 58.5.2a more appropriate approach to fitting the survey might be to fit the index-at-age data using a multivariate likelihood function and the empirical variance-covariance matrix.	WG-SAM WG-FSA	Sensitivity	High	2019
Ageing				
7. In some cases just a single experienced reader has been used. The RP suggests that, where possible, increasing the number of readers to a minimum of two experienced readers, within laboratories, would be beneficial.	Members	Uncertainty	Medium	Ongoing
8. It would be interesting to investigate how smoothing the ALK matrix (by applying a kernel or use some sort of spline function) would affect the SA.	WG-SAM	Sensitivity	Medium	Ongoing
Growth				
9. The RP suggests that all SA's implement methods to account for these potential biases in fitting Von Bertalanffy growth curves.	WG-SAM	Sensitivity	Medium	Ongoing
10. Additionally, investigation of the impact of errors in aging on the VB by the SA scientists have shown that the fit is robust to this error. The RP suggests that this be investigated occasionally to ensure that no biases occur.	WG-SAM WG-FSA	Sensitivity	Medium	Ongoing
11. Because changing the VB can affect the calculated virgin biomass, and thus the depletion estimates, the RP suggests that the SA scientists explore whether the fitted VB in these cases is sufficiently precautionary.	WG-SAM WG-FSA	Sensitivity	Medium	2019
12. The RP also suggests that the SA scientists investigate the use of other growth curves that may exhibit better properties in regard to the data. A more flexible curve might produce a more realistic fit.	WG-SAM WG-FSA	Sensitivity	Medium	2019
13. The RP recommends that sensitivity analyses be used to assess the impact of the different choices of the growth model on stock assessment results and on biological reference points.	WG-SAM WG-FSA	Sensitivity	Medium	2019
14. Potential changes in growth rates and fishery selectivity will influence tag-recapture rates, particularly due to the domed-shaped selectivity of these fisheries. The RP also recommends that more flexible growth curves be investigated.	WG-SAM WG-FSA	Sensitivity	Medium	2019
15. The RP recommends that the use of age-length keys be investigated to estimate the age composition of tagged fish released as an input to the assessment models for all the toothfish stocks, instead of the current approach.	WG-SAM WG-FSA	Sensitivity	Medium	2019/20
Data weighting				
16. The RP recommends that data weighting methods for tagging data should be further investigated. For example, consideration should be given to using data weighting methods based on the average time at liberty.	WG-SAM WG-FSA	Sensitivity	Medium	Ongoing
Tag loss				
17. The RP suggests that it is timely to update this analysis for the Subarea 48.3+Subarea 48.4 and Subarea 88.1, SSRUs 882A and 882B stocks based on more recent information that may include fish with a longer time-at-liberty. Changes in tag loss rates should be investigated. Information on the uncertainty involved in the estimation should be provided.	WG-SAM WG-FSA	Sensitivity	High	2019
Initial tagging mortality				
18. The RP encourages future research on the estimation of initial tagging mortality rates, and factors that may cause this to vary.	WG-SAM WG-FSA	Experimental	Medium	Ongoing
Tag detection				
19. The review panel encourages future research on the estimation of tag detection rates, and factors that may cause this to vary.	WG-SAM WG-FSA	Sensitivity	Medium	Ongoing
20. The RP recommends that implementation of good tagging protocols (release and recapture) be encouraged for all vessels involved in these fisheries.	WG-FSA	Review	High	Ongoing
Time at liberty truncation				
21. Tagging data was limited to recapture years-at-liberty less than 4 for Division 58.5.2 (although data exist for up to six years at liberty) and Subarea 48.3 and Subarea 48.4 assessments, but six years at liberty for Subarea 88.1, SSRU 882A and 882B assessments. The RP recommends further investigation of this issue.	WG-SAM WG-FSA	Sensitivity	Medium	Ongoing
Selectivity				
22. The spatial distribution of the fleets has changed over time, particularly in the early years of the fisheries and in Subarea 88.1, SSRU 882A and 882B and temporal changes in selectivity should be considered.	WG-FSA	Sensitivity	Medium	2019/20
Natural mortality				
23. The RP recommends that consideration should be given to estimating age-specific natural mortality rates using a functional form with few parameters and sex-specific natural mortality rates. Simulation analysis should be conducted to determine in what circumstances natural mortality rates can be reliably estimated.	WG-SAM	Research & sensitivity	Medium	2019/20
Recruitment standard deviation				
24. The RP recommends that consideration should be given to adjusting the penalty for years in which there is incomplete information about year class strength.	WG-SAM WG-FSA	Sensitivity	Medium	2019
Sex structure				
25. The RP suggests that a more thorough evaluation is needed on the necessity of sex. If it is concluded that a sex-structured model is appropriate, all the data collection programs need to be modified to collect the appropriate sex information.	WG-FSA	Sensitivity	Medium	Ongoing
26. A standard set of diagnostic plots across the assessments covering important and sensitive parameters is encouraged to be included in each stock assessment.	WG-FSA	Review	Medium	2019
Ecosystem drivers in assessment models				
27. This was beyond the scope of the Terms of Reference. However, CCAMLR may wish to consider an external review whose goal is to consider this question specifically.	WG-FSA	Review	Medium	This WG

The second issue surrounds natural mortality as suggested in Table 1 comment 23. While it is appropriate that further work be conducted on natural mortality, often estimating natural mortality at age can be difficult within the model given the confounding between natural mortality and selectivity in age-structured models. Nonetheless, Lorenzen (1996) Charnov et al. (2013) Then et al. (2014) methods could be used to set priors after steepness and/or selectivity are set. As such it is agreed that this is an area of further research. This issue is particularly important given that most of the catch appears to be juvenile fish, prior to spawning. Further recommendations on the relationship between natural mortality, steepness, and selectivity are in TOR 2.

The third issue relates to comment 25 in Table 1. Given the biology of toothfish and the apparent sexual dimorphism, there appears to be a need to model the sexes separately. While the data may not currently support this, **ultimately sex-specific models are recommended given the differences in growth, maturity, and potential selectivity between males and females.** A related recommendation for this issue can be found in TOR 2.

TOR 2: Reviewing if biological parameters used in the assessment models are estimated using the best available science and appropriately used in the stock assessment models:

a) *Sex-specific maturation*
b) *Natural mortality*
c) *Length-weight relationship*
d) *Growth*
e) *Stock-recruitment steepness.*

South Georgia in Subarea 48.3

Important parameters are given in Table 2. In the case of Area 48.3, these parameters seemed well-estimated and appropriate. Like some of the other models reviewed, maturation is combined across the sexes. While understandable given the time series of data available, in the future it may be possible to separate the sexes, given the differences in maturity schedules present in the report.

Table 2: Important biological parameters by assessed stock

	Area			
Biological Parameters	48.3	48.4	58.5.2	88.1
Maturity	Sexes combined	Sexes combined	Sexes combined	Sexes Spereate
M	0.13	0.13	0.155	0.13
Length-weight relationship	Since 1998	Since 2005	Since 1997	Since 1998
Growth	von Bertalanffy	von Bertalanffy	von Bertalanffy	von Bertalanffy
h	0.75	0.75	0.75	0.75

It was noted that the assessment, like others, reviewed estimated growth outside the model, rather than having it estimated within the model. While this is appropriate given the short time series of data, as the length of time from which the data are drawn, it may be possible to estimate the growth parameters within CASAL 2.

