Further development the Krill stock hypothesis (KSH) for CCAMLR area 48

REPORT of the online workshop of the SCAR Krill Expert Group (SKEG), 08-11th March 2024, doi: 10.5281/zenodo.12571138

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Summary: The SCAR Krill Expert Group (SKEG) aims to act as a forum to improve the understanding of krill biology and ecology and serve as a link between the scientific krill community and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which manages the Antarctic krill fishery. SKEG also provides a platform for research direction, information exchange, and collaboration within the krill community, focusing on early career researchers (ECRs). The 2024 SKEG annual workshop was held virtually over four days, from 08 to 11th March 2024, from 18:00 to 20:00 UTC, with 108 participants from 22 countries, including ECRs. The number of participants provided a sufficient sample size for polling questions to support CCAMLR in further developing the KSH for their revised krill fishery management approach.

The workshop aimed to refine the preliminary Krill Stock Hypothesis (KSH) developed during the SKEG workshop in 2023 (Meyer et al. 2023). The refinement focused on the data collection needs to better understand the abundance and distribution of krill life stages and krill flux to support progressing CCAMLR's revised krill management approach, for which specific polling questions were developed to gather expert opinions. Another focus of the workshop was on how monitoring of the krill-based ecosystem could be enhanced. Polling questions were developed to gather expert opinions on additional krill parameters that should be monitored during fishing operations and which existing predator-derived data are most valuable to inform interannual changes in krill availability.

Priority areas for further data collection on krill were identified as the North West Weddell Sea, the Branfield Strait, the South Orkneys, and the South Shetlands, respectively. Penguins, seals and flying seabirds emerged as the most valuable predator groups to monitor to evaluate short and long term changes in krill; however, penguins and whales were considered relevant for future monitoring efforts to assess krill availability.

The current document serves as a record of the workshop and a report to including a series of recommendations to CCAMLR's working group on Ecosystem Monitoring and Management (WG-EMM), tasked with developing scientific advice on krill fishery management.

Workshop Proceedings

The annual SKEG workshop in 2023 provides the history of the development of the KSH and its preliminary structure (https://scarkrillexpertgroup.org/resources/).

Based on the results from the workshop in 2023, the main aim was to refine the development of the KSH, get expert opinions on research/data collection priorities, and understand krill flux to further develop the KSH . Another focus was monitoring the krill-based ecosystem to support the ongoing work at CCAMLR to revise the CCAMLR Ecosystem and Monitoring Program (CEMP).

To accomplish the workshop's aims, the SKEG board developed a workshop composed of background talks, guided discussions, surveys conducted before, during, and after the workshop, and two half-days focused on emerging krill-related science, emphasising the science performed by ECRs.

Before the workshop, an online survey was conducted to get expert opinions on two topics (i) Where and what data collection should occur to get an overview of the abundance and distribution of krill life stages and (ii) Which existing predator-derived data are most valuable to provide information on interannual and long-term changes in krill availability.

The workshop started with a series of presentations related to the topics addressed during the workshop. The refinement of the KSH was conducted through a series of sessions focused on (i) where and what data collection should occur to get an overview of the abundance and distribution of krill life stages; (ii) temporal and spatial scales of krill flux relevant to management; (iii) monitoring the krill-based ecosystem; and (iv) how these data can best be utilized to improve the KSH. The presentations provided participants with the background knowledge necessary to answer the polling questions and contribute to the discussions on the following days. The first presentation by So Kawaguchi gave an overview of CCAMLR's request to SKEG to refine the KSH and the CCAMLR Ecosystem Monitoring Programme (CEMP). After that, three specific presentations followed on the topics addressed during the workshop: Christian Reiss gave an overview of the current CCAMLR Ecosystem Monitoring Programme: Objectives and Practice; Zephyr Sylvester focused on the Krill stock hypothesis: purpose, current status and future development; and Simeon Hill gave an overview on krill flux and its importance for fisheries management.

On the first half of the **second workshop day**, the group considered workshop questions that addressed:

- Expertise of workshop participants
- Further development of the KSH
- Monitoring the krill-based ecosystem
- Krill Flux

The second half of the second workshop day began a series of six presentation on krill related research (See Appendix III)

The **third workshop day** consisted of guided discussions based on the results from the survey taken before the workshop and during the workshop on day 2.

The entire **fourth workshop day** were dedicated to showcasing ongoing research related to krill.

The majority of the talks represented the activities of ECRs (Appendix III). The online workshop closed with a recap of the discussions from the previous days and announcements of upcoming events and meetings involving SKEG.

The number of participants at the daily sessions (18:00-20:00 UTC) ranged between 70 to 104 (Appendix I) and the participants were from around the world (United Kingdom, Chile, Australia, China, United States, Germany, Norway, Argentina, Peru, Japan, France, Spain, Canada, India, the Netherlands, Portugal, Belgium, Ukraine, Russian Federation, Mexico, Ecuador and New Zealand; in the order of participants number). This online workshop included sufficient participation to represent the weight of the expert opinion of the current krill research community. Of the experts participated in the online polling, 56%, 5%, 13%, 13% and 13% of them identified their primary expertise as krill biology/ecology, krill fishery management, krill predators, krill statistician/modeler, other including non-krill expert, respectively. The number of participants provided a sufficient sample size for polling questions to support CCAMLR in developing a KSH for their revised krill fishery management approach. What follows are the main results from the polls and discussions from the workshop.

Workshop Results

All polling questions and results can be found in Appendix II

Pre-Workshop Survey

Prior to the workshop, we performed a Survey on the KSH- and CEMP-related topics to get expert opinions on (i) “Where and what data collection should occur to get an overview of the abundance and distribution of krill life stages?”; and (ii) “Which existing predator-derived data are most valuable to provide information on interannual and long-term changes in krill availability?” Of the 108 participants, 47 workshop attendees participated in the survey.

For the first point on data collection for the abundance and distribution of krill life stages (Questions 1.1 – 1.4; Appendix II), according to expert opinion, the priority areas for further data collection on krill ontogenetic stages (eggs, larvae, 20mm juveniles, adults) were identified as the North West Weddell Sea, the Branfield Strait, the South Orkneys, and the South Shetland Islands, respectively (Fig. 1). Surprisingly, given the interest in the Bellingshausen Sea in the previous years workshop, the region further south down the Antarctic Peninsula received a lower priority. The discussions about this aspect revealed that a few respondents had misinterpreted the question to mean which were the main source locations of these various life stages, rather than which areas need to be better sampled. Notwithstanding this slight area of confusion, a clear expert consensus was that areas adjacent to the tip of the Antarctic Peninsula, as well as the South Orkneys, were seen as priorities for better data collection.

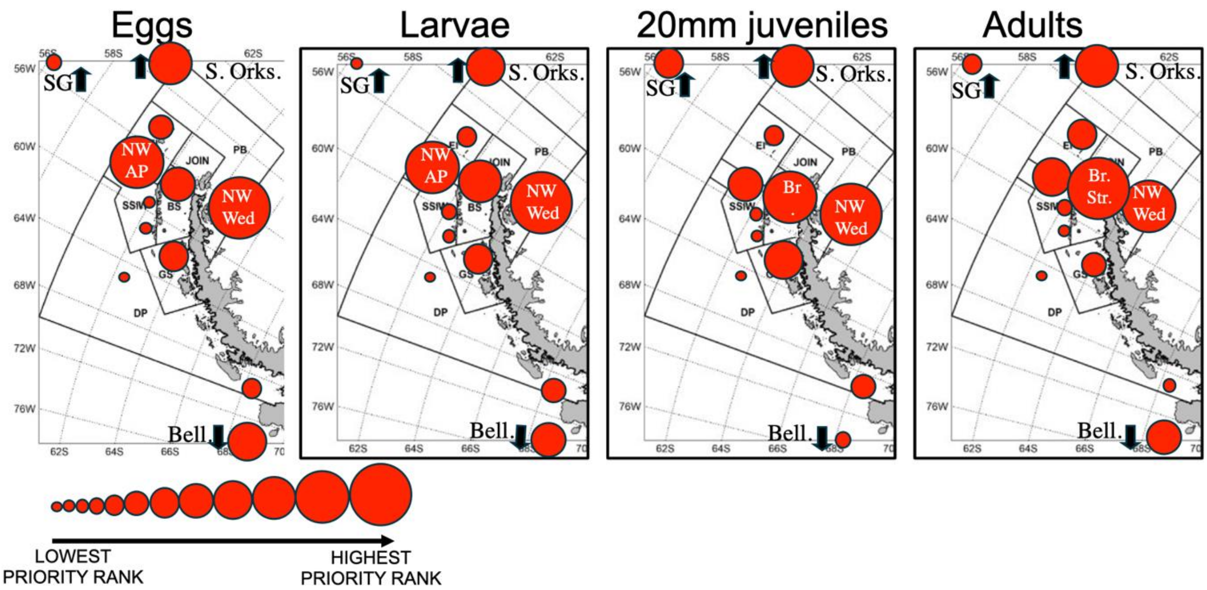

Figure 1*: Survey results of the survey monkey polling asking the question: "Which are the most important areas for data collection on the abundance and distribution of krill life stages, for further development of the KSH?" Respondents responded on this question to all 12 subregions illustrated here in turn, scoring each based on the scoring index of 0 (unnecessary), 1 (low priority), 2 (medium priority) or 3 (high priority). The 47 repondent responses were incorporated into an index of priority using: Scoring index =(0 x no. of people who scored 0) + …………(3 x no. of people who scored 3). Bubble size (see legend) describes the ranked order of the 12 subregions from 1-12 based on the scoring index. Please note that the Bellingshausen Sea (Bell), South Georgia (SG) and the South Orkneys (S. Orks) areas are off the map.*

A second point to get an expert opinion before the workshop was focusing on CEMP. It was asked, "Which **existing** predator-derived data are most valuable to provide information on **interannual** and **long-term** changes in krill availability?" (Questions 2.3 & 2.4; Appendix II). Unfortunately, this question was interpreted variously among respondents (e.g., on the importance of gathering the data, the importance of the ecosystem, and the importance of krill consumption), so workshop participants were kindly requested to fill in Survey Monkey again, after having the meaning of the question clarified. In the second question round during the penultimate day of the workshop penguins, seals and flying seabirds emerged as the most valuable groups, with all the metrics of krill availability having some use (varying partly according to the actual predator species, Fig. 2). However, the diet- and foraging-specific metrics tended to be seen as more valuable in revealing shorter-term (interannual) variability in krill availability. In contrast, the more general metrics, such as breeding success and population size, tended to reflect longer-term trends in krill availability. The follow-up question on priority groups for future monitoring to assess krill availability (Fig. 3) placed priority on whales, penguins and seals, respectively, with relatively more weight on whales and fish than is shown in Figure 2.

