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Advances are urgently needed in providing regular estimates of krill stock status based on the available data

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ABSTRACT: CCAMLR currently manages the krill fishery in subareas 48.1 to 48.4 using an arbitrary measure (the trigger level) which was established in 1991 and is "*not related to the status of the krill stock*". At the same time, CCAMLR recognises that "*advances are urgently needed*" specifically because the trigger level is not related to the status of the stock. The establishing terms of reference for WG-EMM include requests to "a*ssess the status of krill*" and "*develop management advice … for management of krill fisheries*". Although WG-EMM is now a quarter century old, it rarely assesses the status of the krill stock and CCAMLR still manages the krill fishery using the trigger level. Here we describe the single-species feedback loop that is widely used in fishery management elsewhere, including in other CCAMLR fisheries. This feedback loop regularly modifies management measures, such as catch limits, in response to estimates of the status of the target stock. CCAMLR has already implemented the majority of the components of this feedback loop to establish Conservation Measures that limit krill fishing in Subareas 48.1 to 48.4. However, one component of this loop is missing, namely regular estimates of stock status based on the available data. Here, we briefly review some of the progress that CCAMLR working groups and the scientific community have made towards developing such methods. We suggest that WG-EMM should progress these methods further so that the working group is able to provide the advice requested in its establishing terms of reference. Finally, we emphasise that considerable uncertainty will be associated with any assessment of the status of the krill stock, and therefore there is a need for continuing precaution.

WG-EMM TERMS OF REFERENCE

These terms of reference are listed in the text below which is quoted directly from *https://www.ccamlr.org/en/science/working-group-ecosystem-monitoring-and-management-wg-emm* with bold font included for emphasis:

"WG-EMM first met in 1995 after the amalgamation of the Working Group on Krill (WG-Krill) and the Working Group on CCAMLR Ecosystem Monitoring Program (WG-CEMP). The establishing terms of reference requested the group to:

(i) Assess status of krill.

(ii) Assess status and trends of dependent and related populations including identification of information required to evaluate predator/prey/fisheries interactions and their relationships to environmental features.

(iii) Assess environmental features and trends which may influence abundance and distribution of harvested, dependent, related and/or depleted populations.

(iv) Identify, recommend and coordinate research necessary to obtain information on predator/ prey/fisheries interactions, particularly those involving harvested, dependent, related and/or depleted populations.

(v) Liaise with WG-FSA on stock assessment related matters.

(vi) Develop further, coordinate the implementation of, and ensure continuity in CEMP.

(vii) ***Taking into account assessments and research carried out under terms of reference (i) to (v) above, develop management advice on status of Antarctic marine ecosystems and for management of krill fisheries in full accordance with Convention Article II.***"

CURRENT KRILL FISHERY MANGEMENT IN SUBAREAS 48.1 TO 48.4

The krill fishery is managed with a "trigger level" catch limit equal to the sum of the maximum Subarea-specific catches prior to 1991 (CM 51-01). This catch limit of 620,000 t has not changed since 1991.