South Sandwich Islands in Subarea 48.4

Area 48.4 had parameters that were similar to area 48.3 (Table 2), and so many of the comments for area 48.3 apply to this area as well. Unlike area 48.3, area 48.4 has a much shorter time series from which to work with. It is noted that Length-Frequencies are only available since 2005 and aging since 2011. This is a relatively short time series for a stock that matures at ages 6-8, has a generation time of approximately 17-20 years, and has a lifespan of approximately 50 years. Such sex-specific modeling approaches will require more years of data collection to be feasible in this area.

Despite the short time series, the parameters in Table 2 were estimated appropriately. Doubtless, as more years of data are collected some of the variability around these parameter estimates will tighten and become less uncertain.

Heard Island and McDonald Islands in Division 58.5.2

Parameters for this area are also found in Table 2. Most of these are similarly derived as in areas 48.3 and 48.4. Additionally, the assessment team for this stock used a bridge approach where they made incremental changes in the model since it was last reviewed in 2019. Table 6 in this stock's report was very helpful in seeing what changes were made during this process. In general, like with areas 48.3 and 48.4, the use of these parameters represents the best biological information and was handled appropriately.

The key difference for this area is the use of a higher natural mortality rate (0.155) compared to areas 48.3 and 48.4. In this assessment, there was some work allowing *M* to be estimated. The result suggested a lower *M* value (0.129) closer to some of the assessments in area 48 as well as a higher B_0. Previous attempts to estimate *M* in 2019 resulted in values closer to the 0.155 value. The assessment team for this stock concluded that there is likely not enough information for the model to estimate *M*. Such a conclusion is appropriate. The current model configuration with a fixed steepness likely results in the model trying to use *M* and *q* (survey catchability) to best fit the observed data. It is also interesting to note that the fit to the surveys gets progressively worse after 2018, the precise time period when survey *q* rises above 1.0. This leads to the question of whether the model is trying to use either *q* or *M* to explain the observed data since 2018.

Ross Sea in Subarea 88.1 and SSRUs 882A–B

Parameters for the stock can be found once again in Table 2. Like with the other areas, the use of the parameters seems appropriate and consistent. This area differs from the others in two notable ways, however.

The first difference is that it is a separate species, Antarctic toothfish, which seems to have similar maturity and natural mortality to Patagonia toothfish. This is likely the case as they are within the same genus and occupy similar niches in the ecosystem.

The second difference is that this stock is modeled as separate sexes, allowing for sex-specific growth, maturity schedules, fishery selectivity, and length-weight relationships. Given the difference between the sexes in these parameters, a sex-specific model seems appropriate. Despite the differences by sex in many attributes, the *M* between the sexes was the same. While there is likely little difference between *M* between the sexes, it is an avenue that might be interesting to explore in future assessments; particularly given the differences in maturity and Linf.

General Comments and Recommendations: TOR 2

Overall, all assessments have met this term of reference and the analysis presented at the Review should be regarded as the best available information. That said, there are avenues of further exploration that might be interesting to examine in future assessments.

Currently, all of the models fix natural mortality outside the model and then input it in as a single value across years and ages. In reality, the biology of toothfish suggests that natural mortality is likely variable across both. It would be difficult, as suggested elsewhere, to freely estimate natural mortality as it is often confounded with selectivity or in some cases *h*. **That said, explorations of age-variable natural mortality should be undertaken.** Work by Lorenzen (1996), Charnov et al. (2013), and Then et al. (2015) might be informative in this undertaking. Such a study may be quite important, as much of the fishing mortality is likely pre-spawning. It is likely, given some of the work already completed, that there may be a higher B_0 with such a change though there may be little change in the relative stock status. However, this would highlight the stock benefits of moving the fishery selection curves to older fish.

Along those same lines, one clear trend across all of the models examined was to fix both natural mortality and steepness in the models. While often appropriate, this can lead to the problem of the assessment specifying stock productivity ahead of time. A good example of this may be Area 48.3, where the catchability of the survey has recently gone over 1.0. Given there may not be a survey-related reason why catchability should be greater than 1.0, it could be that it is the only (or easiest) way the model can fit the observed data; somewhat erroneously. Often the projections that result from such a fixed approach tend to just give back what was put into the model through the values fixed. **As such it is recommended that assessment teams examine sensitivities where steepness is allowed to vary**, as it is usually easier to do so than natural mortality. Radically different steepness than 0.75, or other diagnostic issues during this process may indicate that there are some aspects of the model with miss-specified or conflicting datasets/parameters.

An important data gap seen across all assessments was a lack of data surrounding the maturity schedule, particularly by sex. Maturity schedules, particularly in how they line up with fishery selectivity and the calculation of SSB are important in age-structured models such as those used in the models reviewed. **As such it is recommended that studies be undertaken to examine sex-**

specific maturity schedules for toothfish in this region. While this is likely to be very difficult and expensive given the winter-time spawning behavior, it would be worth both the effort and expense if it is possible. Ideally, this could be paired with a fecundity study to translate reproductive output with body size. Some stocks have already moved to fecundity-based reference points, a likely better way to monitor stock reproductive capacity.

TOR 3: Reviewing the extent to which the choice and analyses of observations are estimated using the best available science and appropriately used in the stock assessment models, including the representativeness of observations in space and time:

a) *Catch observations*
b) *Survey data*
c) *Catch per unit effort (CPUE) abundance indices*
d) *Tag release and recapture observations*
e) *Age and length compositions*
f) *Selectivity.*

Table 3: Data start year of data observations presented for various toothfish stocks, by area

	Areas			
Data elements	48.3	48.4	58.5.2	88.1
Model start year	1985	1990	1982	1996
Catch	1985	2005	1996	1998
Length Frequency	1998	2005	1997	1998
Age	1998	2011	1997	1998
CPUE	2003	-	-	-
Survey	1987	-	1996	2012
Tagging	2003	2005	1998	2001

South Georgia in Subarea 48.3

Observed data in the model are shown in Table 3. This assessment uses two time blocks for catch and fishery selectivity, one from 1985 to 1997 based on a lack of aging data, and one since 1998 that has aging data. Overall, the selectivity is rather flat-topped, with a weak descending limb.

This assessment is notable in the use of a CPUE (Catch per Unit Effort) in addition to a biennial fishery-independent index. The index itself is culled to only those areas on Shag Rock, with an 85 cm cut-off, to represent to represent the incoming year classes best.

Of these two estimates of abundance the CPUE index tends to be the most influential in the model, likely as a result of just more observations. In fact, for this area, the CPUE is one of the driving factors to lower B_0 given the likelihood profiles.

Like the Ross Sea (area 88) this model also suffers from some patterning of age residuals by year class, though such patterning does not seem as problematic as in area 88.

For this area, the choice and analysis of the observed data seems appropriate. In particular, the use of selectivity blocks around the advent of aging data is a good addition. While other selectivity blocks were considered previously, the current configuration seems acceptable. However further analysis and possible additions of other selectivity blocks in the future are likely warranted.

South Sandwich Islands in Subarea 48.4

The model in this area is perhaps the most data-poor of all of the stocks examined (Table 3). It lacks both CPUE as well as fishery independent indices, its age data is relatively recent, and even the tagging data are less than 20 years old with only 4 years at-large used. While the data and analysis are appropriate, examination of the likelihood profiles reveals a conflict been the size-at-age data, and the most influential data source in the model, the tagging information. Given the lifespan of toothfish, such a "young" model is going to encounter problems. This can be seen in the historical retrospective, which shows a continual lowering of the B_0 value each time it is assessed. In short, the lack of a long time series of data for this stock drives the uncertainty in this particular stock's model. **As such, it is recommended that some form of survey be conducted in this area to anchor any ongoing assessment methods**. Ideally, a fishery-independent survey would help in this regard, but even a fishery-dependent CPUE model may be helpful.

