Evaluating change within the krill-based food web and developing solutions for the future sampling of krill

REPORT OF the online SCAR Krill Action Group (SKAG) workshop, 26-30 April 2021

v 12 May 2021 final

Organising committee:
Angus Atkinson
Bettina Meyer (SKAG chair)
So Kawaguchi (SKAG co-chair)
Simeon Hill
Javier Arata (ARK)
Ryan Driscoll
Jack Conroy
Frances Perry
Keith Reid (CCAMLR)
Rhona Kent (WWF host)
Caroline Coch (WWF host)

Summary: The SCAR Krill Action Group (SKAG) provides a conduit for science to feed into the management of the Antarctic krill fishery, as well a more general forum to promote collaboration, help early career researchers, improve understanding of krill biology and ecology, and facilitate information exchange. From 26-30 April 2021 SKAG held a workshop, as a series of five zoom meetings, each of 2 hours, to help achieve these goals. The workshop was hosted and financed by WWF and was attended by around 100 participants each day from 19 countries. The workshop comprised 16 science talks summarising the current state-of-the-art of both traditional and emerging methods to sample and analyse krill, focusing on their ability to observe spatio-temporal change within the krill-based food web. This workshop report summarises the initial findings of the workshop; shares the talk abstracts; results of zoom-polling questionnaires including the early career researcher component; and shows results of the exercises.

In summary, this online workshop included sufficient participation to represent the weight of expert opinion of the current krill research community. The talks were multi-authored, also providing the required breadth of perspective - our feedback was that this was particularly welcomed among the ECR community. The numbers attending also provided sufficient sample size for zoom polling; this showed a strong appetite for change in how science was linked to krill fishery management. Change was thought to be best achieved through both the provision of data and improved communication with management, underscoring the relevance of SKAG. Understanding the controls on krill recruitment emerged consistently as a clear priority research topic, with identification of spawning hotspots also a priority in the context of management and conservation over shorter timescales. We had sufficient response (33 replies) for the exercises aimed at a) evaluating longer-term change in krill populations and b) mapping the suitability of old and new sampling methods onto research questions. We are still collating a large response on the former, and this will form one of the sections for the paper that will emerge from this workshop. The second, method mapping, exercise showed consensus that newer methods were particularly valuable to detect change and observe krill behaviour at smaller scales of space and time, but that "traditional" nets and acoustics from research vessels remain hard to replace for longer term-issues such as recruitment variability. This throws down challenges for future krill sampling, through a combination of multiple, complementary and emerging approaches. In addition to the new and emerging approaches described in this workshop, a combined approach to *Euphausia superba* dynamics will involve data provided by predators, the fishery itself, the fishery as a scientific platform, alongside the continuation of traditional approaches.

1. Scientific presentations

We thank the presenters of the 16 science talks as well as their co-authors for providing a great overview of methods by which krill are sampled and analysed, seasoned by illustrations of some key results and modern findings.

Monday session - Introduction
Introduction: science background, workshop activities and outputs

(*from members of the SKAG committee*)

The krill fishery and its management (*So Kawaguchi & Keith Reid*)

Changes in Southern Ocean environment that may impact on krill and the krill food web *(Andrea Piñones & Eugene Murphy)*

Tuesday session – Understanding change: from millennia to decadal scales [Past series]
Reconstructing long-term changes in krill availability using isotopic and paleo- reconstructions (*Michael Polito)*

Using scientific nets to understand changes in krill abundance

(Jack Conroy & Franki Perry)

Ship-based acoustic time series and surveys (*Sophie Fielding & Christian Reiss*)

Wednesday session – Predators and the Fishery as sampling tools
Monitoring foraging and diet of krill predators, to examine changing krill availability over time (*Jefferson Hinke & Jaume Forcada*)

Using fisheries to provide data on krill *(Lucas Krüger & Javier Arata)*

Changes in krill recruitment and population structure (*Devi Veytia & Simeon Hill*)

Thursday session – New sampling techniques
Use of moored instrumentation for krill studies (*Hyoung Sul La & Ryan Saunders*)

Instrumented predators to examine krill (*Luis Huckstädt & Akinori Takahashi*)

Developments in under ice krill sampling (*Ryan Driscoll, Bettina Meyer*)

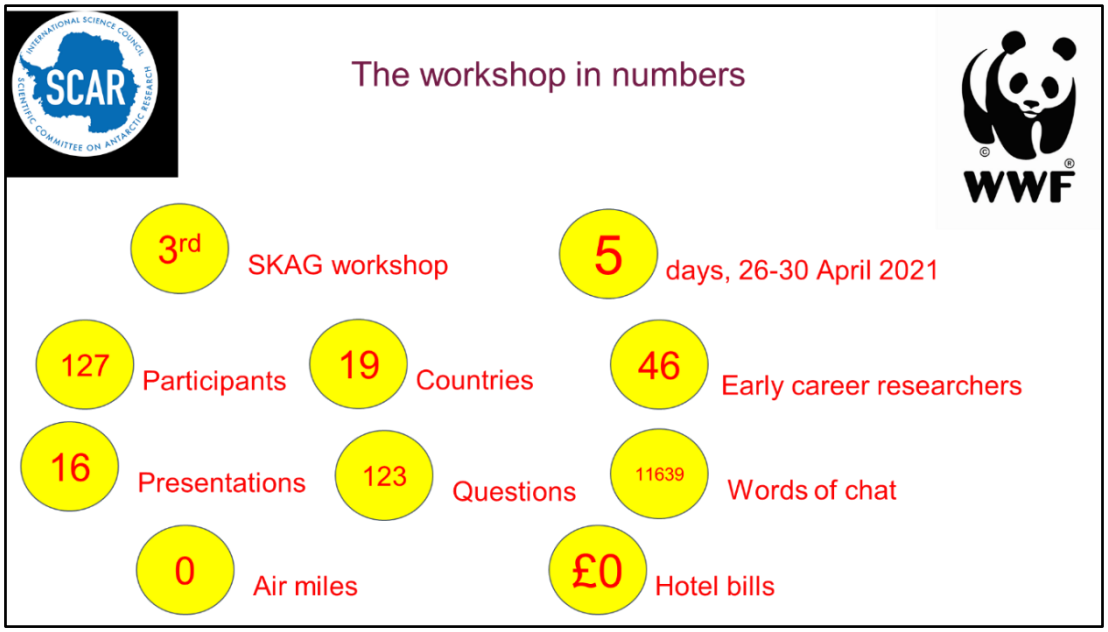
Remote sensing of surface krill swarms (*Anna Belcher, Geraint Tarling*)

Friday session – Emerging techniques and conclusion remarks
Lowered cameras and direct krill observation (*Mary Kane*)

Gliders and AUVs (*Kim Bernard & George Watters*)

Tracing Krill diet and resource allocation (*Katrin Schmidt & Guang Yang*)

The talks throughout the week were interspersed with zoom polling questionnaires (section 2), “homework” exercises (section 3) and short announcements (namely a short presentation by Rodolfo Werner on the Antarctic Wildlife Research Fund, and an announcement of the forthcoming ICED modelling workshop by Devi Veytia).