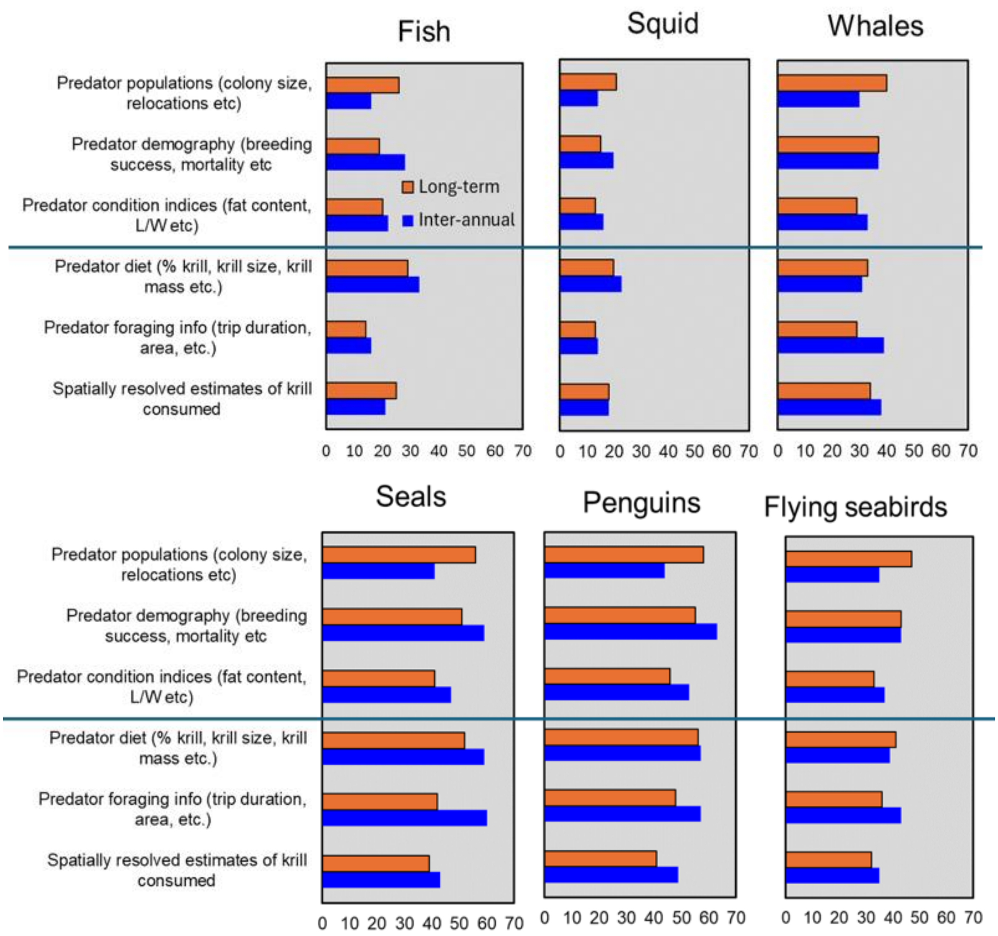

Figure 2*: Results of the second round of polling with 25 responses to the question: "How well do existing data on predator indices inform on changes in krill availability? " The question was asked separately for each of the six predator groups, and respondenst scored 0 (unsuitable), 1 (low suitability), 2 (medium suitability) or 3 (high suitability). The scoring index was calculated as for Fig. 2, ie (0 x no. of people who scored 0) + ……………(3 x no. of people who scored 3). The question was asked separately for long-term trends in krill availability and its interannual variability, denoted by orange and blue bars respectively. The horizontal line divides various predator metrics above from more diet and foraging metric below.*

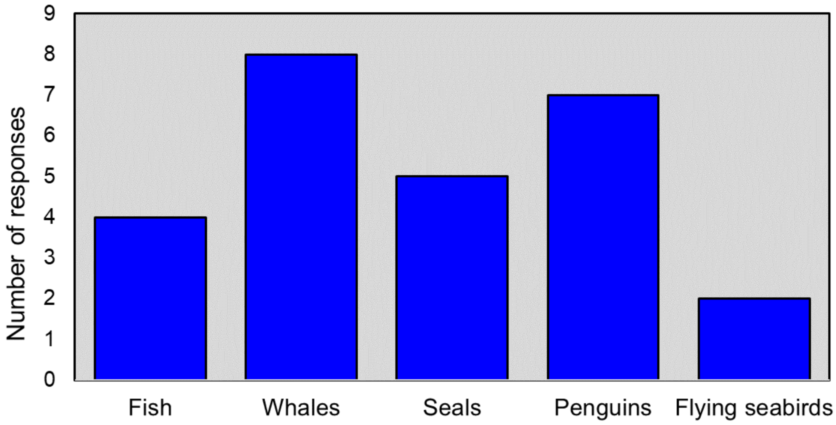

Figure 3*: Respondents' answers to the polling question "What are priority groups for future data collection to provide information on krill availability?"*

CCAMLR Ecosystem Monitoring Programme (CEMP)

In 2023, WG-EMM assigned SKEG the task of leading a temporary team to provide recommendations on "krill fishery and at sea monitoring" in advance of further discussions on updating CEMP scheduled to take place at WG-EMM 2024. This topic was discussed on day three of the SKEG workshop. The discussion was informed by the polling results shown in Figures 2 and 3, and addressed the following questions:

> "What additional ship-based monitoring should be included in an expanded CEMP?"
> "What data should be collected specifically from fishing vessels?"
> "Which additional krill predators should be monitored and how?"

Participants:

- Identified additional information on whales, fish and squid as desirable.
- Recognised the value of the CCAMLR Scheme of International Scientific Observation in ongoing collection of potentially useful ecosystem data, especially on the size-structure of recruited krill.
- Identified the by-catch of krill fishing vessels as a potentially valuable source of information on the biology (size, sex, maturity) of by-catch species as well biodiversity and feeding interactions, through technologies such as stable isotope analysis and stomach DNA analysis.
- Suggested that fishing vessels could be used as platforms for *ad-hoc* whale and seabird observations to establish foraging locations.
- Supported the use of new technologies on fishing vessels, including the deployment of remotely operated vehicles, towed cameras and infra-red camera installation on board) and eDNA sampling.

Surveys during the workshop

The survey results carried out during the workshop provided useful insights to refine the KSH. Specifically, these polls focused on (i) Data collection (where and what data collection should occur to identify spawning, nursery and juvenile hotspots) (Questions 2.1 & 2.2; Appendix II), and (ii) Krill Flux (Questions 3.1 – 3.7).

Data collection

Overall, the experts' collective opinion on data collection was that independent, collaborative research should be given priority to collect data for the KSH (Fig. 4a). Relevant information to collect annually includes krill stage, maturity, sex, length, and derivation of krill size at recruitment and size structure of post-larval krill (Fig. 4b). Still, we need to make maximum use of available platforms to monitor basic krill biological parameters, including krill length, biomass, sex and maturity stage, respectively (Fig. 4c).