Heard Island and McDonald Islands in Division 58.5.2

Data elements for this area can also be found in Table 3. While the treatment of the data sources for this stock is appropriate, there are three items to consider in this assessment. The first is the lack of ages past 25 (fully mature) that make up the aging and the maturity curve. The second is the recent increase in catchability of the survey to >1.0, and the third is the concentration of the fishery in smaller areas.

The lack of older fish in both determining age as well as growth is troubling in this as well as other assessments examined. Understandably these fish are harder to get as they move into deeper waters and are not well sampled by either survey or fishery. Nonetheless, a previous recommendation was made to examine these older fish closer to spawning time, if possible, to help provide data for the assessments. Perhaps such information would be helpful to this stock's assessment as well.

The recent increase in survey catchability (q) is rather vexing. It is a recent phenomenon, having only started in 2017, and seems nonsensical, given there is no readily explainable cause such as herding as seen in some other surveys for other species. As mentioned earlier, the change in q might well be caused by the model having difficulty explaining the observed data, given that both M

and *h* are fixed in the model. Likewise, the recent fits to the survey are not very good, despite this increase in *q*. Solving this problem is difficult, but the recent recommendation to allow *h* to vary might be useful in exploring this issue. As it stands a survey catchability greater than 1.0 is a major red flag for this assessment and should be resolved. For example, a different *M* or *h* is easier to explain than such a catchability without clear evidence of herding.

The last issue with this assessment is in the recent contraction of the fishery, and hence the fishery-dependent sampling. Further, the survey area for this assessment is only a small fraction of the potential juvenile area. There is, therefore, some indication that there may be localized depletion in this area. One possible solution would be further examination of a potential CPUE by fishing sub-area to determine if localized depletion is possible. If so, then the expansion of the survey could help solve the issue.

Ross Sea in Subarea 88.1 and SSRUs 882A–B

Data observations can be found for this region in Table 3, like the other stocks under review. Like the area 58 assessment a CPUE index was available for this region but was not included in the model. This is in part due to management changes which have likely changed the fishery from more of a shelf to more of a deep-water fishery as a result of an MPA implementation. Given those changes, it seems appropriate, especially given that it is a pretty flat index of abundance overall and is unlikely to provide good information stock-wide.

That said, while the treatment and reasons for the inclusion of the data sources for this region are well done, there is an outstanding issue, the age comps. Examination of Figure 3 of the assessment report shows a strong patterning in the fishery Pearson residuals of the catch-at-age data for males and females by age class. The reason for this patterning is not well understood, and work is ongoing on this issue. However, such a patterning suggests some moderate issues within the model, which can hopefully be resolved. A recommendation could be to look more fully into selectivities or to examine some of the underlying aging, but such thoughts are only conjecture at this point without more analysis.

General Comments

All of the assessments under review seem to have essentially passed this TOR. Each did the best that can be reasonably done with the data currently in hand. That said, there are certainly some areas where some improvements could be made, resources permitting.

One idea is the current handling of the fishery-independent and dependent surveys across regions. Elsewhere many assessment teams have moved to model-based surveys, using methods such as VAST, to help decrease variability in the surveys causing erroneous signals within the surveys. **As such, exploration of model-based approaches to fishery-dependent and independent survey analysis is suggested for toothfish.** It is hoped that this may clear up some of the issues encountered, such as the *q* >1.0 in area 58.

Given the importance of aging in all the assessments of toothfish thus far reviewed, ongoing work to examine aging is recommended. It appears that some work is ongoing, but aging data for these types of models is very important to their accurate functioning. **As such, it is recommended that the current aging work be supported and if possible, expanded across all regions.** Getting at the issue of aging variability, either among readers, labs, or preparation methods is an important task. Ultimately it would be best if the assessments could incorporate aging error matrixes, but this is likely something that will have to wait until data is collected as well as the move to CASAL 2.

Another idea is the selective use of CPUE indices. Such information, while not necessarily incorporated within the assessments as an input, could be important secondary data sources. They might be important, for example, to examine to see the overlap between fishery and survey, to compare age comps from even if lagging is needed, or to examine differences in growth between fish caught in the surveys vs. the fishery by contributions. There is a myriad of uses for a well-standardized fishery-dependent survey, even if not directly incorporated within the model. **Therefore, it is recommended that fishery CPUE be examined for all toothfish fisheries.** Such a survey could easily be monitored in off-assessment years, as a regular monitoring tool. It should also be noted that while some of the recommendations made in this report have likely been explored in the past at some point, that periodic re-examination is important. Often conditions change, particularly as years go by and new data is collected.

TOR 4: Determining whether the statistical modeling (including model assumptions, model structure, priors and penalties, data selection and weighting) and the resulting inferences on stock status and dynamics and catch limits are implemented using best-practice methods.

South Georgia in Subarea 48.3

Like other assessments in this region, 48.3 uses CASAL, as a statical catch at age modeling structure. Data elements and treatment have already been discussed in other TORs. Data elements were Francis weighted in keeping with assessment standards in other regions around the world. Priors were stated as not very informative, though it was noticed that they had more influence on B_0 in the likelihood plots than in other areas examined.

Fits to the data weren't particularly good, with some patterning in the ages, moderately acceptable fits to mean ages with worse performance in earlier years, good fits to the survey data except in the most recent years, and not good fits to the 2004-2021 CPUE. Fits to the tagging data was a bright spot for this model. The selectivity produced by the MCMC seems reasonable, though it is noticed that the descending limb is less pronounced than in other regions examined.

Overall, the outputs seemed reasonable, judging from the MCMC diagnostics. Uncertainty in the MCMC seems to be narrowing in recent years with more data included in the model. As configured the model in this area suggests that the stock status of toothfish is just below the $B_{50\%}$ target value.

Despite some of the difficulties with fits and in some of the diagnostics, the model, its assumptions, and treatment are acceptable and should be considered fit for providing management advice.

However, during the meeting it was highlighted that there are alternate views to the narrative provided by this assessment. Some parties, though not in attendance, have suggested that the current assessment and CCAMLR decision rule don't provide a basis for management in Subarea 48.3. Rather, that size at age and maturity has indicated a more rapid depletion of toothfish in the region.

In essence, the alternate view suggests the CASAL model in this region is overly optimistic. Data presented on length and maturity during the meeting by the assessment team refutes this suggestion quite convincingly. Further, despite challenges, model-based stock status is often better than data-limited methods for determining stock status, providing management advice, and setting appropriate catch levels. Model-based approaches allow for scenario testing, take multiple (sometimes conflicting) data sources into account, and produce the most comprehensive view of the stock possible. **As such, analysis based only on biological factors should be avoided unless that is the only data available from which to draw conclusions.**

South Sandwich Islands in Subarea 48.4

Like the area previously discussed, this again uses the statical catch-at-age approach via the CASAL software. Unlike most other regions, this area lacked either CPUE or a survey to anchor the model to or to provide an index of recruitment. The data for this model are relatively recent, with aging only being available since 2011.

Fits, given the rather short time series, seem reasonable for this region: though this may be due more to a lack of time and data sources. The largest difficulty in this model is the likelihood profile, with clear tension between tagging and age composition data. A standard predicted vs. observed age composition plot was not provided, so more insights could not be drawn.

The MCMC diagnostics do not show many difficulties, though some year class strength density plots show odd binormal distributions. One interesting aspect of this model is the increase in SSB above B_0 from 2005 to 2006, right when the tagging data becomes available in the model. The reason for this is not clear at this point, though it is likely the tagging data is pushing the estimates of B_0 higher, much like it does in the likelihood profiles.