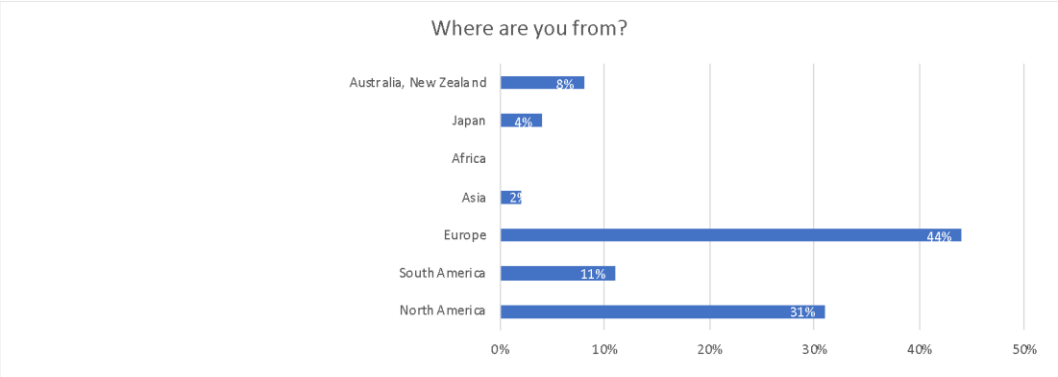


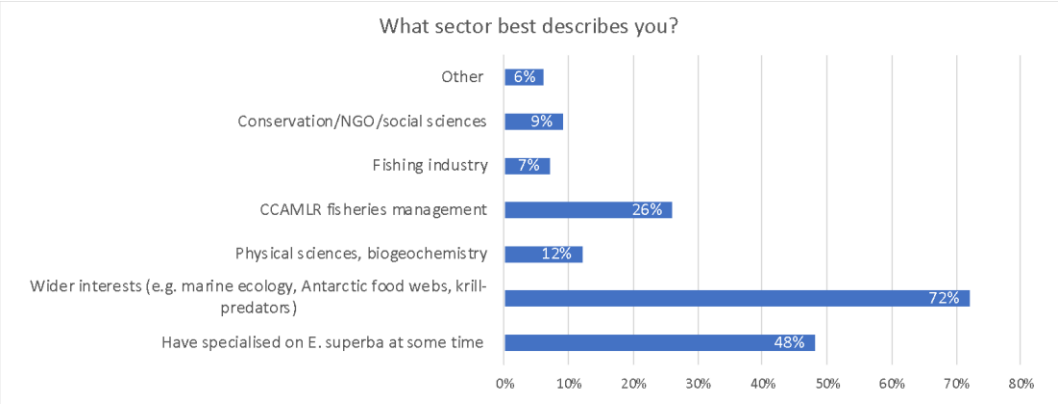
2. Zoom polling questionnaires.

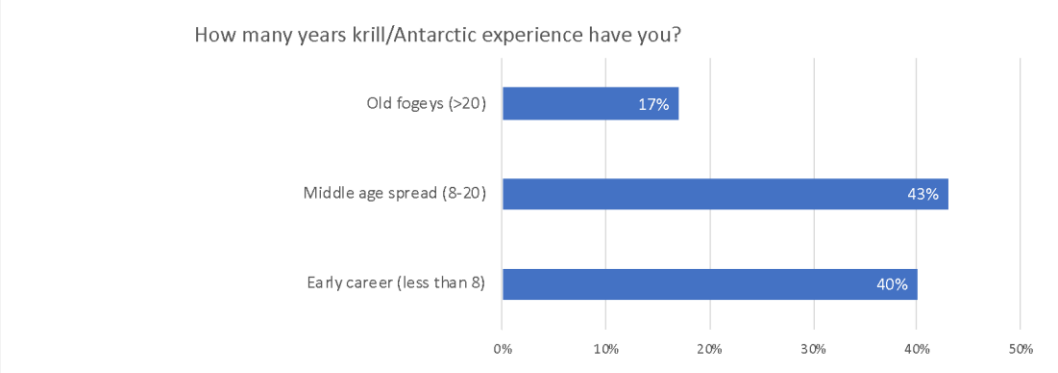
Initial polling via zoom was used to establish the scientific background, career stage and skills of the participants. Please note that in some of these polls, the percentages do not add up to 100% since participants were allowed to tick several boxes in these polls, in which case the percentages refer to the fraction of participants voting for each option.

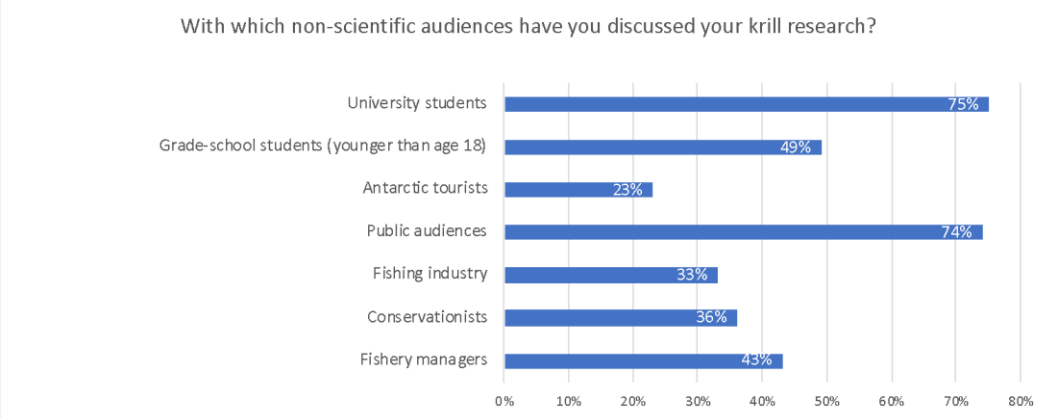
2.1 Zoom polling: background information of participants