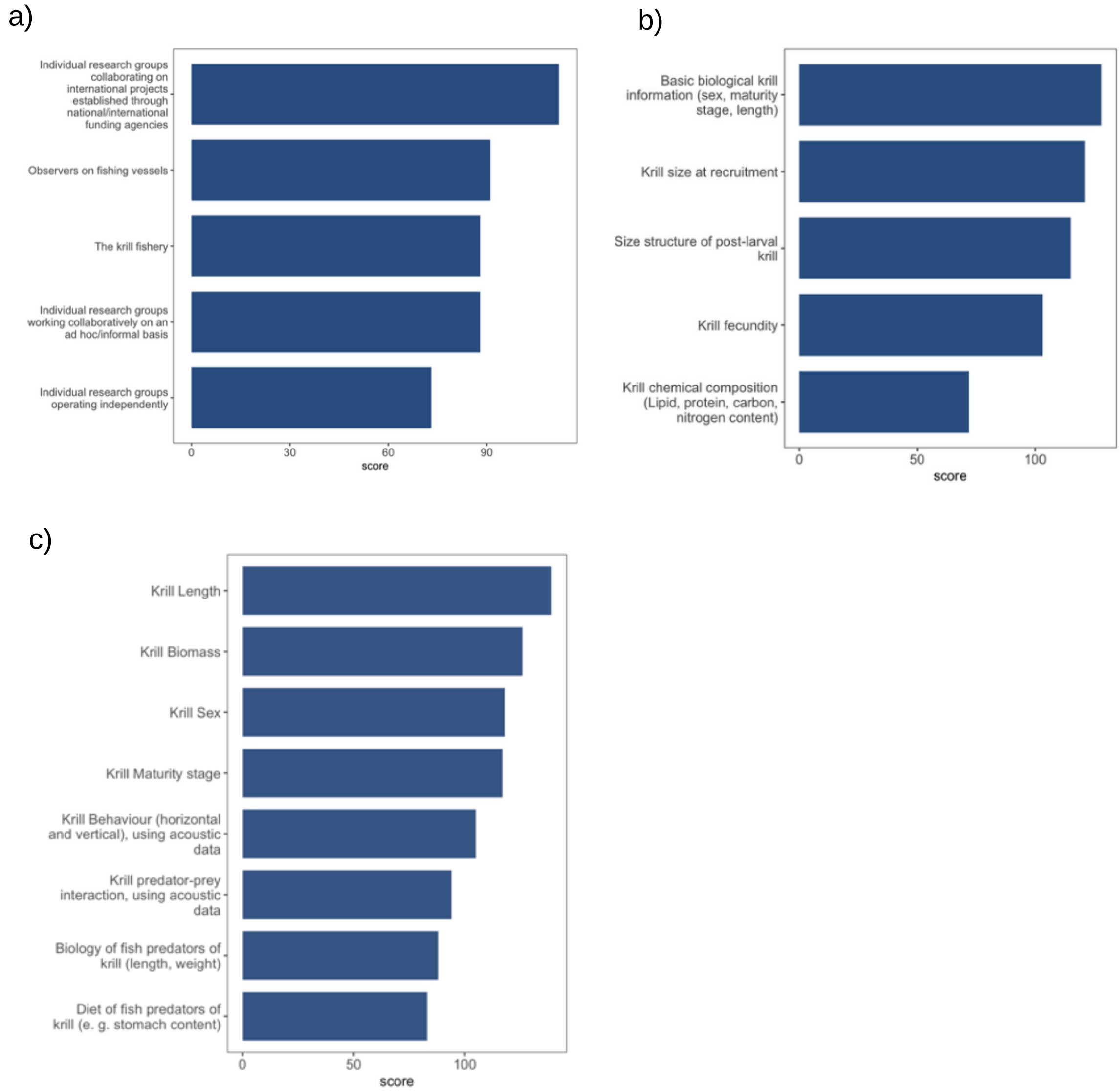

Figure 4*: Results of the polling questions to refine the KSH (for details, see text above). Workshop attendees provided feedback on the following: a) "Who should collect the data needed to develop the KFH further?"; b) "How important are the following parameters for continued (year after year) monitoring of the krill-based ecosystem?"; c) "What biological data should be monitored on krill fishing vessels for the KSH, spatially and temporally?".*

Krill flux and retention

Understanding the flux and retention of krill within fishing areas is extremely important when considering allocation of the distribution of catch in space and time. Polling was used to gauge the opinions of the SKEG workshop participants (hereafter “SKEG”) on krill flux for Subarea 48.1 and the surrounding regions at a range of temporal and spatial scales and their relevance to krill fishery management (Questions 3.1 – 3.3; Appendix II).

Area 48 Scale

SKEG’s collective view on the spatial scales that krill flux (movement of post-larval krill) could be considered relevant for fishery management are at the Area 48 level (flux between Subareas) and at Subarea level (flux between management strata within a Subarea) (Fig. 3.1, Appendix II Polling results).

The opinion of the SKEG was that the southern boundary of the ACC (sbACC) serves as an important potential pathway for krill flux into Subarea 48.1, from the Bellingshausen Sea to the northern Antarctic Peninsula, and into Subarea 48.2. The Weddell Front and Antarctic Slope Front were also considered important pathways for krill flux into Subarea 48.2.

Regarding the temporal resolution on which krill flux becomes relevant for management (Question 3.7; Appendix II), SKEG’s collective view is that a temporal resolution of a year or less is appropriate for krill fishery management, with most preference by month. Resolution higher than a month (i.e. week) was considered too fine and would lose relevance to management.

Flux and retention within Subarea 48.1

To gauge opinion on the relevance of flux and retention within Subarea 48.1 for krill fishery management, SKEG were asked the following question (Question 3.4; Appendix II):

“Considering that major krill fishing areas are formed in management units South Shetland Islands West (SSIW) (summer) and Bransfield Strait (BS) (winter), which krill fluxes and retentions are critical for management? Please score each combination 0 (not important or no connection), 1 (low importance), 2 (medium importance) or 3 (high importance)”.

To analyse these polling results (Table 3.4; Appendix II Polling results), mean scores for importance were categorized into four levels based on their ranks from high to low. “High”: score ranking within top 25%, “medium-high”: ranking 25 to 50% from the top, “medium-low”: ranking 50 to 75% from the top, and “low”: ranking below 75% from the top). Also, the level of agreement for the answers between participants were categorized into “high” (low standard deviation, SD<0.9), “medium (0.9≤SD<1.0), and “low” (high standard deviation, SD≥1.0).

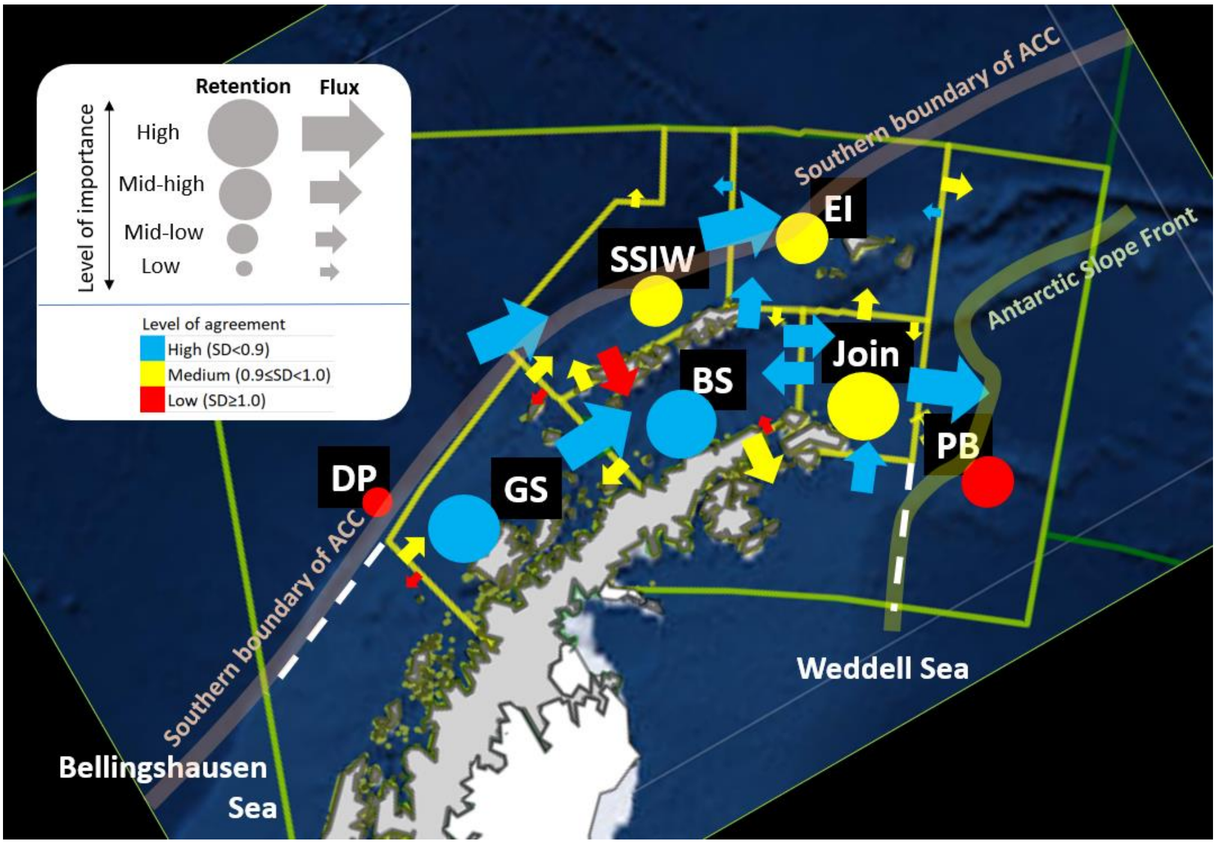

Figure 5: *Graphic representation of Krill flux and retention in management strata proposed in the revised krill fishery management strategy within Subarea 48.1, as indicated by the SKEG polling results (Q. 3.4; Appendix II). Circles describe krill retention within a stratum, and arrows indicate the flux direction between strata. Size of the symbols denotes the level of importance, the colour of the symbols expresses the level of agreement by the participants. Yellow lines: Boundaries between management strata. White dashed lines: Potential additional boundaries suggested by SKEG for the improvement of management strata. GS: Gerlache Strait, BS: Bransfield Strait, Join: Joinville Islands, SSIW: South Shetland Islands West, EI: Elephant Island, DP: Drake Passage, and PB: Powell Basin. Southern Boundary of ACC and Antarctic Slope Front (after Ferreira et al. 2020).*

SKEG's collective view on flux and retention within Subarea 48.1 (Fig. 5) is that

- The strata important for retention are GS (high agreement), BS (high agreement), and Join (medium agreement).
- Flux from GS to BS is important (high agreement), as well as flux from Join to PB (high agreement).
- Retention in DP is considered as of medium-low importance (low agreement).
- Fluxes in the north side of South Shetland Islands, from DP to SSIW, and SSIW to EI, were both considered of high importance (high agreement).
- Role of PB (Weddell)-> Join -> BS for retention, which reflects North WAP Loop Current (NWLC; Ferreira et al., 2020), is of "medium-high" importance.

In the discussion of differences in the level of agreement in key fluxes and retentions, participants identified key issues in uncertainties in our understanding of krill behaviour, the robustness of observed fluxes, and the representation of advection fields by oceanographic models. For example, oceanographic models cannot replicate some of the observed fluxes (i.e., movement from offshore SSIW into the Bransfield Strait), and the temporal variability of advection introduces additional complexity.