After careful review, it appears that the model in this region has met this TOR. The data weightings, priors, and approach to the model seem appropriate. However, the short time series of data given the longevity of the species, some odd model diagnostics, and the lack of either a fishery-independent or dependent survey suggest caution when interoperating the results for management purposes.

Heard Island and McDonald Islands in Division 58.5.2

Again, this region uses the CASAL software to implement a statistical catch-at-age approach to model the toothfish in this region. Like other regions, it uses the Francis weighting method for likelihood components, which is a standard practice in other parts of the world.

Model fits were acceptable, though it was noticed that differences between predicted and observed biomass in the survey are becoming larger especially in recent years, suggesting a divergence that could become problematic as more years are added to the model. Likewise, the MCMC plots showed no large irregularities, except for survey catchability, discussed more below.

This region did employ some analysis not found in some other areas. The first was the use of a bridging analysis, which was particularly useful in examining the effect of these changes on B_0. The second was the use of retrospective analysis which shows some interesting insights. For the retrospective analysis data from the most recent years are sequentially dropped from the model to test the model's behavior and to provide some measures of uncertainty in the advice.

The results of the retrospective were interesting in their pattern. There wasn't much of an overall bias, but there is some suggestion of an underestimation of SSB relative to the terminal year. This bias was much more pronounced from the start of the aging data (1997) to 2015 and has since become less pronounced. From experience, this seems to be an atypical pattern when compared to other stocks, which tend to have more pronounced retrospective patterns in more recent years. The reasons for such a pattern are not known. It would be interesting to see if such patterns emerge in other toothfish stocks in the CCAMLR area.

The last issue under this TOR, again, concerns the catchability of the survey (q). Unlike most other stocks around the world, the catchability here is >1.0. While some assessments do find that q can be >1.0, these tend to be special cases where there is documented herding or some other survey-specific issue. Given the increase in q is relatively recent, this seems unlikely. A detailed recommendation for this issue has already been suggested, and it bears mentioning here. Ultimately the decision was made to allow q =1.13. In the future, this should be considered a red flag, where the model has increased uncertainty beyond the MCMC results.

Despite all of these issues the assessment as presented appears to be the best scientifically defensible advice for this area. As such the stock status as outlined in the report is acceptable and in line with scientific best practices.

<u>Ross Sea in Subarea 88.1 and SSRUs 882A–B</u>

Like other assessments in the region, area 88 was a statistical catch-at-age model formulated in CASAL. Also like other approaches in CCAMLR, Francis weighting methods were used for likelihood components.

Overall fits to the survey data were good, though 2014 to 2016 fits were less than compelling. MCMC diagnostics also showed no apparent issues, though some descending limb parameters on selectivities did show some signs of non-convergence. Preliminary runs with CASAL 2 suggest that some improvement will be made once the switch to that model is concluded.

Like area 88 this assessment used both bridging between previous assessments and the current one. This is a good approach to use and allows for some indications as to what data or analysis changes change the outcome of the model from year to year.

Additionally, the assessment team conducted both a historical and a within-model retrospective analysis. In a historical retrospective, the previously supplied stock trajectories are plotted on one graph, to show how the assessments (and advice) have changed over time. In the within-model retrospective, years are sequentially dropped to examine model behavior. Both types of analyses indicate the same issue, that while there is no persistent retrospective pattern of over or under-estimating current stock status, there is some retrospective uncertainty. The cause for this uncertainty is not understood, but certainly, the relative weights of the likelihood components, and how those weights change from assessment to assessment is likely an underlying factor.

Overall, the assessment in this area meets this TOR. While there are avenues that could be explored in the future, the stock status as outlined in the report seems appropriate and represents the best available advice at this time.

General Comments

After examining the toothfish assessments in the CCAMLR region in detail, it is concluded that each represents the best available science and provides the most appropriate advice in terms of stock status. As outlined above, a statistical catch-at-age approach is the most useful given the data at hand. Other more data-limited methods have serious shortfalls in the advice they can provide, as well as the inability to incorporate all of the information available by area. This, rather than more qualitative maturity or length-at-age approaches, is the most promising in providing the best scientific advice to ensure the sustainability of toothfish in the CCAMLR region. **As such, it is recommended that the assessments within the CCAMLR region focus efforts on statistical catch-at-age approaches for providing management advice, and, if possible, increase the flexibility of that approach by moving to the CASAL 2 platform.**

The “bridging analysis” where changes to the current model from the previous model are done in a step-by-step fashion is a preferred approach. Such an analysis allows reviewers, the public, stakeholders, and others, to see what changes to the model result in the changes seen from one assessment to the next. It is therefore easy to see, for example, if a change to the relative stock status is due to additional data, changes to the analysis of that data, or changes to the assumptions. **As such, it is recommended that all assessments in the CCAMLR region for toothfish use a bridging analysis from one assessment to the next**, to allow for transparency.

Some of the assessments reviewed used either within-model or historical retrospective analysis. Both types of retrospective analysis are done in many other regions around the world. While the historical retrospective analysis is most useful to managers and stakeholders to see how assessments have changed over time, it is the within-model retrospective that is the most powerful diagnostic tool. Retrospective patterns or even uncertainty can allow the analysis to see what data or analysis changes the model's view of the stock under assessment. **As such, it is recommended**

that both historical and within-model retrospective analysis be a standard diagnostic tool used for toothfish assessments across the CCAMLR region.

As outlined previously, the assessments in the CCAMLR region tend to fix both steepness and natural mortality outside the model. While appropriate for the models under review at this time, in the future extensive sensitivity analysis and other work should focus on this issue. A recommendation to this effect has already been made, but it bears repeating that continual sensitivity analysis focused on this issue be continued during each assessment.

While Francis weighing methods (Francis 2017) among likelihood components are currently the standard for use in many assessments, there are certainly others. McAllister–Ianelli (1997), and Dirichlet-multinomial methods (Thorson et al. 2017) have been used in multiple assessments in the US with success. While not a full recommendation it might be interesting to explore these other data weighting methods to see if there are differences in diagnostics and outputs.

Overall, all assessment teams did a good job in conducting diagnostics, and there were certainly many sensitivity analyses in the supporting document for all areas. That said none of these seemed standardized from area to area; what diagnostics were presented seemed haphazard and based on the nuances of the assessment under examination. **As such, it is recommended that a standard set of diagnostics and sensitivities be constructed and that these appear in each assessment each year.** For example, it should be standard practice that summary MCMC plots, historical and within-model retrospectives analysis, and Pearson age compositions are presented for each area and for each year. Others can be added as needed, but there should be consistency in what is presented, and how it is presented.

TOR 5: Reviewing if there are trends in parameters through time or other spatial and temporal effects on the biological parameters, other parameters such as selectivity, and observations that should be taken into account in each stock assessment.

General Comments

Rather than going through each of the stocks individually, it is likely best to make more general comments and recommendations across all of the assessments under review. This is in part because many changes are occurring across all assessments as a result of model changes, changes in fishing behavior, and the rapid climate change seen over the last decades.

There are clear spatial trends in the data. For example, in areas 88 and 58 spatial changes in the fishery as a result of either changing management or changing fishing practices affect modeling efforts. In area 88, the recent implementation of an MPA has likely changed the fishery and selectivity, while accounted for by the use of different fleets. This behavior change is likely to further impact the model. Likewise, the concentration of effort in the area 58 fishery is also likely to affect both the tagging and the selectivity data for this region and should be monitored in future assessments.