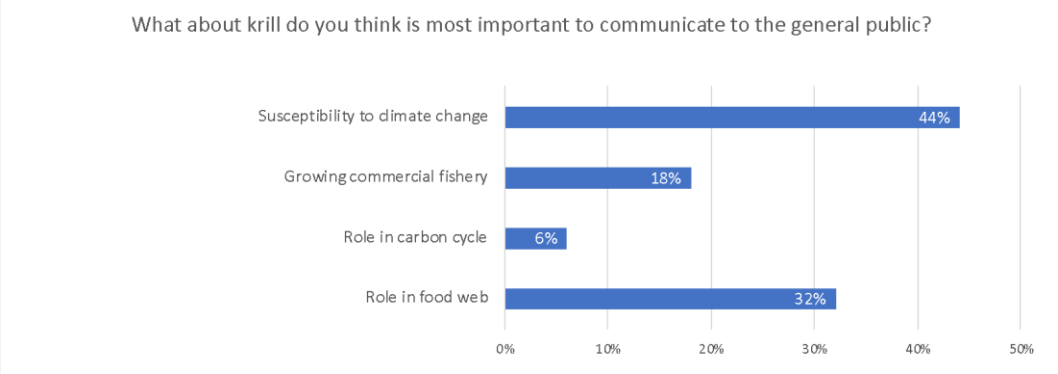
The participants at the daily sessions (13:00-15:00 GMT) averaged about 100 at any one time and were from around the world (mainly Europe, North America and South America) of which about 40% were Early Career Researchers (ERCs). Whilst this was designed as mainly a scientific workshop, the participants had a very diverse working background ranging from general marine ecologists, krill-related Southern Ocean research through to krill specialists and CCAMLR fisheries management, and conservation NGOs. The largest motivation to attend the workshop was to better understand changes in the krill-based food web and this was followed by discussing relevant information on the implications of krill ecology for management and to improve networking among the krill related community.

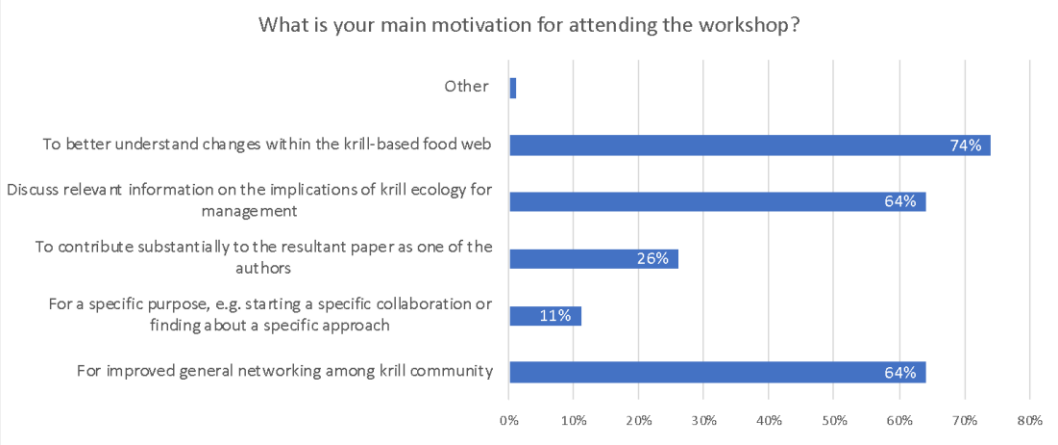

Where are you from?
Australia, New Zealand
8%
Japan
4%
Africa
Asia
2%
Europe
44%
South America
11%
North America
31%
0%
10%
20%
30%
40%
50%


What sector best describes you?
Other
6%
Conservation/NGO/social sciences
9%
Fishing industry
7%
CCAMLR fisheries management
26%
Physical sciences, biogeochemistry
12%
Wider interests (e.g. marine ecology, Antarctic food webs, krill-predators)
72%
Have specialised on E. superba at some time
48%
0%
10%
20%
30%
40%
50%
60%
70%
80%


How many years krill/Antarctic experience have you?
Old fogeys (>20)
17%
Middle age spread (8-20)
43%
Early career (less than 8)
40%
0%
10%
20%
30%
40%
50%

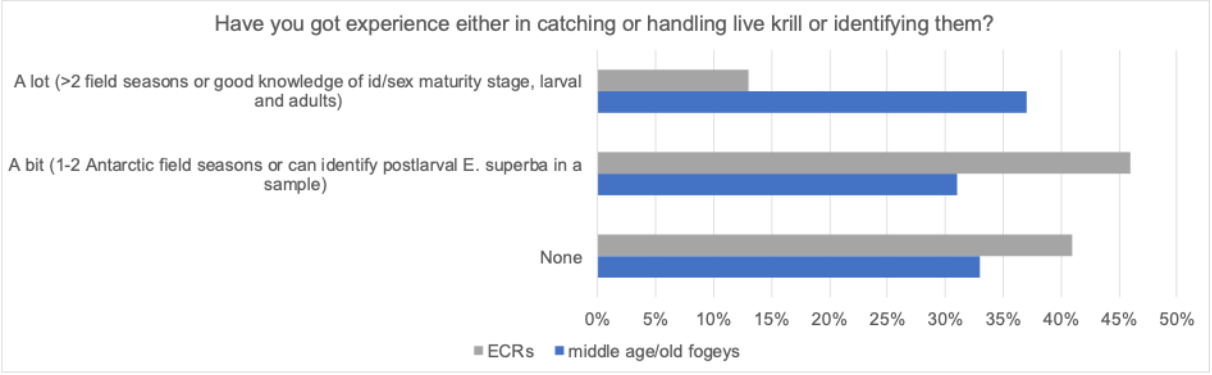

With which non-scientific audiences have you discussed your krill research?
University students
75%
Grade-school students (younger than age 18)
49%
Antarctic tourists
23%
Public audiences
74%
Fishing industry
33%
Conservationists
36%
Fishery managers
43%
0%
10%
20%
30%
40%
50%
60%
70%
80%