Comments on Management Strata within Subarea 48.1

SKEG noted some cases where management units could be made more suitable by adjusting or splitting the boundaries based on the knowledge of the stock structure and distribution. One apparent example is DP, which extends from Anvers Island south to the Bellingshausen Sea, and from far offshore to the coast, even into Marguerite Bay. From the coast region, although not currently fished, a wealth of information on krill distribution and dynamics is available (e.g., Palmer LTER: Lascara et al., 1999; Ross et al., 2014), indicating that it is an important source region for krill along the northern Antarctic Peninsula (Meyer et al., 2020). Therefore, the Southern part (shelf area) of DP could be separated from the oceanic DP (Fig. 5, white dashed line in DP).

Another example is PB, which extends from 60°S down to 65°S, well into the Weddell Sea region along the Eastern Antarctic Peninsula. The region west of 54°W is approximately aligned with the Antarctic Slope Front (ASF), and water west of the ASF flows into BS, but water to the east flows northward (Ferreira et al., 2020). Hence, from a water circulation point of view, the region west of 54°W within PB could be separated from the rest of PB (Fig. 5, white dashed line in PB).

Ongoing krill-related research

Steve Parker gave a keynote, providing insights into "How decisions regarding data collection are made in CCAMLR (WGs, SC, Commission, Workshops)". Following the keynote talk, six 5-minute presentations were given, covering various topics, from modelling and krill flux to krill source regions and developing new experimental setups to study krill behaviour. In addition, 9 ECRs presented their research in 5-minute talks, ranging from krill distribution results from expeditions in the Indian and Atlantic sectors of the Southern Ocean, variability in krill transport pathways, diet shifts of krill from summer to autumn, Antarctic krill studied by predators to mapping encounters between krill fishing vessels and air-breathing krill predators by using acoustic data from the fishery. Please see Appendix III for the list of all talks from both days.

Summary and Recommendations for the CCAMLR Working Group on Ecosystem Monitoring and Management (WG-EMM)

With this workshop, SKEG aimed to gather its collective view on aspects on data collection needs to better understand the abundance and distribution of krill life stages and krill flux to support progressing CCAMLR's revised krill management approach by refining the preliminary Krill Stock Hypothesis (KSH) developed during the SKEG workshop in 2023 (Meyer et al. 2023).

The priority areas for further data collection on krill ontogenetic stages (eggs, larvae, 20mm juveniles, adults) were identified as the North West Weddell Sea, the Branfield Strait, the South Orkneys, and the South Shetland Islands, respectively. The priority groups for future monitoring to assess krill availability placed whales, penguins and seals into the forefront for data collection.

The results and discussions at the SKEG workshop in 2024, based on distribution and dynamics of krill in Area 48, led to the following recommendations for WG-EMM,

- Knowledge on the dynamics of krill in time and space provides important basis for considering management strata

- Importance of retention and flux (source to destination relation) identified by SKEG should be taken into account when allocation of catch limits, particularly the importance of retention in the Gerlach Strait, Bransfield Strait and Joinville Island strata, and the directions of the important fluxes
- The proposed arrangement of management strata with the revised krill fishery management approach could be improved by adjusting and/or changing boundaries according to frontal systems, including splitting the southern part of Drake Passage stratum along sbACC, as well as splitting west part of Powell Basin stratum at 54°W (along Antarctic Slope Front)

Acknowledgements:

The online workshop was hosted by Deutsche Umwelthilfe (DUH), and we are grateful for the support of Francheska Ilse Tacke for the smooth running of the event.

Reference:

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Appendix I

Workshop Participants

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Brokensha, Luke
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Cavanagh, Rachel
Chen, zhuang
Chiessi , Luca
Cleary, Alison
Collins, Martin
Conroy, Jack
Cornejo, Rodolfo
Corney, Stuart
Dallosto, manuel
Deregibus, Dolores
Dong, Sisong
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Farber Lorda, Jaime
Fielding, Sophie
Font, Alejandro
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Hellessey, Nicole
Henderson, Angus
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Liszka, Cecilia
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Maschette, Dale
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Suter, Leonie
Sylvester, Zephyr
Tacke, Francheska Ilse
Tarling, Geraint
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Young, Emma
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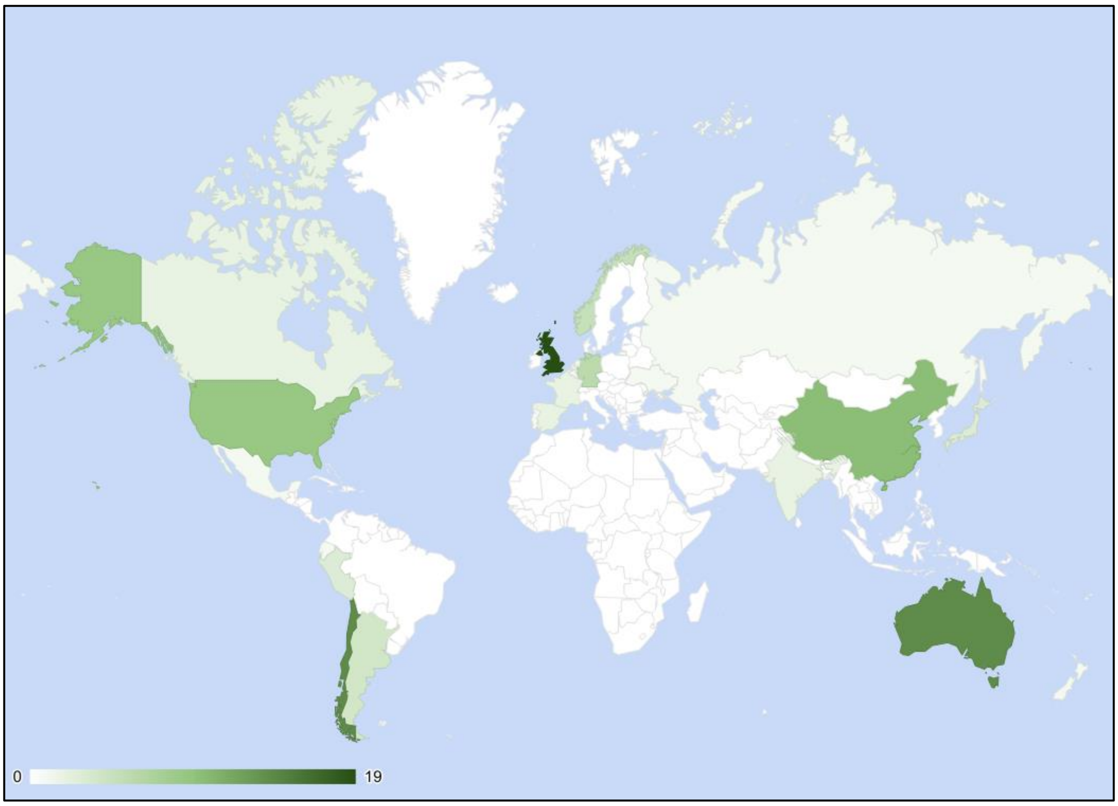


Registrations by country											
GB: 19	CL: 14	AU: 14	CN: 10	US: 9	DE: 6	NO: 5	AR: 4	PE: 3	JP: 3	FR: 2	
ES: 2	CA: 2	IN: 2	NL: 1	PT: 1	BE: 1	UA: 1	RU: 1	MX: 1	EC: 1	NZ: 1	n/s.: 5

Appendix II

Overview of the polling questions

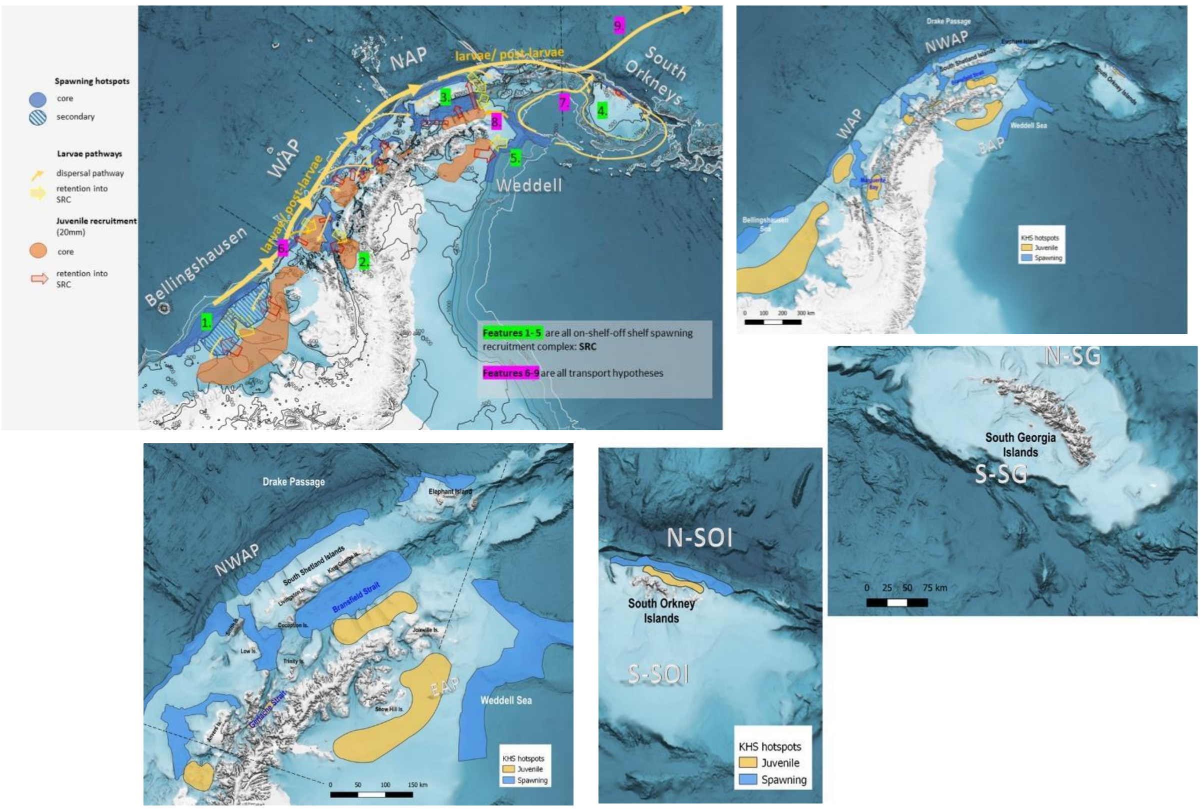
Intro: Question about your expertise

How do you describe your expertise?
Multiple options can be chosen.