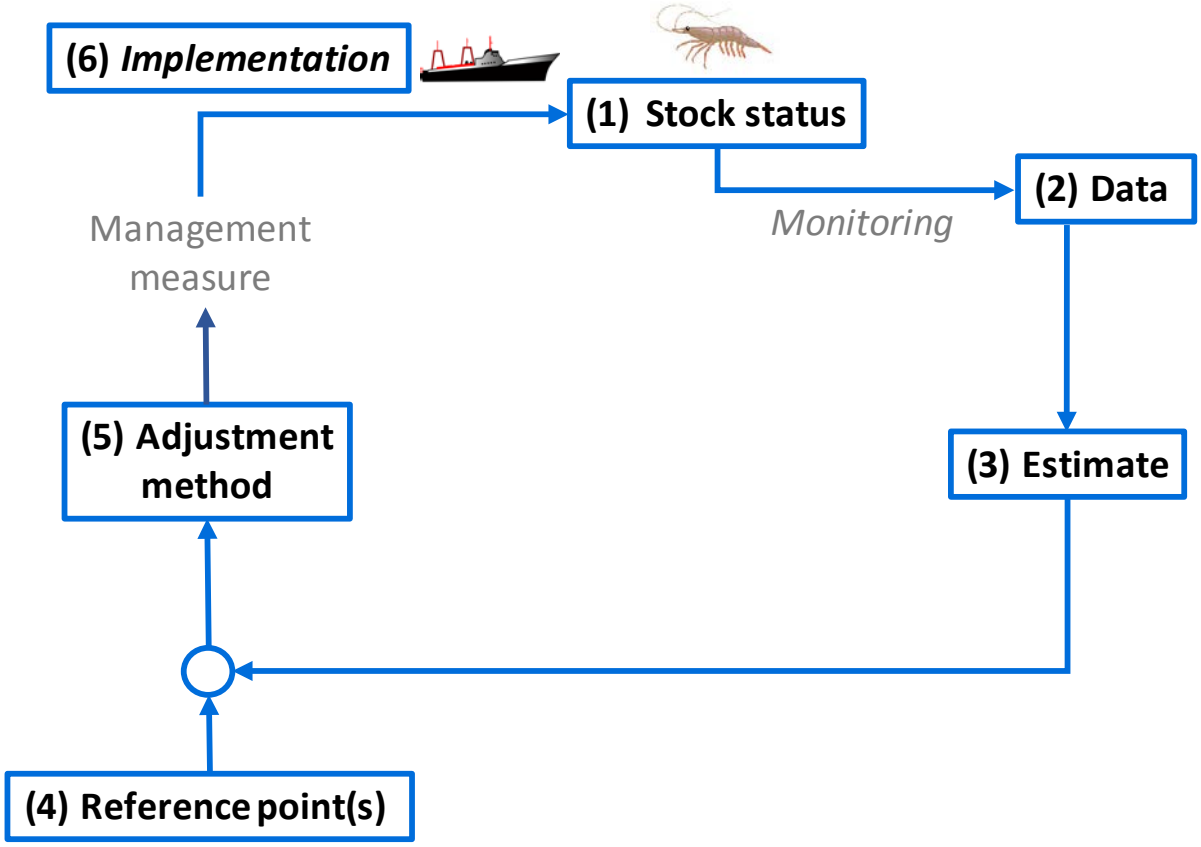
In the absence of a suitable spatial allocation among small-scale management units, the trigger level itself may not mitigate the risks that CCAMLR will fail to achieve its management objectives (Watters *et al*. 2013). Consequently, since 2009 each Subarea has had its own interim catch limit that is equal to some fraction (15% to 45%) of the trigger level. These Subarea catch limits were negotiated during discussions at Scientific Committee during 2009, but the report of that meeting does not record the details of these negotiations or the evidence on which the catch limits are based. The Conservation Measure that establishes these limits (CM 51-07) will expire at the end of the 2020/21 fishing season if agreement to update or replace it has not been reached. The Conservation Measure states that "*advances* [in krill-fishery management] *are urgently needed as the trigger level itself is not related to the status of the krill stock*."

There is also a notional higher catch limit (the "precautionary catch limit") which, according to CM 51-01, could supersede the trigger level and therefore the Subarea catch limits when

"*the Commission has defined an allocation of this total catch limit between smaller management units.*" This precautionary catch limit is based on an estimate of krill stock size in an area of c. 2,000,000 km^2, using results from the CCAMLR 2000 Synoptic Survey, undertaken during the year 2000.

SINGLE-SPECIES FISHERY MANAGEMENT

The management of many fisheries is based on feedback loops like that illustrated below (see also Constable 2002). The feedback loop regularly (e.g. annually) updates management measures (such as catch limits) in response to estimates of the status of the target stock (usually spawning-stock biomass) based on new and revised data. CCAMLR has never updated the operational catch limit (trigger level) for krill in response to new data.