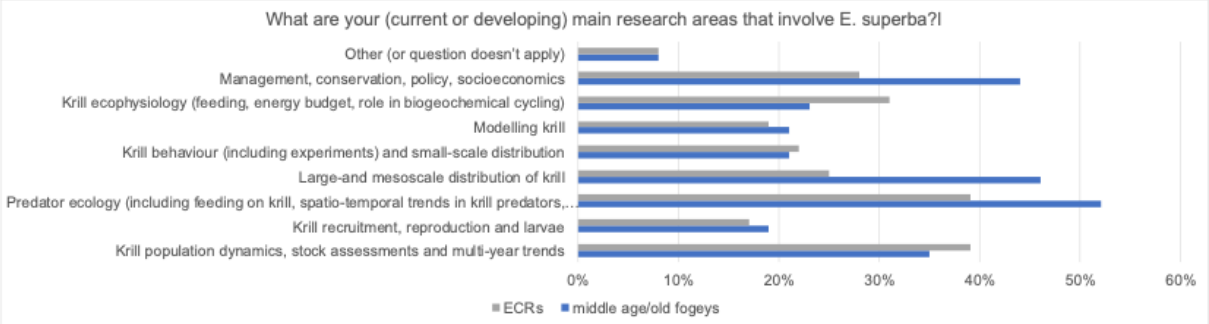


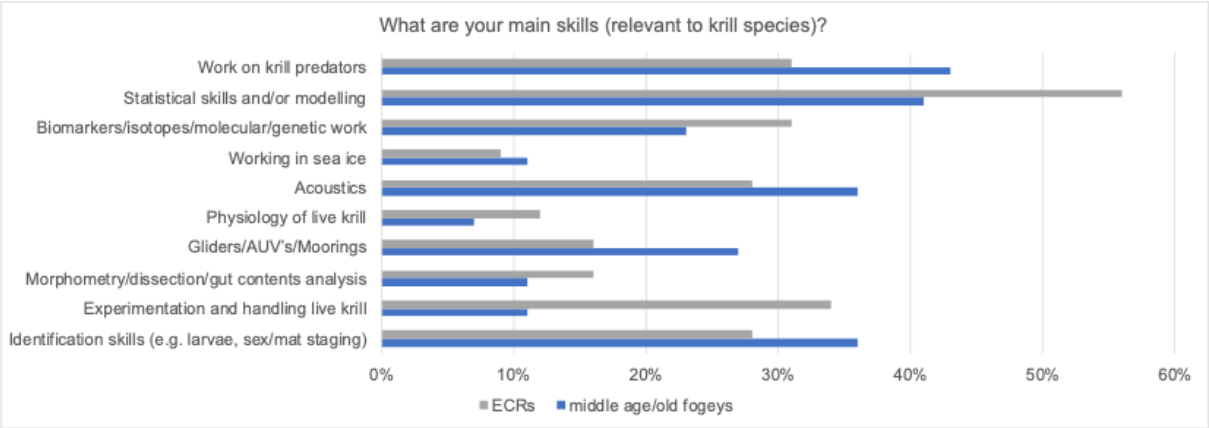


2.2. Zoom polling: skills in relation to career stage

From the around 100 participants voting on Monday, about 40% were Early Career Researcher (ECRs). The ECRs are mainly involved in research that focus on krill population dynamics, predator ecology and krill physiology, respectively, closely followed by conservation and management. The research of the middle and later career stage participants focusses mostly on predator ecology, large and mesoscale distribution, followed by management and conservation. The main skills of the ECR are by far dominated by statistics and modelling, whereas in the middle/old age classes it is the work on krill predators, followed by statistics, modelling and acoustics.