Across all areas, there is a change in how the fishery is prosecuted, either as a result of market demand or as a response to changing management. Overall, there has been a move by harvesters into deeper water, which increases the mean age at which fish are caught. Further, this has resulted in a change in gear types, with many fisheries moving from trawl to more long line harvest. Such changes affect the selectivity of the model but also impact the representativeness of the tagging information as well.

There are generally two approaches to this issue in other areas, changes or incorporation of fleet structure, or changes in selectivity by using blocks. Often in many assessments, both are employed to account for changes in spatial distribution and fleet behavior and some of the assessments under review already do so. **It is recommended that each assessment reexamine its fleet structure and selectivity time blocks to determine if more substructure in the models is needed.** Both approaches have trade-offs. The use of selectivity blocks can confound diagnostics such as retrospective analysis. Alternatively, using a fleets-as-areas approach can introduce a number of additional parameters reducing parsimony and increasing the computational overhead required. Nonetheless, examination of fleet structure and time blocks for selectivity is recommended for each assessment, each time the process is started. Such an examination would also be helpful for accounting for harvester behavior, particularly if changes in the seasonality of the fisheries become apparent.

While it seems unlikely that natural mortality would vary, given the longevity of the species, steepness could vary across time. As climate-induced changes occur in the CCAMLR region, it is likely to affect the reproductive output and therefore the stock-recruitment relationship. **As such, it is recommended that steepness be a routine sensitivity analysis across all assessments each time an assessment is conducted.** This may be particularly important as new data are added to the stock-recruitment relationship in each area, given the concentration of SSB levels sampled.

Further changes in maturity schedules could also occur. Both fishing and environmental pressures often change the A50 of a stock, shifting maturity at age lower as outlined in some of the supporting materials. As outlined in another recommendation, maturity schedules and fishery-independent monitoring of mature fish should be one of the priorities for data collection.

It is recommended that the use of variable weight-at-age be included, either in the current model or in CASAL 2, across areas. Often through either environmental or fishery pressure, weights or size at age change in response. Yearly weights at age allow for the most recent data to determine overall SSB calculations and are important when discussing projections as well as the number of fish caught per ton of biomass removed. Additionally, the use of variable weights at age could alleviate some of the criticisms levied at some of the current assessments under review. More importantly, changes in weight or length at age could become problematic for the fitting of growth within many of the models used for toothfish if not accounted for. There is generally good sampling of the toothfish fisheries across all of CCAMLR to allow for support of this.

Other parameters also should be monitored over time. Marine mammal or other depredation issues affect some of the assessment reviewed. Additionally, some areas are experiencing an

increase in these issues. Generally all of the assessment teams seem to be aware of these issues and have already been monitoring it. The same is the case for the instances of IUU fishing. While not currently problematic, all assessment teams are aware of the issue and have corrected for it in the past as applicable.

TOR 6: Review whether population projection methods, recruitment series used, and implementation of decision rules are conducted using the best available science.

General Comments

Like the previous TOR, it is likely that this is best commented on across all the assessments more generally. This is particularly true since all of the assessments approached projections similarly.

During the meeting, the question was asked as to why there was a 35-year projection period. While it is understandable given policy directives, it appears somewhat curious. Overall while toothfish in this region are long-lived, the portion of the population that is exposed to the fishery is fairly short across ages, given the selectivity curve. Moreover, most of the models under consideration are fairly new to being assessed. It seems rather counterintuitive to have a 35-year time projection when age data in the model only span a decade or two. **As such, it is recommended that projections be no longer than the availability of the age data within the model as a rule of thumb.** It is acknowledged that this is likely, not possible given the policy burden, but this recommendation should at least start a discussion about the plausibility of such long projections given the short time series of the underlying data. Overall, the length of the current projections is not too problematic, given that the assessments are updated every two years. But it bears repeating that these projections are uncertain, more so than the error bars on future stock trajectory would suggest.

One of the most uncertain aspects of producing projections is the forecast of future recruitment. It should be noted that this recruitment has effectively already been set in the model via the fixing of steepness. That said, the other aspect of recruitment, and related to the previous point above, is the time span from which the stock-recruitment relationship is drawn. Overall, all toothfish in the CCAMLR region have only experienced stock levels roughly between B_0 and $B_{50\%}$. As such, only a small part of the stock-recruitment curve has, in fact, been sampled. This can lead to some uncertainty as it is not well understood how the stock will really respond at low biomass levels below $B_{50\%}$ as that has not yet been experienced.

Another uncertain aspect when providing projections is the weight/length at age into the future. While it is generally understood that weight/length at age tends to be inversely related to stock size, it is also well understood that it can vary considerably due to environmental conditions such as available habitat, sex ratio, and food availability. Currently, the models in this region tend to use a singular weight/length at age. While acceptable in the short term, moving to a yearly weight/length at age could provide benefits. For example, if weight at age has been declining over the assessed

time period, it would not be prudent to use the average over that time period to provide projections of future SSB as it would assume that the mean weight at age would return to that average rather than staying in decline. **Given this, it is recommended that if a yearly weight/length at age is used in the future assessments the most recent 3-year average be used to provide projections of SSB in the future.**

It was also noted that only one projection scenario was completed for each assessment: the constant catch that resulted in a 50% probability that the SSB would be at $B_{50\%}$ in 35 years. This constant catch should also have less than a 10% probability of driving the stock below $B_{20\%}$. While this is perfectly acceptable for providing management advice, it should be noted that other scenarios can and should be tested. For example, setting catch at zero should allow the stock to go back to B_0 and it may be important to see how the stock recovers in the absence of fishing. Alternatively, because area 48.3 only draws recruitment from the most recent (1993-present) period it seems unlikely that it would return to B_0 even in the absence of fishing. Moreover, selecting different scenarios would allow for more rigorous testing of various harvest strategies via a Management Strategy Evaluation (MSE). **As such, it is suggested that more than one scenario be tested during the projection process, not only to provide some insight into stock behavior but also to provide managers more options**.

It should also be noted that climate variability and environmental covariates overall have not been addressed by any assessments reviewed. This is understandable as the assessment themselves are relatively new and are undergoing other changes such as the move to CASAL 2. However, given the rapid changes across all the CCAMLR regions, it is certainly an avenue for further exploration. This is especially true given the long time horizons over which projections are conducted. A recommendation appears below.

It is recommended that an MSE for all toothfish in the CCAMLR region be considered, and that part of this MSE explicitly addresses climate-related issues facing toothfish. While the conservation goals are clearly laid out for toothfish management in the CCAMLR region, the precise route to achieving these goals is less clear. The current focus on consistent catch, for example, potential leaves yield unfished when there is strong recruitment. Moving fishing activity to deeper water, for example, could increase the value of the catch while simultaneously reducing removals. And there are other examples. An MSE would also be important to identify, and potentially develop, management measures in response to changes in productivity as a result of climate change. There are many applications of an MSE approach, from mitigation of ETP interactions to setting different reference points or HCRs in the fact of climate change. It can provide a clearer picture of management goals other than the maximum constant sustainable catch, and one that can be developed with and for all stakeholders.

As seen in other TORs, while there is more work to be done, each of the assessments has used best practices to provide the best scientifically defensible scientific advice. There is much uncertainty in the precision of the projection, particularly the longer the period over which the projections are

conducted, however, the methods employed seem sound. Overall, the projections are appropriate for providing management advice.

TOR 7: Identify and consider any additional stock-specific analyses or investigations that are critical for this assessment and warrant peer review and develop additional TOR(s) to address as needed.

Most of the specific recommendations have already been made in previous TORs. Given that many of the assessments in the CCAMLR region are structured very similarly, most of those recommendations could apply across assessments. Many of the assessment teams did present plans for further research which were sound given the data gaps within each of the current assessments within those regions.