- ☐ Krill biologist/ecologist
- ☐ Krill statistician/modeler
- ☐ Krill predator expert
- ☐ Krill fishery management expert
- ☐ Other, including non-krill expert

1. Questions to develop the Krill Stock Hypothesis (KSH) further

1.1. Which are the most important areas for data collection on the abundance and distribution of krill life stages, for further development of the KSH?
Please score each combination: 0 (unnecessary), 1 (low priority), 2 (medium priority) or 3 (high priority)



	Eggs	Larvae	Juveniles 20 mm (0+)	Juveniles 30 mm (1+)	Adults
Marguerite Bay					
Open sea of the Bellingshausen Sea					
Northwest of the Antarctic Peninsula (NWAP) region					
East of the Antarctic Peninsula (EAP) region (NW Weddell Sea)					
Drake Passage					
Gerlache Strait					
North of Livingston Island (inshore)					
North of King George Island (inshore)					
Around the Elephant Island					
Bransfield Strait					
North and West of South Orkney Islands (NW-SOI)					
Subarea 48.3 (Around South Georgia)					

1.2. Which studies are needed to test the KSH?

Please score: 0 (unnecessary), 1 (low priority), 2 (medium priority) or 3 (high priority)

- Identification of spawning (i.e., egg laying) grounds ___
- Identification of summer habitats of calyptope larvae ___
- Identification of winter nursery grounds ___
- Identification of recruitment grounds of 20mm (0+) krill ___
- Seasonal, ontogenetic, and environmental (e.g., in the presence of sea ice versus open water) variability in vertical migration patterns ___
- Improved understanding/modelling of currents and advection processes ___
- The ability of post-larval krill to actively migrate horizontally ___

1.3. What archived collections or datasets already exist that can be used to support the development and evaluation of the KSH?

Please name any that you know of and identify the study/studies from Q1.2 that it will assist (e.g., 1.2a is identification of spawning ground)

1.4. From the list below, score who should collect the data needed to develop the KSH further?

Please score: 0 (unnecessary), 1 (low priority), 2 (medium priority) or 3 (high priority)

- Individual research groups operating independently ___
- Individual research groups collaborating on international projects established through national/international funding agencies ___
- Individual research groups working collaboratively on and ad hoc/informal basis ___
- The krill fishery ___
- Observers on fishing vessels ___

2. Monitoring the krill-based ecosystem

2.1. How important are the following parameters for continued (year after year) monitoring of the krill-based ecosystem?

Please score each parameter: 0 (unnecessary), 1 (low priority), 2 (medium priority) or 3 (high priority)

- Size structure of post-larval krill ___
- Krill size at recruitment ___
- Basic biological krill information (sex, maturity stage, length) ___
- Krill fecundity ___
- Krill chemical composition (Lipid, protein, carbon, nitrogen content) ___

2.2. What biological data should be monitored on krill fishing vessels for the KSH, spatially and temporally?

Please score each type of data 0 (unnecessary), 1 (low priority), 2 (medium priority) or 3 (high priority)

- Krill Length ___
- Krill Sex ___
- Krill Maturity stage ___
- Krill Biomass ___
- Krill Behaviour (horizontal and vertical), using acoustic data ___
- Biology of fish predators of krill (length, weight) ___
- Diet of fish predators of krill (e. g. stomach content) ___
- Krill predator-prey interaction, using acoustic data ___

2.3. Which existing predator-derived data are most valuable to provide information on interannual changes in krill availability?

Please score each combination: 0 (unnecessary), 1 (some value), 2 (moderate value) or 3 (high value)

	Fish	Squid	Whales	Seals	Penguins	Flying seabirds
Spatially resolved estimates of total krill mass consumed						
Predator foraging information (e.g., trip duration, foraging area)						
Predator diet (e.g., % krill, krill size, mass of krill)						
Condition indices of the krill-reliant predator (e.g., L/W, body fat, etc)						
Predator demographic indices (e.g., recruitment, breeding success, mortality, etc)						
Predator colony/population size and regional changes in this						
Notes: e.g., which predator species the answer refers to (or is the best indicator); any caveats; the identification of a measurement that should be prioritized; a regional specific note						

2.4. Which existing predator-derived data are most valuable to provide information on longer-term changes in krill availability?
Please score each combination: 0 (unnecessary), 1 (some value), 2 (moderate value) or 3 (high value)

	Fish	Squid	Whales	Seals	Penguins	Flying seabirds
Spatially resolved estimates of total krill mass consumed						
Predator foraging information (e.g., trip duration, foraging area)						
Predator diet (e.g., % krill, krill size, mass of krill)						
Condition indices of the krill-reliant predator (e.g., L/W, body fat, etc)						
Predator demographic indices (e.g., recruitment, breeding success, mortality, etc)						
Predator colony/population size and regional changes in this						
Notes: e.g., which predator species the answer refers to (or is the best indicator); any caveats; the identification of a measurement that should be prioritized; a regional specific note						

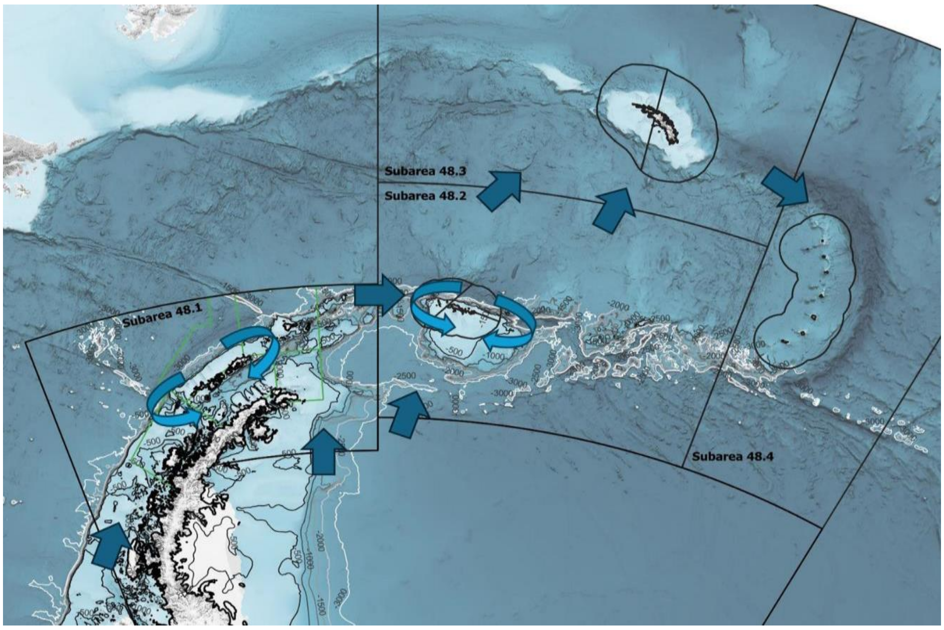
3. Krill Flux – Which questions can be answered with existing data?

Please read the background information before answering the questions in this Krill-Flux Section

Spatial scale

3.1. At which spatial scale do you consider "Krill flux" relevant for fishery management? Krill flux is defined as the movement of postlarval krill by advection or swimming from one area to another in terms of biomass (grams) per unit volume (m3) per second (s-1)
Please score each option: 0 (unlikely), 1 (low priority), 2 (medium priority) or 3 (high priority)

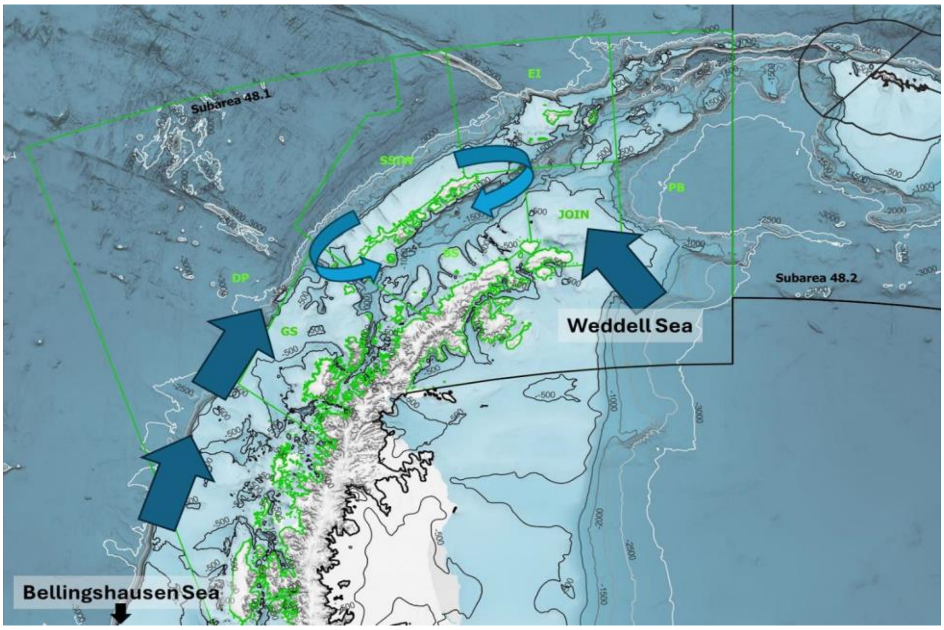
- Area 48 level – krill flux is relevant when considering the sources and pathways into each Subarea ___
- Subarea level – krill flux is relevant when considering connectivity between management units within a Subarea ___
- Fishing management unit level – offshore-inshore seasonal migration is more relevant in explaining changes in krill abundance than krill flux due to current advection ___