CCAMLR has access to (or has already developed) most of the components of this loop. However, Component 3 (regular estimates of stock status) has not been developed and Components 4 (reference points specifying management objectives) and 5 (a method, such as a set of harvest control rules, for adjusting management measures in response to estimates of stock status) may need further development. Below, we briefly summarize the state of development of the six components of the feedback loop for the krill fishery.

(1) Stock status: The precautionary catch limit and the methods used to derive it demonstrate that CCAMLR has already defined a measure of krill stock status in Subareas 48.1 to 48.4. That is the spawning-stock biomass in the CCAMLR 2000 Synoptic Survey area (Hewitt *et al*. 2004; SC-CAMLR-XXIX 2010).

(2) Data: A second multi-ship survey of the CCAMLR synoptic survey area was conducted in 2019, nineteen years after the previous synoptic survey. Synoptic surveys have thus far been too infrequent to provide regular updates on krill stock status. Nonetheless, CCAMLR has access to a variety of more frequent data which provide potential indices of stock status (see Hill *et al*. 2016 for review). These include fishery catch and effort data; biological information, including demographic structure, from observer data; regular "local scale" (<150,000 km^2) acoustic surveys; and the various predator indices monitored in the CCAMLR Ecosystem Monitoring Programme. For several decades, the scientific programmes of CCAMLR Members have collected a variety of additional data on krill (e.g. net-based estimates of population density), its predators and environmental conditions, which are complemented by more recent data sources such as acoustic data from fishing vessels and autonomous underwater vehicles. Thus, while neither CCAMLR, nor any of its Members, monitor krill spawning-stock biomass at the scale of the CCAMLR 2000 Synoptic Survey, CCAMLR has access to a wide variety of data that could be used to indicate stock status.

(3) Estimate: In most fisheries an estimation procedure is required to assess stock status from the raw data collected in Component 2. Neither WG-EMM nor any other CCAMLR working group provides regular updates on the status of the krill stock, nor is there any agreed procedure for doing so.

(4) Reference point: The process for setting the precautionary catch limit includes a set of decision rules that evaluate projections of krill spawning stock biomass against two reference points (Constable *et al*. 2000). These provide a quantitative description of management objectives for krill spawning-stock biomass, i.e. that the probability of it dropping below 20% of its pre-exploitation median level over 20 years should be no more than 10% and that the median escapement over 20 years should be at least 75% of the pre-exploitation median level.

(5) Adjustment method: These decision rules have already been used to revise the precautionary catch limit in response to updated estimates of pre-exploitation biomass. They could be adapted to update catch limits in response to estimates of the current status of the stock, particularly in light of variability in krill biomass (see Kinzey *et al*. 2013) and ongoing trends in the ecosystem (see Kinzey *et al*. 2016).

(6) Implementation: CCAMLR appears to be effective at ensuring compliance with Conservation Measures.

The availability of five of these six components suggests that CCAMLR could implement feedback management of fishery impacts on the krill stock if it could establish a process that provides regular estimates of stock status.

In the following section, we outline progress that has been made towards developing estimates of krill stock status on the basis of regularly available data. We also discuss modifications that might be necessary to other components of the feedback loop as a consequence of the nature of these data.

ESTIMATES OF STOCK STATUS

There has been substantial work over the past decade to develop an integrated stock assessment model for krill (e.g., Kinzey *et al*. 2015, 2016, 2018a, 2018b), which could ultimately draw on data from a variety of sources including the fishery, fishery-independent surveys and predators. A fully developed integrated assessment model could provide direct estimates of krill spawning-stock biomass, and the associated uncertainty, at a spatial scale that is appropriately matched to the spatial scale of the fishery.