That said there is one recommendation not touched upon earlier: **the recommendation to continue transitioning all toothfish assessments to the CASAL 2 package.** This should be a priority. While it was beyond the scope of this review to test or even examine the CASAL 2 package, the presentations given at the review meeting appear promising. During this review, it was found that the current CASAL software was limited in its capacity, particularly in running computationally intensive diagnostics. Further, it appears that CASAL 2 will also have some built-in features that will make some of the recommendations made in this report easier to implement.

Given this transition is already underway, **it is recommended to lay out a vision for what elements should be included for all toothfish assessments, data permitting.** These elements could include:

Data

- Catch and catch-at-age
- Year and sex-specific length at age
- Year and sex-specific weight at age
- Fishery-independent survey or dependent CPUE (preferably both and model-based)
- Tagging
- Maturity at age (sex-specific, see below)

External parameters

- Natural mortality (preferably age-varying or at least explored)
- Priors via previous work

Model structure

- Statistical catch-at-age approach
- Sex-specific
- Sensible fleet structure based on selectivity or gear/area changes.
- Fishery selectivity
    - At least 4 parameters with priors (explore a 5th)
    - By fleet

    - With appropriate time blocks as needed
- VB growth by sex estimated internally
- Steepness allowed to vary with priors

Diagnostics

- Typical fits to surveys
- Tagging fits
- Catch-at-age residuals for fleets
- Historical and within-model retrospective
- MCMC plots
- Likelihood plots
- Sensitivities to *M* and *h*
- Etc.

Others could certainly be added. Many toothfish models in the CCAMLR region have many of these elements already. It is also noted that not all toothfish assessments would be able to have all of these elements and that some differences between assessments due to data availability or quality might occur. The point, however, is to take a broader view and structure all of the toothfish models as similarly as possible given the constraints; as well as provide a plan for what data gaps need to be filled, by assessment, to reach this idealized structure. By defining an idealized structure, departures from this structure can be identified and rationalized to the managers as well as stakeholders/interested parties.

Conclusions and Recommendations

After careful consideration, each assessment team was found to have met each of the TORs. The data and analysis presented in each of the assessment reports for toothfish in 48.3, 48.4, 58.5.2, and 88 should be considered the best available science. Additionally, each assessment team did a great job not only in performing the analyses but also in moving each stock assessment forward within the rapidly changing field of population dynamics.

There are, however, areas where some improvement can be made. A series of 27 recommendations were made in this report, including the recommendations made in the next section.

1. There should be one document with all the needed information, including model description, data treatment, and diagnostics.
2. Sex-specific models are recommended given the differences in growth, maturity, and potential selectivity between males and females.
3. Explorations of age-variable natural mortality should be undertaken.
4. It is recommended that assessment teams examine sensitivities where steepness is allowed to vary.

5. It is recommended that studies be undertaken to examine sex-specific maturity schedules for toothfish in this region.
6. It is recommended that some form of survey be conducted in 48.4 to anchor any ongoing assessment methods.
7. Exploration of model-based approaches to fishery-dependent and independent survey analysis is suggested for toothfish.
8. It is recommended that the current aging work be supported and if possible, expanded across all regions.
9. It is recommended that fishery CPUE be examined for all toothfish fisheries.
10. Analysis based only on biological factors should be avoided unless that is the only data available from which to draw conclusions.
11. It is recommended that the assessments within the CCAMLR region focus efforts on statistical catch-at-age approaches for providing management advice, and, if possible, increase the flexibility of that approach by moving to the CASAL 2 platform.
12. It is recommended that both historical and within-model retrospective analysis be a standard diagnostic tool used for toothfish assessments across the CCAMLR region.
13. It is recommended that a standard set of diagnostics and sensitivities be constructed and that these appear in each assessment each year.
14. It is recommended that each assessment reexamine its fleet structure and selectivity time blocks to determine if more substructure in the models is needed.
15. It is recommended that steepness be a routine sensitivity analysis across all assessments each time an assessment is conducted.
16. It is advocated that the use of variable weight-at-age be included, either in the current model or in CASAL 2, across areas.
17. It is recommended that projections be no longer than the availability of the age data within the model as a rule of thumb.
18. It is recommended that if a yearly weight/length at age is used in the future assessments the most recent 3-year average be used to provide projections of SSB in the future.
19. It is suggested that more than one scenario be tested during the projection process, not only to provide some insight into stock behavior but also to provide managers more options.
20. It is recommended that an MSE for all toothfish in the CCAMLR region be considered, and that part of this MSE explicitly addresses climate-related issues facing toothfish.
21. It is recommended to continue transitioning all toothfish assessments to the CASAL 2 package.
22. It is recommended to lay out a vision for what elements should be included for all toothfish assessments, data permitting.
23. In the future, it is hoped CCAMLR will consider more in-person reviews, as it is more effective and generally leads to better products despite the costs of travel.
24. In the future, it is hoped that the CCAMLR process will invite peer review before models are used for management advice.
25. Some method of better organizing the documentation for review is recommended.

26. It is recommended that CCAMLR revisit its protocols on document structure to increase readability and transparency.
27. It is recommended that two sections be considered in future assessment reports: an Assessment Uncertainty section and a Research Recommendations section.

Other Comments and Recommendations

Often during peer reviews, some comments do not seem to fit neatly under and particular TOR. This section at the end of the report, is where some of those comments on process documentation, or more general comments, are best added.

The review was mostly well organized, but some improvements could be made. The lack of an in-person meeting really detracted from the overall process. There was no real opportunity for the reviewers to collaborate off-line and discuss all of the assessments. Often having collaboration with other reviewers is important to get a clear and consistent message. Additionally, there were some technical issues, that detracted somewhat from having a productive meeting. **In the future, it is hoped CCAMLR will consider more in-person reviews, as it is more effective and generally leads to better products despite the costs of travel.**

A curious feature of this review was the fact that it was retrospective. Most of the documents reviewed were two to three years old. As such, the models reviewed, and the documents produced by the assessment teams had already been used for providing management advice. Because of this, it was simply not possible to request additional analysis or sensitivity testing of the various assessments. While understandable given how the process was set up, it was a missed opportunity. Peer review is most effective in those steps between model finalization, and management advice. It is in those steps where reviewers and the assessment teams can come together, test various model formulations, produce diagnostics, and thoroughly vet the models under consideration. **In the future, it is hoped that the CCAMLR process will invite peer review before models are used for management advice.**

One way in which improvements could be made to the peer review process was in the organization of the documents for the review. It was often difficult to find the correct information. Supporting documents, while useful, hampered this further as the file naming convention did not lend itself well to searching for the correct document. Often one would click from the main document or the document list to a subfolder to search for the appropriate supporting material. This was time-consuming and sometimes frustrating even with a document list. One idea to help with this issue would be to use hyperlinks in the document list and folders to allow for supporting materials to be available with just a click. Whether this setup occurs online, or in an extractible zip-type file, **some method of better organizing the documentation for review is recommended**.

Standardization of the review documents was already touched upon under TOR 1, but it bears some repetition. As suggested above, finding the correct information proved troublesome. In addition, references in one document would point to a previous year's document, only to have that

document point to another previous year. It is recommended that CCAMLR re-evaluate how its documents are structured, keeping in mind that some readers are going to be outside the CCAMLR sphere or "family" and may not understand the file naming conventions or structure. **As such, it is recommended that CCAMLR revisit its protocols on document structure to increase readability and transparency.**

A good example is how the Northeast Fishery Science Center in the US handles its documents. One document (plus related working papers) is given to the reviewers prior to the review meeting. This one document contains all the information required for the review: fishery and management history, data treatment, model structure and assumptions, diagnostics, etc. It is, out of necessity, quite large spanning hundreds of pages in some cases. A second much shorter document is produced for a manager or stakeholder-type audience. This allows a more technical reader to see all the information on the assessment in one document, without having to move between multiple documents. It also allows for a non-technical reader to get a summary of the assessment in the shorter document but find the more detailed discussion in the larger full document if interested.