Subarea level

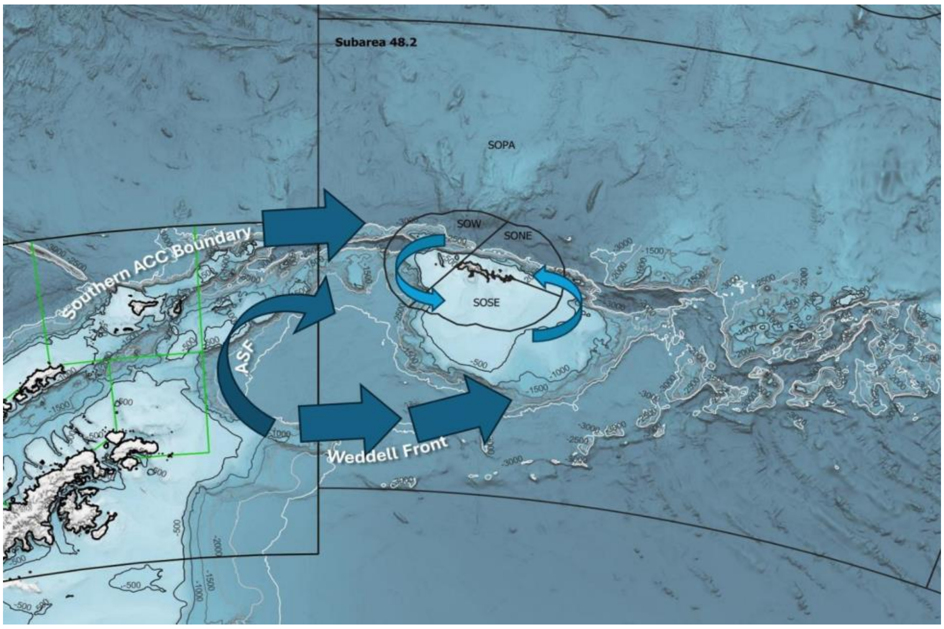
3.2. **Potentially significant sources and pathways of krill flux into <u>Subarea 48.1</u> are listed as (i)-(iii) below based on existing information.** Please identify how important each potential pathway is as a source of krill in Subarea 48.1: 0 (unlikely), 1 (low), 2 (medium) or 3 (high)

i. From Bellingshausen Sea northwards into the North WAP (West Antarctic Peninsula) through the SBdy (Southern ACC Boundary) (Moffat and Meredith 2018; SKEG 2023 report) ___
ii. From NW Weddell Sea carried by the CC (Antarctic Coastal Current) into the Bransfield Strait (maps from Thompson et al. 2009, Ferreira et al. 2020; SKEG 2023 report) ___
iii. There are no significant sources of krill flux; most recruitment comes from local sources ___



3.3. **Potentially significant sources and pathways of krill flux into <u>Subarea 48.2</u> are listed as (i)-(iii) below based on existing information.**
Please identify how important each potential pathway is as a source of krill in Subarea 48.2: 0 (unlikely), 1 (low), 2 (medium) or 3 (high)

i. From the northern South Shetland Is. through the SBdy (Southern ACC Boundary) (i.e., SKEG 2023 report) ___
ii. From NW Weddell Sea carried by WF (Weddell Front) and ASF (Antarctic Slope Front) (maps from Thompson et al.2009, Ferreira et al. 2020) ___
iii. There are no significant sources of krill flux; most recruitment comes from local sources ___



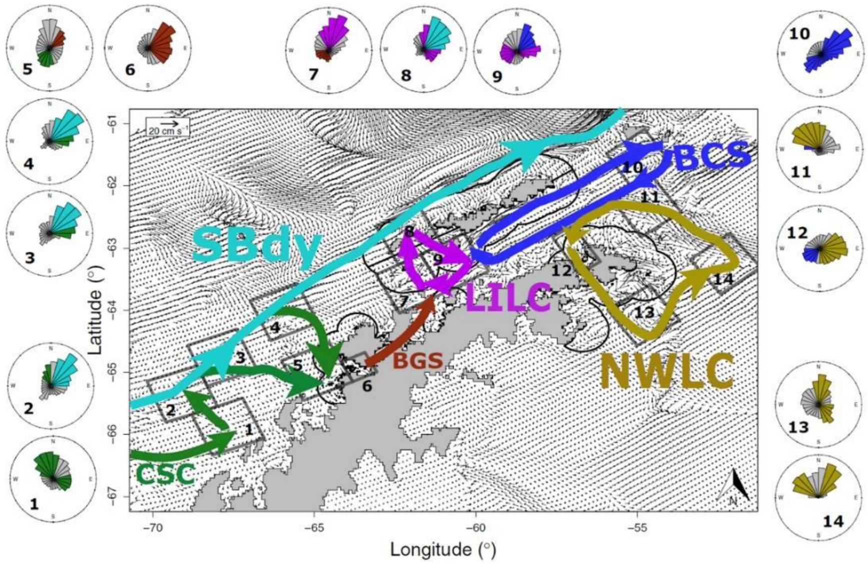
Krill Flux impact on management within Subarea 48.1

[Here the emphasis is on transport from one management unit of a Subarea into another of the same Subarea.]
CCAMLR has been focusing on Subarea 48.1 as an urgent priority for krill management, thus, only krill connectivity within this subarea is addressed here.

Before answering question 3.5. related to krill flux in the subarea 48.1, please review important information below (Gallagher et al. 2023). Six oceanic pathways that promote or inhibit connectivity are identified.

The following features with regard to connectivity are suggested:

- *SBdy facilitates the transport of krill from the Bellingshausen Sea to Gerlache Strait (GS), South Shetland Islands (SSI) and Elephant Island (EI)*
- *BCS helps retain krill in the Bransfield Strait (BS)*
- *LILC acts as a major barrier for krill entering BS from the GS*
- *NWLC helps retain krill within the North WAP region, and facilitates transport of krill to SSI, EI and BS*



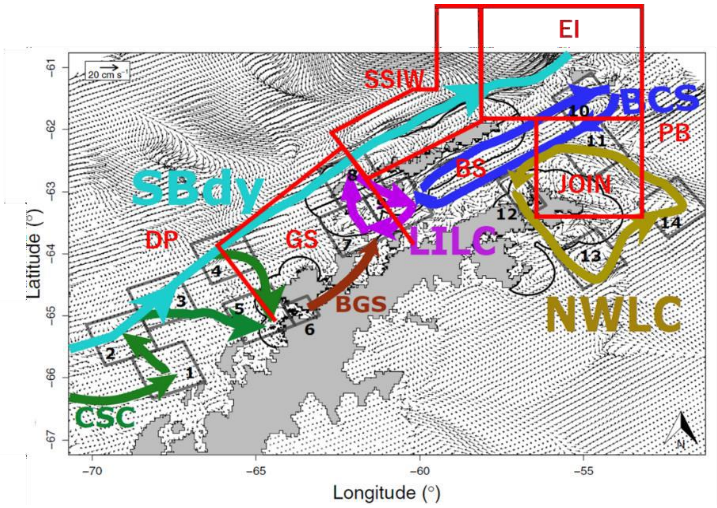


Figure. (above) Mean current velocities and directions illustrating persistent current features upper 150 m depth. (below) Krill management units are superimposed.

SBdy (Southern ACC Boundary), BCS (Bransfield Current System), NWLC (North WAP Loop Current), LILC (Low Island Loop Current), BGS (Bismarck and Gerlache Straits), and CSC (Cross Shelf Currents).

The Rose plots were used to illustrate the distribution of current directions at the intersections of these features.

3.4. Considering that major fishing areas are formed in management units SSIW (summer) and BS (winter), which krill fluxes and retentions are critical for management?

Please score each combination 0 (not important or no connection), 1 (low importance), 2 (medium importance) or 3 (high importance)

Table. Particle transport between units (blue colour fields) and particle retention in each unit (yellow colour fields)

					TO (destination)			
		DP	GS	SSIW	BS	EI	JOIN	PB
FROM (source)	DP							
	GS							
	SSIW							
	BS							
	EI							
	JOIN							
	PB							

3.5. **The presence of horizontal subsurface eddies, in which DVM can increase retention, is locally restricted in area 48.1 and not relevant for larger scale fluxes.**

☐ I disagree ☐ I agree ☐ I don't know

3.6. **Horizontal subsurface eddies, combined with the vertical migration behaviour of krill, are responsible for increased retention in Subarea 48.1, resulting in a self-sustaining krill population that could exist largely independent of inflow from other regions.**

☐ I disagree ☐ I agree ☐ I don't know

3.7. **At what temporal scale does krill flux become relevant for management?**

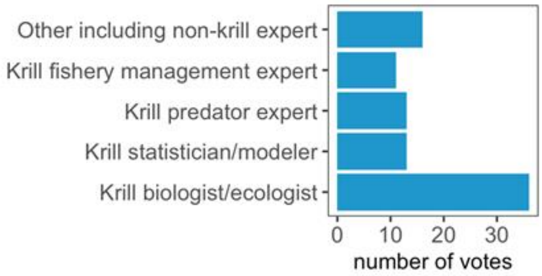
☐ Week ☐ Month ☐ Quarter ☐ Semester

☐ Year (e.g. different ENSO phases, positive/negative SAM)

Polling results

Intro: Question about your expertise

How do you describe your expertise?