Hill *et al*. (2016) used conservative extrapolation from local scale acoustic surveys to estimate a plausible lower limit for spawning-stock biomass. This estimate is therefore unsuitable for evaluating whether the true biomass is consistent with the reference points defined by the decision rules. Nonetheless, the approach was used to assess whether the exploitation rates within each Subarea were within defined limits. Therefore, this approach might be suitable for use with reference points defined in terms of exploitation rates.

Net data have been used to examine trends in krill population density, most recently by Cox *et al*. (2018) and Atkinson *et al*. (2019), as well as demographic structure and distribution (Atkinson *et al*. 2019). Each of these variables is related to CCAMLR's preferred measure of stock status, but these relationships are currently unquantified. Consequently, either more work is needed to establish these relationships, or these variables could be used with reference points specified in terms of the variables themselves. The contrasting interpretations of Cox *et al*. (2018) and Atkinson *et al.* (2019) suggest that more work would be needed to agree an estimation process based on net data.

Finally, the possibility of using predator data for adjusting krill fishery management measures has been proposed several times (e.g., Constable 2002; Hill *et al*. 2010; Watters *et al*. 2016). There are significant issues which must be overcome in the use of such data, as important predator groups remain unquantified (Hill *et al*. 2012) and competitive interactions, diet switching, and other ecological processes could result in either buffering or exaggeration of the effects of changes in krill availability to any monitored predator. Thus representative species across the guild of krill-eating predators need consideration (Trathan and Hill 2016). The relationships between predator variables and CCAMLR's preferred measure of stock status are highly uncertain, and it might be appropriate to define reference points in terms of the predator variables themselves.

The current lack of regular advice on the status of the krill stock is in part due to the lack of regular direct information on the krill spawning-stock biomass in the CCAMLR synoptic survey area. There is no current basis for expecting synoptic surveys to occur on a more regular basis. Nonetheless, there are other data sources available to estimate the status of krill. There has also been substantial investment in developing approaches to estimating stock status on the basis of these data.

Many of these data are indirect, nonlinear or noisy indicators of stock status and are potentially less reliable than direct indicators. Uncertain estimates do not preclude feedback management, but they may require more precautionary reference points or decision rules.

Developing an estimation procedure can be a considerable undertaking, as illustrated by the fact that it took CCAMLR a decade to agree a final spawning-stock biomass estimate for the synoptic survey conducted in the year 2000 (Fielding *et al*. 2011) and the years of work to develop an integrated assessment model. This highlights the key requirements for progress, which are the structure, time and resources to undertake a substantial piece of scientific work.

CONCLUSION

Feedback management, as proposed for the krill fishery is intended to achieve CCAMLR's objectives under Article II of the Convention, which include maintenance of ecological relationships and prevention of irreversible change. CM 51-07 states that "*The Commission shall seek to update or replace this Conservation Measure, in progressing feedback management, no later than the end of the 2020/21 fishing season*." This expectation of imminent progress with feedback management should be balanced against the facts that WG-EMM does not routinely provide advice on the status of the krill stock nor have an agreed process for doing so. Thus CCAMLR has not even managed to implement feedback management to control fishery impacts on the stock itself.

CM 51-07 also states that "*advances are urgently needed*". In the absence of regular direct estimates of spawning-stock biomass in the CCAMLR synoptic survey area, the advance which is most likely to progress feedback management is to establish a process for estimating stock status using those data that are available.

Progress with regular estimates of stock status does not preclude the need to manage potential fishery impacts on other parts of the ecosystem, including krill predators. Indeed, given that catches are not randomly distributed and are mostly taken from a limited number of hotspots, spatial or temporal distribution of the catch still remains a key objective.

It is essential to recognise that any estimates of krill stock status based on currently available data will have substantial uncertainties, and therefore require substantial precaution. The requirement for precaution is even stronger given the *status quo* situation in which WG-EMM does not provide regular advice on stock status. For this reason, precautionary measures like CM 51-07 should remain in place for as long as the *status quo* persists.