As a corollary to the comment made above, two document sections could really be useful for reviewers or any interested reader: an Assessment Uncertainty section and a Research Recommendations section. **It is recommended that two sections be considered in future assessment reports: an Assessment Uncertainty section and a Research Recommendations section.**

The Assessment Uncertainty section is not about how uncertainty is handled within the model (though it could). Rather this is a section where the assessment teams can comment on where they think the model is not performing well or may have some diagnostic issues. Typically, this section will include comments on data gaps, weak model fits, retrospective patterns, or other uncertainties not captured in the overall model structure. Additionally, this area is important for managers to examine, as it relays uncertainty that may not be accounted for in the confidence interval or MCMC. This also lends to creating a culture of transparency, where stakeholders, managers, and other technical teams can see what issues in the assessment need either data or analytical improvement.

A Research Recommendation section is exactly that. A place where the assessment team can point to needed research to improve the function of the model, as well as lay out plans to collect needed data to support the assessment. This section can be particularly important as a jumping-off point for academic researchers seeking funding, or to pass project ideas off to students for further study.

Overall, this was an enjoyable review. This is an interesting and challenging part of the world to conduct fishery stock assessments. This was also the first time formally working with the CASAL platform for this reviewer, and it appears to be an impressive platform. The CASAL 2 platform sounds even more powerful and flexible. The assessment teams did a wonderful job with the presentations and in helping to explore their respective assessments. The Chair of the review meeting, Dirk Welsford, did a great job in keeping the meeting on track and providing pertinent comments on the CCAMLR process.

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Appendix 1: Bibliography of materials provided for review

Documents for independent review of toothfish stock assessments, 2023

1 Division 58.5.2

1.1 Stock assessment

Ziegler P. 2021. Draft integrated stock assessment for the Heard Island and McDonald Islands Patagonian toothfish (*Dissostichus eleginoides*) fishery in Division 58.5.2. Document WG-FSA-2021/21, CCAMLR, Hobart, Australia

1.2 Main supporting documents

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5.2 Presentations

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Devine, J. and A. Dunn. Ross Sea Region Antarctic Toothfish. ToR (i): Reviewing the status and report on the implementation of the recommendations arising from the CCAMLR Independent Stock Assessment Review for Toothfish in 2018.

Devine, J. and A. Dunn. Ross Sea Region Antarctic Toothfish. ToR (ii): Reviewing if biological parameters used in the assessment models are estimated using best available science and appropriately used in the stock assessment models.

Devine, J. and A. Dunn. 2023. Ross Sea Region Antarctic Toothfish. ToR (vii): Identify and consider any additional stock specific analyses or investigations that are critical for this assessment and warrant peer review, and develop additional ToR(s) to address as needed.

Devine, J., A. Dunn and A. Grüss. 2023. Overview of the Ross Sea Region Antarctic toothfish stock assesment.

Dunn, A. and J. Devine. 2023. Introduction to stock assessment using CASAL.

Dunn, A. and J. Devine. 2023. Ross Sea Region Antarctic Toothfish. ToR (iii): Reviewing the extent to which the choice and analyses of observations are estimated using the best available science and appropriately used in the stock assessment models, including the representativeness of observations in space and time.

Dunn, A. and J. Devine. Ross Sea Region Antarctic Toothfish. ToR (iv): Determining whether the statistical modelling (including model assumptions, model structure, priors and penalties, data selection and weighting) and the resulting inferences on stock status and dynamics and catch limits are implemented using best-practice methods.

Dunn, A. and J. Devine. 2023. Ross Sea Region Antarctic Toothfish. ToR (v): Reviewing if there are trends in parameters through time or other spatial and temporal effects on the

biological parameters, other parameters such as selectivity, and observations that should be taken into account in each stock assessment.

Earl, T. and L. Readdy. Assessment of Patagonian Toothfish in Subarea 48.3. ToRs 1 and 2.

Earl, T. and L. Readdy. Assessment of Patagonian Toothfish in Subarea 48.3. ToRs 3 and 4.

Earl, T. and L. Readdy. Assessment of Patagonian Toothfish in Subarea 48.3. ToRs 5, 6 and 7.

Readdy, L. and T. Earl. Patagonian toothfish (*Dissostichus eleginoides*) in Subarea 48.4: ToRs i and ii.

Readdy, L. and T. Earl. Patagonian toothfish (*Dissostichus eleginoides*) in Subarea 48.4: ToRs iii and iv.

Readdy, L. and T. Earl. Patagonian toothfish (*Dissostichus eleginoides*) in Subarea 48.4: ToRs v and vi.

Welsford, D. 2023. Governance of CCAMLR's toothfish fisheries.

Ziegler, P. An integrated stock assessment for the Heard Island and McDonald Islands Patagonian toothfish (*Dissostichus eleginoides*) fishery in Division 58.5.2. Introduction. Based on WG-FSA-2021/21.

Ziegler, P. An integrated stock assessment for the Heard Island and McDonald Islands Patagonian toothfish (*Dissostichus eleginoides*) fishery in Division 58.5.2. ToR (i): Reviewing the status on the implementation of the recommendations arising from the CCAMLR Independent Stock Assessment Review in 2018. Based on WG-FSA-2021/21.

Ziegler, P. An integrated stock assessment for the Heard Island and McDonald Islands Patagonian toothfish (*Dissostichus eleginoides*) fishery in Division 58.5.2. ToR (iii): Reviewing the extent to which the choice and analyses of observations are estimated using the best available science and appropriately used in the stock assessment models, including the representativeness of observations in space and time. Based on WG-FSA-2021/21.

Ziegler, P. An integrated stock assessment for the Heard Island and McDonald Islands Patagonian toothfish (*Dissostichus eleginoides*) fishery in Division 58.5.2. ToR (v): Reviewing if there are trends in parameters through time or other spatial and temporal effects on the biological parameters Based on WG-FSA-2021/21.

Ziegler, P. CCAMLR Decision Rules.

Appendix 2: A copy of this Performance Work Statement

Performance Work Statement (PWS)

National Oceanic and Atmospheric Administration (NOAA)
National Marine Fisheries Service (NMFS)

Center for Independent Experts (CIE) Program
External Independent Peer Review

Independent Review of Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Toothfish Stock Assessments

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 (1) 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. Specifically, science products that the agency can reasonably determine that will have, when disseminated*, "a clear and substantial impact on important public policies or private sector decisions*." Additionally, peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards[1].

Scope

The CCAMLR toothfish stocks are assessed every two (2) years on a routine basis. Four (4) Bayesian age-structured integrated stock assessments for toothfish using an advanced software

[1]https://www.whitehouse.gov/wpcontent/uploads/legacy_drupal_files/omb/memoranda/2005/m05-03.pdf

package (**C++ Algorithmic Stock Assessment Laboratory** (CASAL)) were reviewed by three (3) independent stock assessment scientists in 2018 (SC-CAMLR-XXXVII/02 Rev. 1, Division 58.5.2, Subarea 88.1 and SSRUs 882A–B, Subareas 48.3 and 48.4). Since then, each assessment has been further developed to address the recommendations detailed by the review (SC-CAMLR-XXXVII, Appendix 9, Table 3). As it has been five (5) years since the review, a new assessment of the performance of these stock assessments is appropriate.