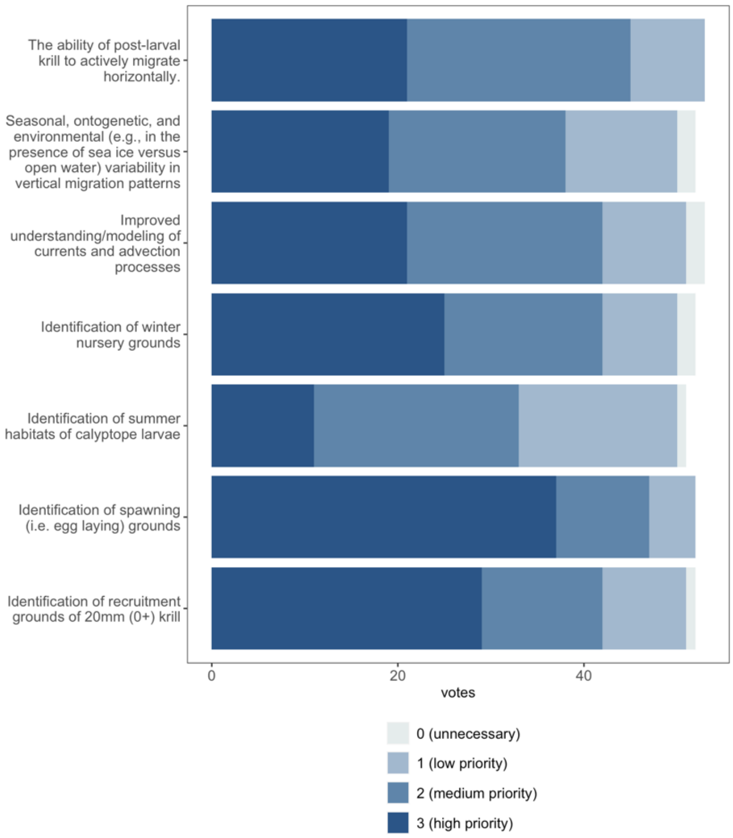


1. Questions to develop the Krill Stock Hypothesis (KSH) further

1.1. Which are the most important areas for data collection on the abundance and distribution of krill life stages, for further development of the KSH?

See Figure 1

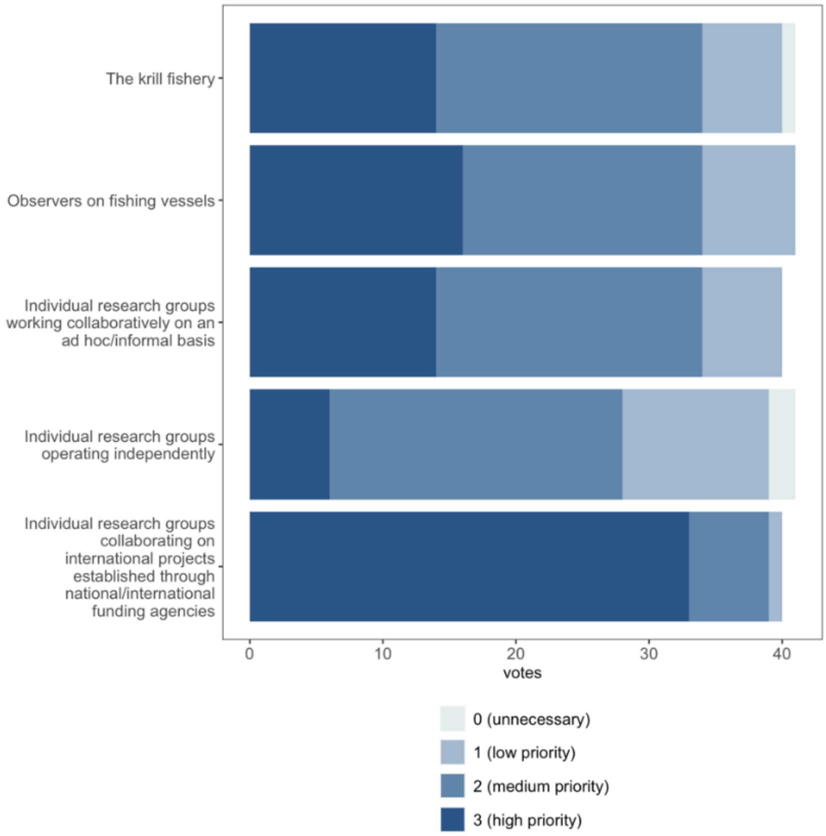
1.2. Which studies are needed to test the KSH?



1.3. What archived collections or datasets already exist that can be used to support the development and evaluation of the KSH?

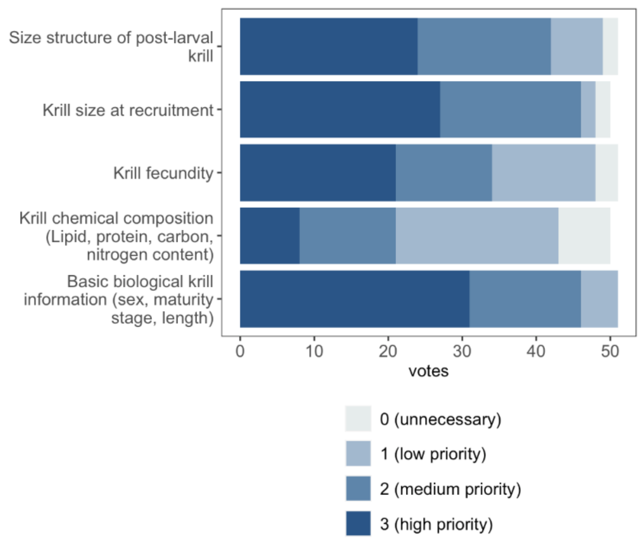
Open text field

1.4. From the list below, score who should collect the data needed to develop the KSH further?

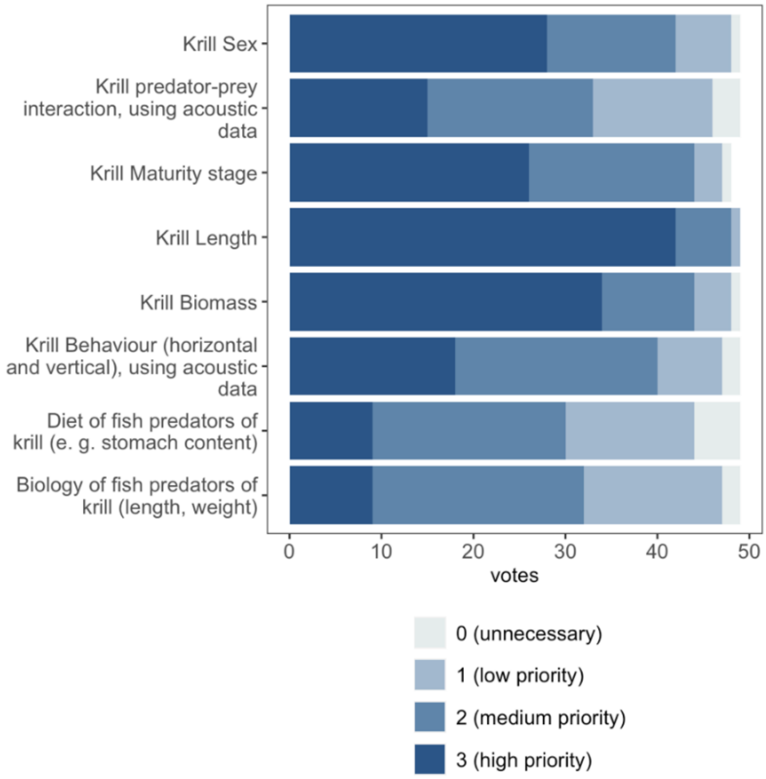


2. Monitoring the krill-based ecosystem

2.1. How important are the following parameters for continued (year after year) monitoring of the krill-based ecosystem?



2.2. What biological data should be monitored on krill fishing vessels for the KSH, spatially and temporally?



2.3. Which existing predator-derived data are most valuable to provide information on interannual changes in krill availability?

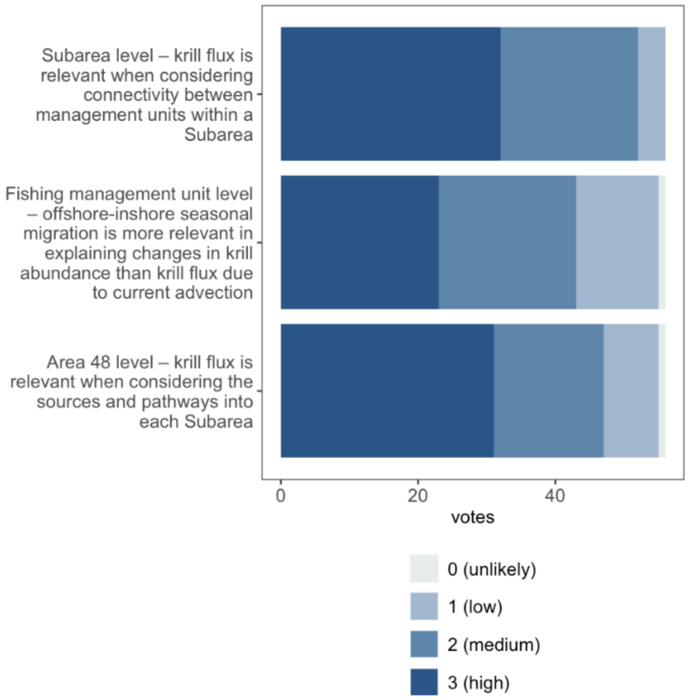
See Figure 2

2.4. Which existing predator-derived data are most valuable to provide information on longer-term changes in krill availability?