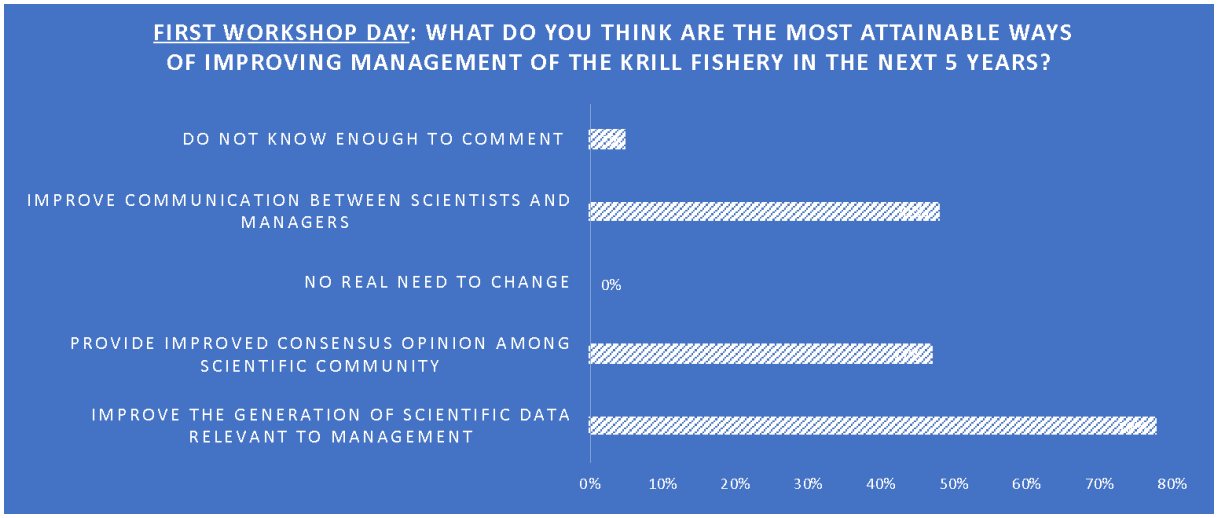


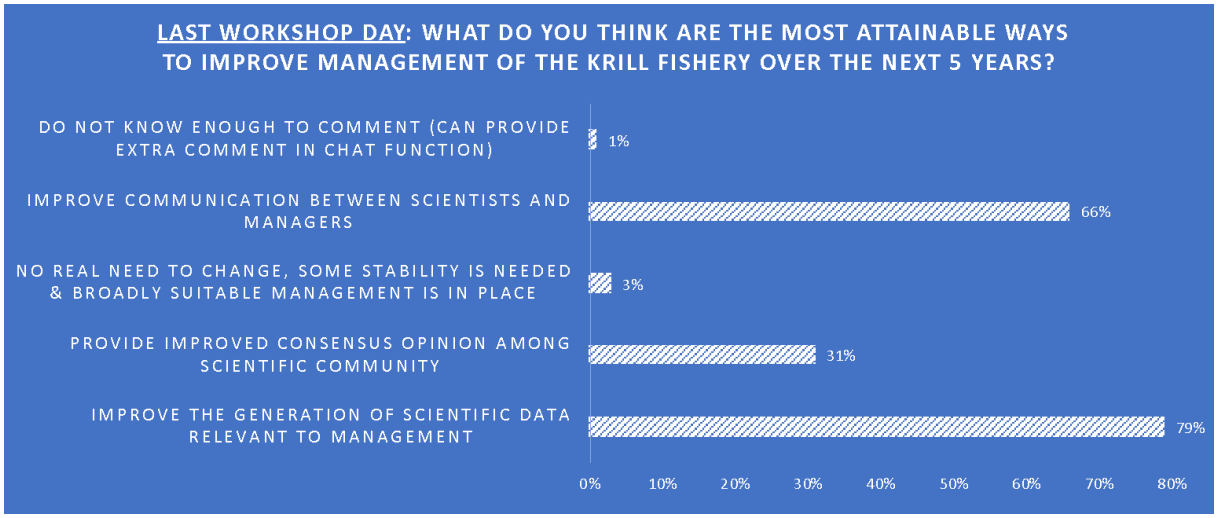


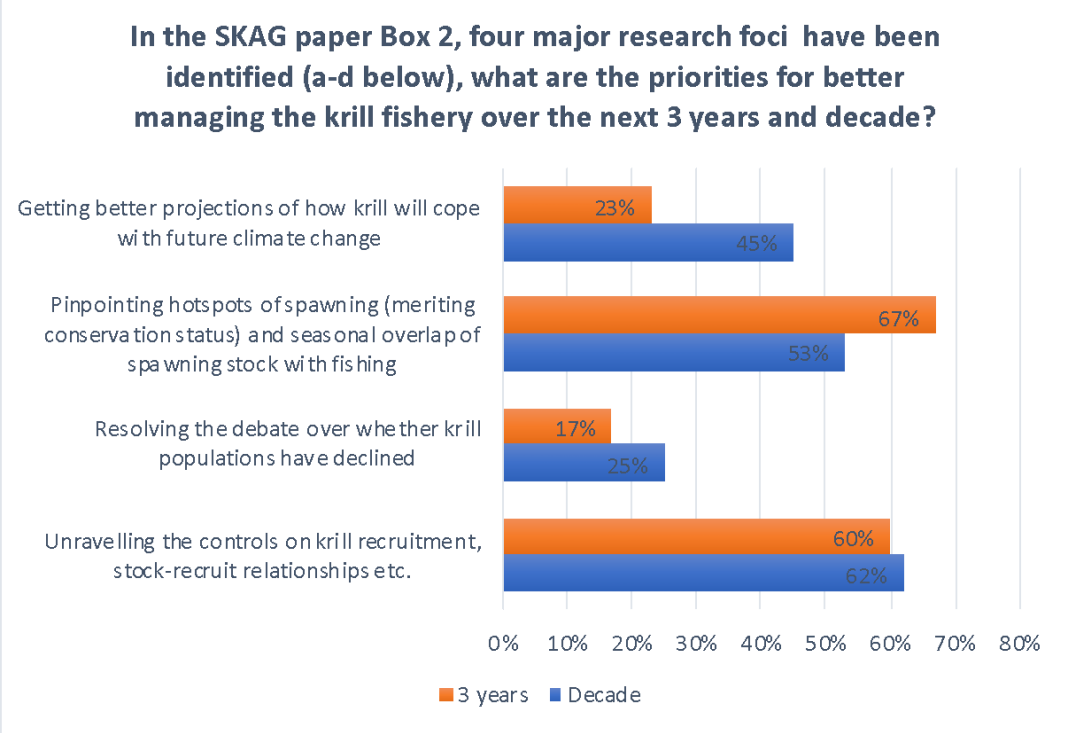


2.3. Zoom polling: Priority science needs for improved krill fishery management

The majority of participants agreed that, over the shorter term (i.e. in the next 5 years), we need to improve the generation of scientific data relevant to krill fishery management and the communication between scientists and managers, respectively. Regarding the 4 main research foci that were identified as priorities to improve management by Meyer et al (2020) *Commun Earth Environ* **1,** 28 (2020). https://doi.org/10.1038/s43247-020-00026-1, the majority of participants thought that, on a time scale of 3 years, pinpointing hotspots of spawning and seasonal overlap of spawning stock with fishing has the highest priority followed by unravelling the controls on krill recruitment. Even on a time scale of a decade, these research topics achieved the highest priority. For a wider understanding of how the krill-based food web operates, krill recruitment remained a priority issue to understand, according to the ~100 participants, alongside better projections of how krill will cope with future climate change.