In addition, concerns have been raised by one (1) CCAMLR Member since 2018 about the performance of the stock assessment in Subarea 48.3 and the resulting precautionary management of the fishery. Currently, this disagreement has resulted in a lack of consensus to agree on an appropriate conservation measure for Subarea 48.3 in 2021 and in 2022. In an effort to resolve this issue, the Scientific Committee recommended an independent review of relevant data, the stock assessment, and application of CCAMLR decision rules, in the context of the assessment and management of all CCAMLR toothfish stocks (SC-CAMLR-41, paragraph 3.108). This task order will support a portion of this recommended independent review.

It should be noted that the independent reviewer reports for this task order will be used by the U.S. Delegation to CCAMLR to inform the U.S. position on whether toothfish fisheries are managed in a manner consistent with U.S. objectives for these fisheries. Since decision making within CCAMLR is by consensus of all Members to the Commission, the U.S. position will affect how these fisheries are managed in the future.

Tasks

CCAMLR will convene a formal, virtual, multiple-day panel review meeting involving three (3) independent CIE stock assessment experts to conduct a peer review of the four (4) CCAMLR toothfish stock assessments in August 2023. The purpose of this meeting will be to provide an external peer review of the approach that CCAMLR uses to develop management advice for toothfish stocks as well as a technical review of four (4) toothfish stock assessments (SC-CAMLR-41, paragraph 3.108, CCAMLR-41, paragraph 4.39). Note that this task order is not responsible for any of the logistics, attendance, or facilitation of the multiple-day panel meeting.

Task 1: Synthesize, quality control, and review all information and final materials from the panel review meeting

- The three (3) CIE reviewers will evaluate the information provided at the August 2023 CCMALR review meeting for use as the basis for developing three (3) independent CIE peer review reports.

  (i) *Dissostichus eleginoides* in Heard Island and McDonald Islands in Division 58.5.2
  (ii) *Dissostichus mawsoni* in the Ross Sea in Subarea 88.1 and SSRUs 882A–B
  (iii) *Dissostichus eleginoides* in South Georgia in Subarea 48.3
  (iv) *Dissostichus eleginoides* in the South Sandwich Islands in Subarea 48.4.

Task 2: Produce draft independent CIE reviewer reports

- The contractor shall have the three (3) independent reviewers develop and create draft peer review reports addressing the PWS Terms of Reference (TORs) for the four (4) toothfish stock assessments.

Task 3: The contractor shall review and finalize all three (3) individual peer review reports.

- The contractor shall evaluate the reports to ensure that these work products address all the Terms of Reference and whether they are of a quality and robustness that qualifies these products as having met the CIE standard of independence and effectiveness. This task also includes all post-review contracting, invoicing, and related matters.

Final Task Order Deliverables - Independent CIE Peer Review Reports

Each CIE reviewer shall complete an independent peer review report in accordance with this PWS. Each CIE reviewer shall complete the independent peer review addressing each TOR as described in **Annex 1**. Each CIE reviewer shall complete the independent peer review according to required format and content as described in **Annex 2**.

Period of Performance

The period of performance shall be from the time of award through **October 2023**. Each reviewer's duties shall not exceed **7** days to complete all required tasks.

Place of Performance

The place of performance shall be at the contractor's facilities and/or home site.

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

Timing	**Deliverable/activity**
Immediately following panel meeting	Reviewers evaluation information and materials received from the panel meeting and commence work on draft independent peer review reports
August 2023	Virtual panel review meeting
Approximately two (2) weeks following the panel meeting	Contractor receives draft independent peer review reports
Within two (2) weeks of receiving draft reports	Contractor submits final reports to the Government

* Tasks under this task order may not begin until the panel review meeting has concluded. Any modifications in the timing of the milestones shall be approved by the Contracting Officer Representative (COR) and the CIE contractor.

Travel

No travel is necessary.

Applicable Performance Standards
The acceptance of the task order deliverables shall be based on three (3) 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.

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Annex 1. Terms of Reference

The aim for the CIE review is to provide advice to the Scientific Committee on the adequacy of the data collection, modelling approaches and methods used in CCAMLR's integrated toothfish stock assessments and if they are appropriate for all toothfish stocks relative to international best practices.

Specifically, the terms of reference for the CIE review are to determine if the integrated toothfish stock assessments within the CCAMLR area, in particular for South Georgia in Subarea 48.3, the South Sandwich Islands in Subarea 48.4, Heard Island and McDonald Islands in Division 58.5.2, and the Ross Sea in Subarea 88.1 and SSRUs 882A–B, use the best available science, are consistent with Article II of the Convention, and likely to achieve CCAMLR's objective by:

(i) Reviewing the status and report on the implementation of the recommendations arising from the CCAMLR Independent Stock Assessment Review for Toothfish in 2018 (SC-CAMLR-XXXVII/02 Rev. 1, and SC-CAMLR-XXXVII, Annex 9, Table 3).

(ii) Reviewing if biological parameters used in the assessment models are estimated using are sufficient and appropriately used in the stock assessment models:
   a. Sex-specific maturation
   b. Natural mortality
   c. Length-weight relationship
   d. Growth
   e. Stock-recruitment steepness.

(iii) Reviewing the extent to which the choice and analyses of observations are estimated using the best available science and appropriately used in the stock assessment models, including the representativeness of observations in space and time:
   a. Catch observations
   b. Survey data
   c. Catch per unit effort (CPUE) abundance indices
   d. Tag release and recapture observations
   e. Age and length compositions
   f. Selectivity.

(iv) Determining whether the statistical modeling (including model assumptions, model structure, priors and penalties, data selection and weighting) and the resulting inferences on stock status and dynamics and catch limits are implemented using best-practice methods.

(v) Reviewing if there are trends in parameters through time or other spatial and temporal effects on the biological parameters, other parameters such as selectivity, and observations that should be taken into account in each stock assessment.

(vi) Reviewing whether population projection methods, recruitment series used, and implementation of decision rules are conducted using the best available science.

(vii) Identify and consider any additional stock specific analyses or investigations that are critical for this assessment and warrant peer review, and develop additional TOR(s) to address as needed.

Annex 2. Individual Independent Peer Reviewer Report Requirements

1. The independent Peer Reviewer report shall be prefaced with an Executive Summary providing a concise summary of whether they accept or reject the work that they reviewed, with an explanation of their decision (strengths, weaknesses of the analyses, etc.).

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. The independent report shall be an independent peer review, and shall not simply repeat the contents of the Peer Reviewer Summary Report.

    a. Reviewers shall describe in their own words the review activities completed during the panel review meeting, including a concise summary of whether they accept or reject the work that they reviewed, and explain their decisions (strengths, weaknesses of the analyses, etc.), conclusions, and recommendations.

    b. Reviewers shall 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 shall elaborate on any points raised in the Peer Reviewer Summary Report that they believe might require further clarification.

    d. The report should include recommendations on how to improve future assessments.

3. The report shall include the following appendices:

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

Appendix 3: Panel membership or other pertinent information

List of participants
2023 Independent review of toothfish stock assessments

Reviewers

Cieri, Matthew
Chen, Yong
Sparholt, Henrik

Participants

Belchier, Mark
Collins, Martin
Devine, Jennifer
Dunn, Alistair
Earl, Timothy
Fields, Lauren
Ghebrezgabhier, Danait
John, Mitchell
Maschette, Dale
Masere, Cara
Parker, Steve
Readdy, Lisa
Stoute, Selina
Walker, Nathan
Wallis, Claire
Welsford, Dirk
Ziegler, Philippe