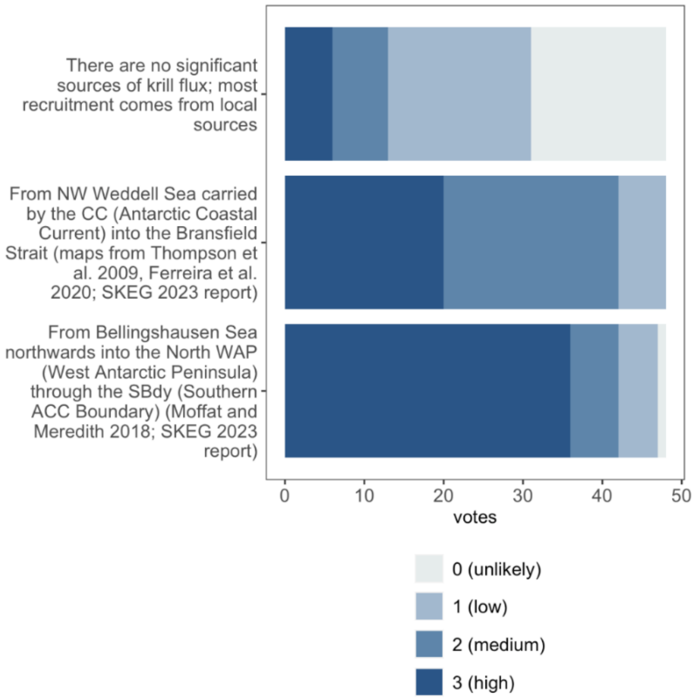
See Figure 2

3. Krill Flux – Which questions can be answered with existing data?

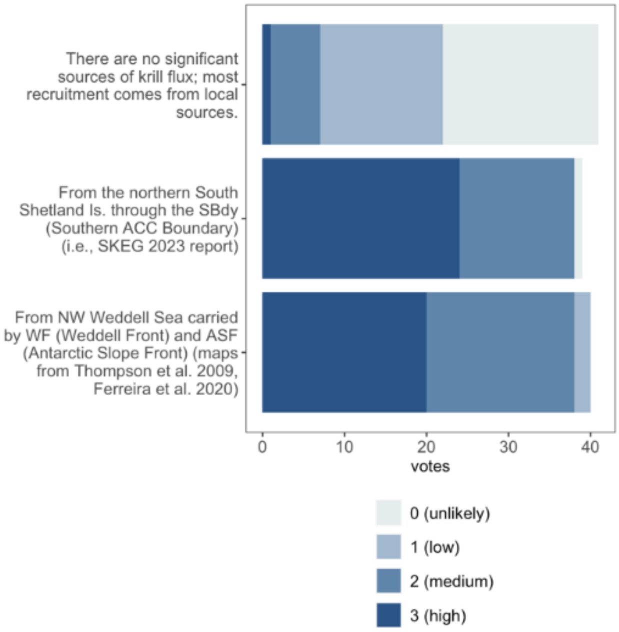
3.1. At which spatial scale do you consider "Krill flux" relevant for fishery management? Krill flux is defined as the movement of postlarval krill by advection or swimming from one area to another in terms of biomass (grams) per unit volume (m3) per second (s-1)



3.2. Potentially significant sources and pathways of krill flux into <u>Subarea 48.1</u> are listed as (i)-(iii) below based on existing information.



3.3. **Potentially significant sources and pathways of krill flux into <u>Subarea 48.2</u> are listed as (i)-(iii) below based on existing information.**



3.4. **Considering that major fishing areas are formed in management units SSIW (summer) and BS (winter), which krill fluxes and retentions are critical for management?**

Table. Particle transport between units (purple colour fields) and particle retention (green colour fields). Black fields indicate combinations of strata that do not neibour each other.

a) Mean Score

To (Destination) / From (Source)

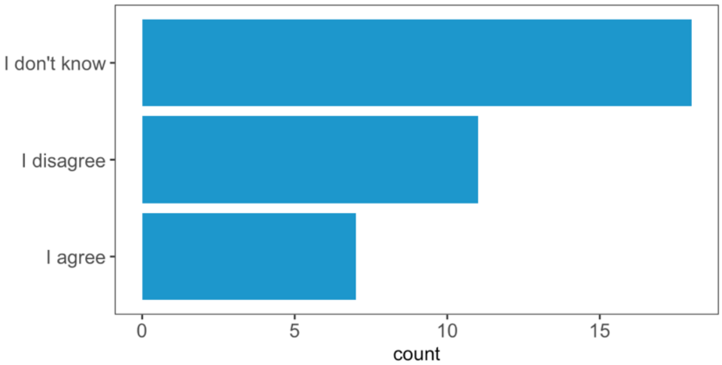
	BS	DP	EI	GS	Join	PB	SSIW
BS	2.62	1.12	2.38	1.94	2.31	2.13	1.97
DP	1.59	1.97	1.59	2.09	0.97	0.87	2.41
EI	1.84	1.06	2.27	0.79	1.84	1.90	1.53
GS	2.47	1.61	1.53	2.41	1.03	1.00	2.11
Join	2.32		2.09	0.79	2.41	2.62	0.81
PB	1.65	0.66	1.73	0.72	2.34	2.30	0.59
SSIW	2.00	1.64	2.50	1.55	1.21	1.40	2.19

b) Standard Deviation (SD)

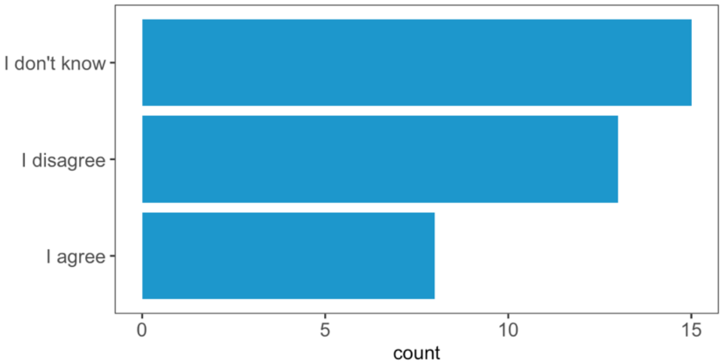
To (Destination) / From (Source)

	BS	DP	EI	GS	Join	PB	SSIW
BS	0.78	0.96	0.82	0.95	0.82	0.92	0.90
DP	1.01	1.18	1.02	0.98	0.95	0.85	0.70
EI	0.95	0.93	0.91	0.78	0.95	0.96	0.90
GS	0.75	1.03	1.05	0.82	0.91	0.97	0.90
Join	0.77		0.98	0.89	0.95	0.68	0.86
PB	1.08	0.83	0.88	0.77	0.83	1.07	0.80
SSIW	1.00	0.99	0.75	1.00	0.94	0.97	0.95

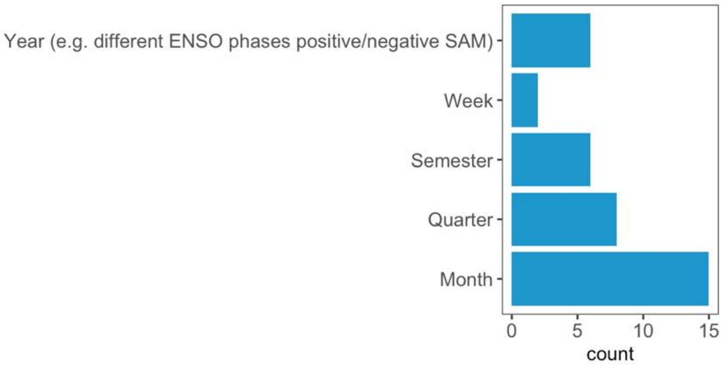
3.5. The presence of horizontal subsurface eddies, in which DVM can increase retention, is locally restricted in area 48.1 and not relevant for larger scale fluxes.



3.6. Horizontal subsurface eddies, combined with the vertical migration behaviour of krill, are responsible for increased retention in Subarea 48.1, resulting in a self-sustaining krill population that could exist largely independent of inflow from other regions.



3.7. At what temporal scale does krill flux become relevant for management?



Appendix III

List of presentations

Krill-related science talks:

Day 2	Presentation Title
Steve Parker	How decisions regarding data collection are made in CCAMLR (WGs, SC, Commission, Workshops)
Nicole Hellesey (ECR)	An Individual-Based Model (IBM) of Antarctic krill (*Euphausia superba*) swimming behaviour: From experimental observations to a working model
Christian Reiss	Seasonal variability in transport of krill-like Scatterers into Bransfield Strait resolved from an array of echosounders
Cecilia Liszka	Diurnal variability in the distribution of Antarctic krill (*Euphausia superba*) during austral winter
Angus Atkinson	Are we underestimating sources of krill from the Weddell Sea?
Lukas Hüppe (ECR)	A new Activity Monitor for Aquatic ZooplanktEr (AMAZE) allows the recording of swimming activity in wild-caught Antarctic krill (Euphausia superba)
Alison Cleary	Bottom-up control of mortality variation in Antarctic krill: insights from age-structured catch-at-length model
Day 4	**Presentation Title**
Fokje Schaafsma	New insights in krill biology from the multidisciplinary ecosystem survey by the Japanese research vessel Kaiyo-maru in CCAMLR Division 58.4.1 (2018/19)
Simeon Hill	Climate change implications for krill fishery management
Danilo Astorgagallano (ECR)	License to krill: a biogeophysical AI model to manage Krill Ecosystem in the Antartic Peninsula
Emilce Rombolá	Comparison of the density and distribution of krill larvae and salps densities during the summer seasons of 2019 and 2020 in the Mar de la Flota /Bransfield Strait and Elephant Island surroundings
Mei Xue (ECR)	Autumn Antarctic krill (*Euphausia superba*) in the Bransfield Strait shifts diets spatially- temporally
Aditya Sharma (ECR)	Variability in krill transport pathways
Sara Labrousse (ECR)	First post-moult crabeater seal deployments in East Antarctica: Antarctic krill studied by predators
Dominik Bahlburg (ECR)	Mapping encounters between krill fishing vessels and air-breathing krill predators
Sisong Dong (ECR)	Bottom-up control of mortality variation in Antarctic krill: insights from age-structured catch-at-length model