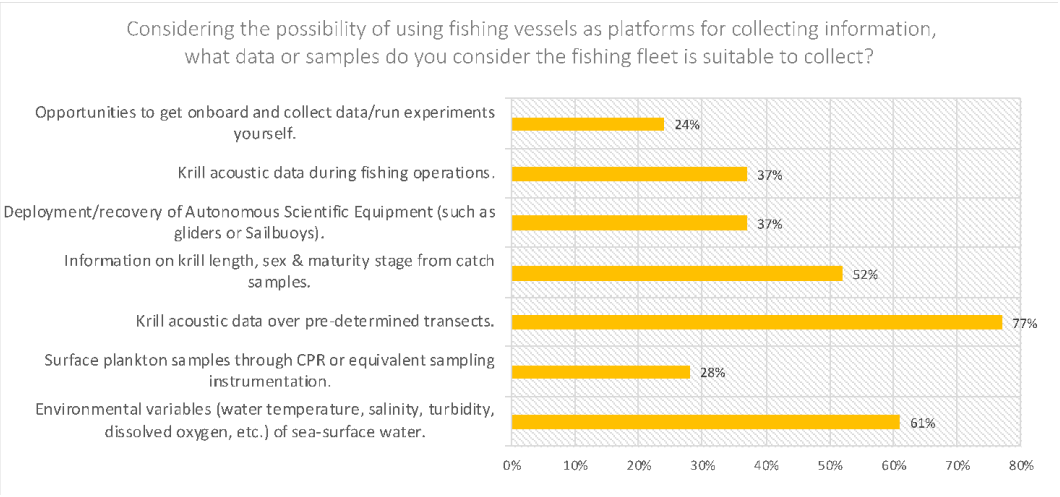


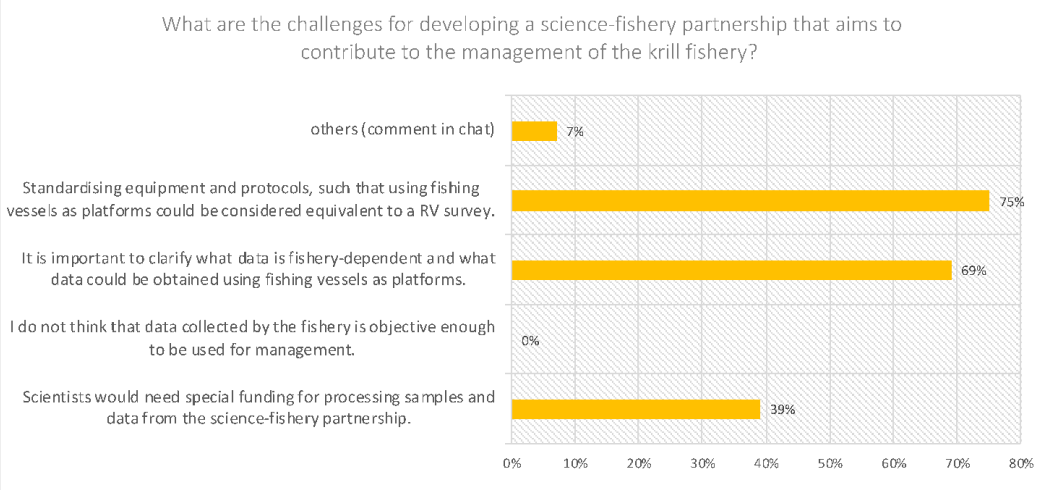

LAST WORKSHOP DAY: WHAT DO YOU THINK ARE THE MOST ATTAINABLE WAYS TO IMPROVE MANAGEMENT OF THE KRILL FISHERY OVER THE NEXT 5 YEARS?
DO NOT KNOW ENOUGH TO COMMENT (CAN PROVIDE EXTRA COMMENT IN CHAT FUNCTION)
1%
IMPROVE COMMUNICATION BETWEEN SCIENTISTS AND MANAGERS
66%
NO REAL NEED TO CHANGE, SOME STABILITY IS NEEDED & BROADLY SUITABLE MANAGEMENT IS IN PLACE
3%
PROVIDE IMPROVED CONSENSUS OPINION AMONG SCIENTIFIC COMMUNITY
31%
IMPROVE THE GENERATION OF SCIENTIFIC DATA RELEVANT TO MANAGEMENT
79%
0% 10% 20% 30% 40% 50% 60% 70% 80%

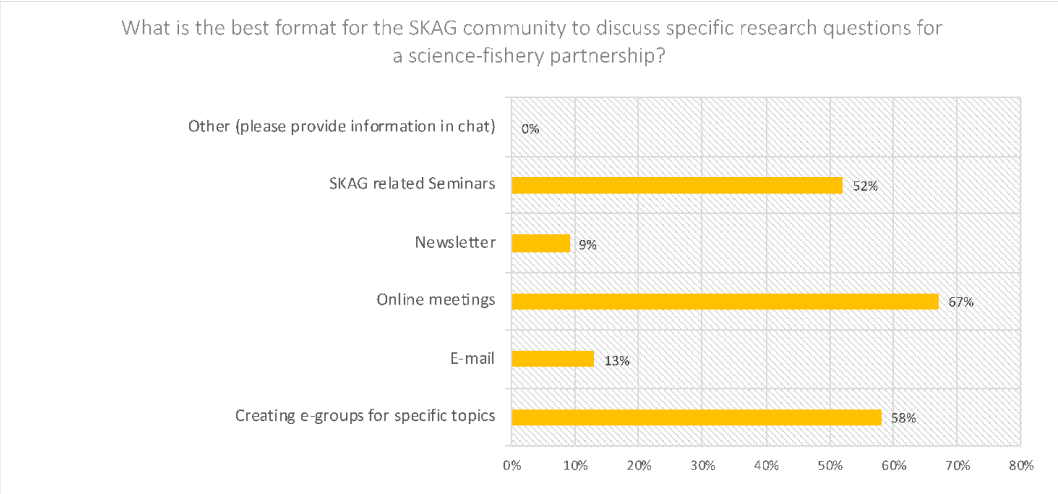

In the SKAG paper Box 2, four major research foci have been identified (a-d below), what are the priorities for better managing the krill fishery over the next 3 years and decade?
Getting better projections of how krill will cope with future climate change
23%
45%
Pinpointing hotspots of spawning (meriting conservation status) and seasonal overlap of spawning stock with fishing
67%
53%
Resolving the debate over whether krill populations have declined
17%
25%
Unravelling the controls on krill recruitment, stock-recruit relationships etc.
60%
62%
0% 10% 20% 30% 40% 50% 60% 70% 80%
3 years
Decade

2.4 Zoom polling: Science-Fishery partnership

In general, the majority of participants were in favour of linking science and fisheries to improve management. However, two issues were identified as a challenge for developing a science-fishery partnership, 1. use of standardized equipment and protocols to generate data comparable between those collected on fishing and research vessels and 2. having clarity on what comprises fishery-dependent data and how fishery independent data could be obtained using fishing vessels as platforms. Three most important data were identified as being suitable for the fishing fleet to collect: Krill acoustic data over pre-determined transects, environmental data, and Information on krill length, sex and maturity stage from catch samples. The Workshop considered best formats to discuss research questions related to science-fishery partnership are online meetings, e-groups and SKAG related seminars.







3. Homework exercises

Homework exercises involved populating two tables, the first being adding entries or comments onto a table showing evidence for and against changes in krill stocks within the Southern Ocean. The evidence was grouped in the table according to timescale of measurements (century scale, within the last 50 years, or and since the 1990s) and according to the sampling method used (acoustics, nets and predators). We had about 30 responses with comments/additions to our initial table and are collating these to include as a table in the workshop paper. We had 33 usable responses to the second homework table: mapping sampling methods onto krill research areas (see Table below). We are particularly grateful to all those who took the time to return these tables to us, as it provides a good cross section of opinion on these tricky topics, providing a valuable consensus view.

3.1 Mapping established and developing krill sampling methods onto some of the key current research areas

Methods of sampling krill are diverse and with a wide variety of backgrounds among those studying the species or its predators, perspectives differ radically on suitable ways of sampling them. Evaluating these sampling methods was one major strand of the workshop, and another was evaluating priority areas of krill research to enhance management. To bring these strands together, participants were requested, as a homework exercise, to populate the table below that maps various methods of sampling and analysing krill (covered by the talks during the workshop) onto some of the key areas in current krill research. The question posed was:

"***Which of the existing and developing methods do you think will, by 2025, provide useable inferences on these aspects of* E. superba*?"***

Requested responses for each cell were whether the methods were usable/useful or whether this should be qualified (with a question mark). Remaining blank cells signified that the method was not currently thought appropriate. We received 33 responses from a variety of researchers spanning discipline areas, career stage and experience. Thanks very much for taking the time to do this. The 3

response types above were scored as 2 (Useable), 1 (Useable?) or 0 (blank cell) and the scores were summed per cell. We received a wide variety of opinions and the colour coded results table below shows the total scores for each cell. Cell score totals (shown in the table below) ranged from 0 to 65 of a total of 66, and are colour-coded as below:

< 20	20-29	30-39	40-49	50-59	60-66

Measurement	Long-term, large scale……Inference it provides on krill…….. Small scale						
	Long-term stock trajectory	Large-scale Distribution (meso, basin, circumpolar scale)	Recruitment long-term (multi-decadal) trends	Changing availability to predators	Inference on how the krill-based food web operates	Behaviour, Swarming, seasonal-to decadal and vertical distribution	Growth reproduction, energy budget, biogeochem. role
Population genetics	20	18	12	11	17	4	13
Paleo- isotopes and other proxies	28	14	7	31	37	1	15
Net-sampling	45	59	62	40	40	47	52
Ship-born acoustics	50	65	22	53	29	61	14
Predator diets & foraging indices	26	32	42	55	53	24	21
Fisheries data: catch/effort/position	28	37	18	24	11	21	5
Fisheries data: observer pop structure	24	18	48	23	18	16	36
Fisheries data: acoustic info	31	39	16	24	16	44	2
Moorings, in situ instrumentation	24	19	22	30	27	47	20
Instrumented predators	7	34	15	59	46	47	9
Under ice sampling/observation	7	16	27	31	46	58	43
Gliders, AUVs	20	54	13	38	26	56	7
Lowered cameras	0	4	9	21	27	59	14
Earth observation	12	33	7	16	5	17	2
Trophic markers	4	6	9	34	55	12	56