REFERENCES

Atkinson A, Hill SL, Pakhomov EA, Siegel V, Reiss CS, Loeb VJ, Steinberg DK, Schmidt K, Tarling GA, Gerrish L, Sailley SF. (2019) Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming. Nature Climate Change. 9(2):142.

Constable AJ, de la Mare WK, Agnew DJ, Everson I, Miller D. (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 1;57(3):778-91.

Constable, AJ (2002) CCAMLR ecosystem monitoring and management: future work. *CCAMLR Science*, *9* 233-253.

Cox MJ, Candy S, de la Mare WK, Nicol S, Kawaguchi S, Gales N. (2018) No evidence for a decline in the density of Antarctic krill *Euphausia superba* Dana, 1850, in the Southwest Atlantic sector between 1976 and 2016. Journal of Crustacean Biology. 8;38(6):656-61.

Fielding, S., J. Watkins A. Cossio, C. Reiss, G. Watters, L. Calise, G. Skaret, Y. Takao, X. Zhao, D. Agnew, D. Ramm and K. Reid. 2011. The ASAM 2010 assessment of krill biomass for Area 48 from the Scotia Sea CCAMLR 2000 Synoptic Survey. WG-EMM-11/20.

Hewitt RP, Watkins J, Naganobu M, Sushin V, Brierley AS, Demer D, Kasatkina S, Takao Y, Goss C, Malyshko A, Brandon M. (2004) Biomass of Antarctic krill in the Scotia Sea in January/February 2000 and its use in revising an estimate of precautionary yield. Deep Sea Research Part II: Topical Studies in Oceanography. 51(12-13):1215-36.

Hill SL, Atkinson A, Darby C, Fielding S, Krafft BA, Godø OR, Skaret G, Trathan PN, Watkins JL (2016). Is current management of the Antarctic krill fishery in the Atlantic sector of the Southern Ocean precautionary?. CCAMLR Science. 23:31-51.

Hill SL, Forcada J, Trathan PN, Waluda CM (2010) Using ecosystem monitoring data to detect impacts. CCAMLR Science. 17:197-212.

Kinzey D, Watters G, Reiss CS (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.

Hill, S.L., K. Keeble, A. Atkinson and E.J. Murphy 2012. A foodweb model to explore uncertainties in the South Georgia shelf pelagic ecosystem. Deep-Sea Research II 59-60:237–252.

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

Kinzey D, Watters GM, Reiss CS (2016). The integrated krill assessment model for Subarea 48.1 with future catches meeting alternative decision rules. WG-SAM-16/36 Rev. 1.

Kinzey D, Watters GM, Reiss CS (2018a) Parameter estimation using randomized phases in an integrated assessment model for Antarctic krill. PloS one. 13(8):e0202545.

Kinzey D, Watters GM, Reiss CS (2018b) Estimating recruitment variability and productivity in Antarctic krill. Fisheries Research. https://doi.org/10.1016/j.fishres.2018.09.027.

SC-CAMLR-XXIX 2010. Scientific Committee for the Conservation of Antarctic Marine Living Resources. Report of the fifth meeting of the Subgroup on Acoustic Survey and Analysis Methods. CCAMLR, Hobart, Australia.

Trathan, P.N., and S. Hill 2016. The importance of krill predation in the Southern Ocean. In: Siegel, V. (ed), Biology and Ecology of Antarctic krill. Springer, Berlin, Germany, pp. 321–350.

Watters GM, Hill SL, Hinke JT, Matthews J, and Reid K. (2013) Decision-making for ecosystem-based management: evaluating options for a krill fishery with an ecosystem dynamics model. Ecological Applications. 23(4):710-725.

Watters GM, Hinke JT, Reiss CS. (2016) A feedback management strategy for the krill fishery in Subarea 48.1. WG-EMM-16/48.