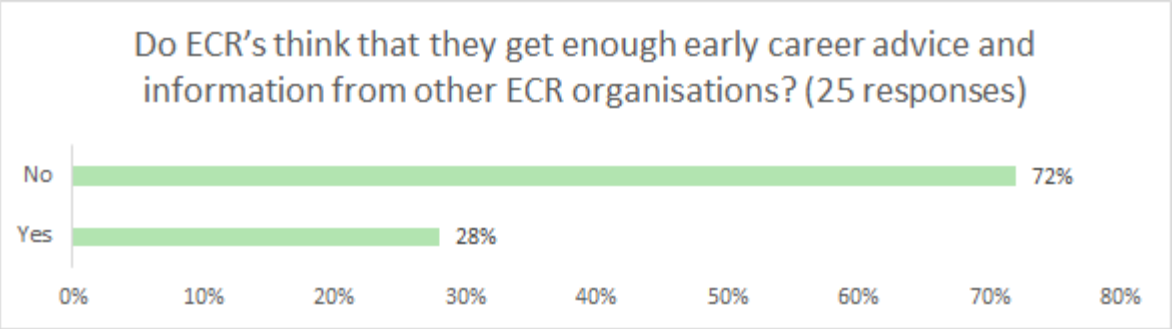
Opinions on method suitability differed often radically across researchers, with ECRs generally much more optimistic about method suitability than more experienced researchers. A couple of the Methods (e.g Earth Observation) were slightly ambiguously worded (apologies, we meant EO of krill swarms). One result emerging from this exercise is that all the various methods provide valuable, complementary information about krill and the krill-based food web at different scales, with many of the newer methods better at smaller time and space scales. Some of the more traditional methods provide key information over larger time- and space scales, posing challenges as to how fisheries platforms and other developing methods will provide this kind of information into the future. The more detailed workshop outputs will combine this table with some of the zoom polling results to provide an index of the current state of expert opinion on krill sampling.

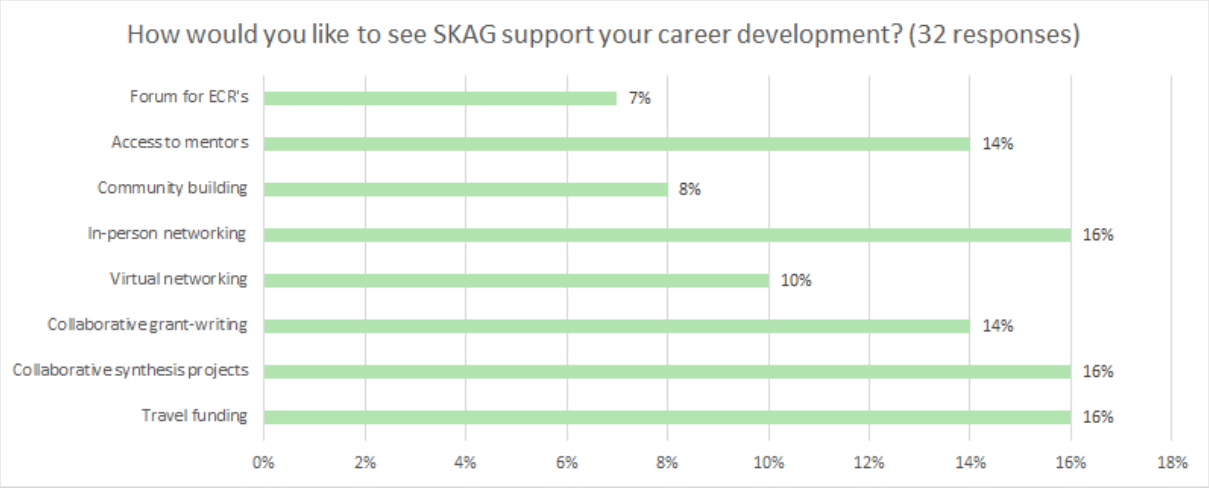
4. Early Career Researcher session

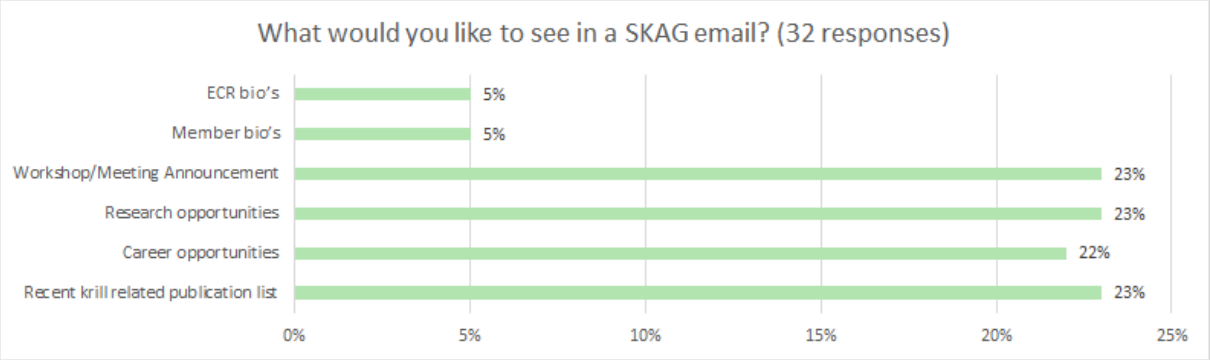
Section 2.2. compares research areas of ECR and more experienced researchers. Of the 40% of workshop respondents who identified themselves as ECR's (< 8 years of Antarctic/krill experience), 13% considered themselves to have a lot of experience of catching, handling or identifying krill. In contrast 41% responded that they had no experience in the Antarctic or with krill. The most common ECR skill is the use of modelling or statistics followed by the experimentation and handling of live krill. Experience of working in sea ice and understanding of the physiology of live krill were the two rarest skills. ECR's had almost as much experience of working on krill predators as they had of experimentation and handling live krill. This is reflected in the main research areas being studied by ECR's which are krill population dynamics, stock assessments and multi-year trends and predator ecology which both had 17% of ECR's selecting.

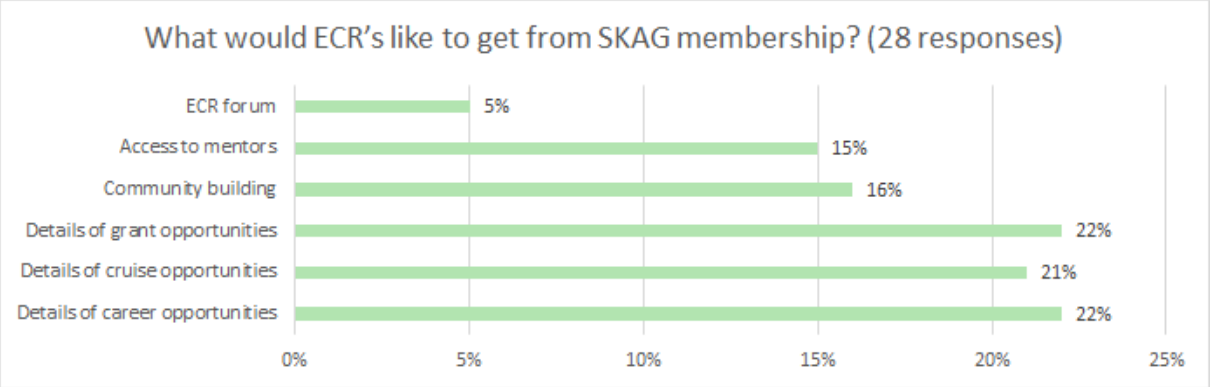
Summary of responses from the Friday ECR session

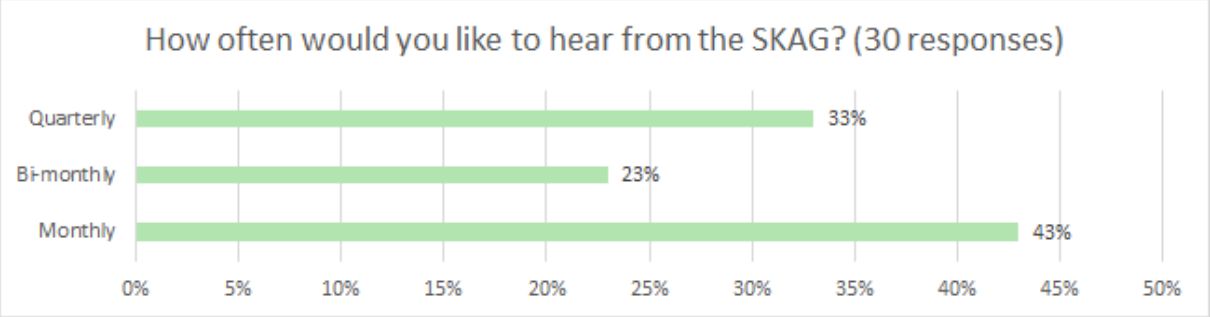
ECR's in general do not feel that they receive enough early career advice and information from other ECR organisations. Specifically, ECR's would like SKAG to support their career development through in-person networking, collaborative synthesis projects and travel funding. Access to mentors and collaborative grant writing are also important areas where ECR's would like support. Unanimously ECR's would like to be added to an email list through which they can find out about future workshops, conferences and meetings, research and career opportunities and get links to recent krill research on a monthly basis. They would also like access to a seminar series given by more senior SKAG members.

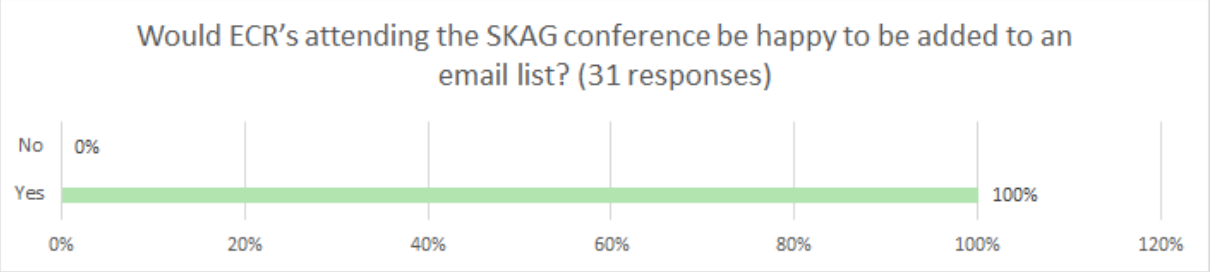


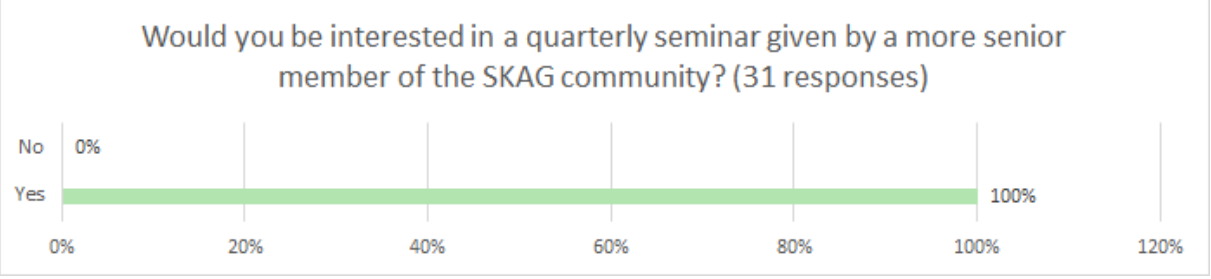



What would you like to see in a SKAG email? (32 responses)
ECR bio's
Member bio's
Workshop/Meeting Announcement
Research opportunities
Career opportunities
Recent krill related publication list
5%
5%
23%
23%
22%
23%
0%
5%
10%
15%
20%
25%


What would ECR's like to get from SKAG membership? (28 responses)
ECR forum
Access to mentors
Community building
Details of grant opportunities
Details of cruise opportunities
Details of career opportunities
5%
15%
16%
22%
21%
22%
0%
5%
10%
15%
20%
25%


How often would you like to hear from the SKAG? (30 responses)
Quarterly
Bi-monthly
Monthly
33%
23%
43%
0%
5%
10%
15%
20%
25%
30%
35%
40%
45%
50%


Would ECR's attending the SKAG conference be happy to be added to an email list? (31 responses)
No
Yes
0%
100%
0%
20%
40%
60%
80%
100%
120%


Would you be interested in a quarterly seminar given by a more senior member of the SKAG community? (31 responses)
No
Yes
0%
100%
0%
20%
40%
60%
80%
100%
120%