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COMMENTARY

# Research on climate-change impact on Southern Ocean and Antarctic ecosystems after the UN Paris climate conference—“now more than ever” or “set sail to new shores”?

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**Abstract** The *Paris Agreement*, being the main result of the COP21 UN climate conference in 2015, included the ever most clearly defined political statement on anthropogenic climate change and the need for it to be reduced. In an opinion survey, Antarctic ecosystem researchers expressed their views, in which direction science should develop, after their mission to provide evidence for the existence of anthropogenic climate change and its impacts is accomplished. Four options for answers were offered. The majority voted in support for research for a better ecosystem understanding under climate change, since overarching questions seem to not yet be sufficiently answered. Applied research for mitigation received an intermediate amount of support. Similar amount of support was received for no changes in research strategies. This might be a result of an already existing lively progression of new developments, but might also be due to some old and burning questions, which still remain unanswered, e.g. on the Southern Ocean acting as a biological $CO_2$ sink. Fewest experts thought that scientists should define totally new scientific themes. The results were also analysed separately for different groups of respondents in terms of stage of career, employing institutions (mission orientated or independent), and terrestrial or marine scientists. New student courses and university degrees are proposed, since new requirements by stakeholders demand new research strategies but traditional academic education and creativity is also still needed.

**Keywords** Opinion survey · Novel research developments · Ecosystem understanding · Mitigation

## Introduction

The outstanding result of the *21st Conference of the Parties* (COP21) of the *United Nations Framework Convention on Climate Change* (UNFCCC) in November 2015 in Paris was the first ever legally binding aim to limit warming of the global atmosphere. The *Paris Agreement* is based on the most widely ever accepted agreement among policymakers that anthropogenic climate change exists: “The *Conference of the Parties*, …recognizing that climate change represents an urgent and potentially irreversible threat to human societies…decides to adopt the Paris Agreement. This Agreement, …, aims to strengthen the global response to the threat of climate change, …, including by: Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels…” (UNFCCC 2016). The *Paris Agreement* was signed by 193 and ratified by 112, of the 195 participating countries in the COP21 (as of November 2016) and went into force on 4 November 2016.

Enormous scientific and societal efforts have been undertaken to make this agreement possible (IPCC 2014). Hundreds of scientists studied the effects of increased greenhouse gases and developed projections for the future (Anderegg et al. 2009). They thereby accomplished the mission to provide scientific evidence for the existence of

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anthropogenic climate change and its impact to the global biosphere (e.g. Solomon et al. 2009; Hoegh-Guldberg and Bruno 2010; Chen et al. 2011; Cicerone and Nurse Sir 2014). Civil society, including NGOs, political decision-makers and independent journalism ensured the dissemination and interpretation of the main scientific findings and conclusions, especially with respect to human well-being. The *Intergovernmental Panel of Climate Change* played a key role in this process. Despite this, sporadic instances of public scepticism seem to remain (Poortinga et al. 2011).

Based on this development a shift in mission-driven ecological research can be observed. Research organisations, including their funding opportunities such as the EU Horizon 2020 programme (http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-focus_en.pdf; accessed 21 November 2016), the *Intergovernmental Panel on Climate Change* (IPCC 2014; Magnan et al. 2016) and EU-PolarNet (http://www.eu-polarnet.eu/; accessed 21 November 2016) may not focus primarily on studying the impact of climate change on the biodiversity and the response of ecosystem functioning. They support economic and societal benefits including technological developments ("blue infrastructure") and related research including nature-based solutions to mitigate and reduce greenhouse gas emissions (Rhodes 2016; http://www.eu-polarnet.eu/news-and-events/publications/; accessed 21 November 2016). Based on the *Paris Agreement,* the implementation of climate-change mitigation strategies became the main focus of the COP22 2016 in Marrakech.

The core of the study presented here is the results from an online opinion survey. The aim was to give scientists a voice on required changes in research directions, which result from the large-scale acceptance of the existence of anthropogenic climate change. The survey focussed on Antarctic terrestrial and marine ecosystems: this area comprises approximately 10% of the world's surface. Reasons for the preference of different science directions by the respondents of the opinion survey and future perspectives are discussed and related to scientific key challenges arising from the *1st Scientific Committee on Antarctic Research (SCAR) Antarctic and Southern Ocean Scientific Horizon Scan* (Kennicutt et al. 2015), hereafter referred to as the *1st SCAR Horizon Scan*.

## Background

This opinion survey was aimed at experts in Antarctic ecosystems because, on the one hand, their working environment is unique in a number of ways. Firstly, life on land and in parts of the surrounding Southern Ocean is mostly isolated from that of neighbouring continents and adjacent oceans (Clarke et al. 2005). In contrast to the Arctic, Antarctica has no indigenous human population, and thus, $CO_2$ emissions are very low. On the other hand, Antarctic ecosystems, especially the Southern Ocean, play an important role in the entire Earth system (Hall and Visbeck 2002; Meincke et al. 2003) since they contribute to global chemico-physical cycles (Turner et al. 2009a, 2014) and ecosystem goods, as well as services (Grant et al. 2013). The circumpolar current connects the three other oceans and potentially allows some organisms to disperse globally within ecological and evolutionary timescales (Strugnell et al. 2008; Leese et al. 2010). In addition, Antarctic ecosystem services have global implications. For example, $O_2$ is produced by marine biological primary production (growth of algae) to the benefit of worldwide occurring organisms, which fundamentally depend on respiration, including humans. Conversely, $CO_2$ produced in any region of the world and released to the atmosphere is taken up by the Southern Ocean and converted to biomass (Ducklow et al. 2001). Other macro- and micronutrients are remineralised by organisms in the water column and at the sediment surface. A certain proportion of nutrients, including $CO_2$-derived carbon, are buried in the sediments for very long geological timescales, while others provide the basis for new primary production, either already in the Southern Ocean, or after transportation with the global current system in upwelling regions (Sarmiento et al. 2003). Our knowledge on these complex global cycles, including regional variation and long-term effects, is still incomplete (Marinov et al. 2006; Arrigo et al. 2008). This is just a selection of the most important ecosystem services, which are potentially threatened by climate change. However, they clearly illustrate why a comprehensive understanding of the global biosphere and its relevance to humans is never complete without including knowledge from the Antarctic.

Despite the general description of climate change as a global phenomenon, there seems to be huge variation in the regional strength of the impact (Turner et al. 2005). This is especially pronounced in the Southern Ocean and Antarctica (Mayewski et al. 2009). The anthropogenic contribution to the observed regional climate change has resulted in lively and somewhat controversial discussions (Böning et al. 2008; Thompson et al. 2011; Turner et al. 2016). It is well known that a larger region of the West Antarctic, including the ocean and waters along the polar frontal system, has warmed much more than the global average over decades. This warming is due to various reasons, including changing wind patterns causing changed upwelling of warm deep water as well as changes in sea-ice patterns and heating due to atmospheric warming (Turner et al. 2009b; Holland et al. 2010; Pritchard et al. 2011; Dinniman et al. 2012). It impacts terrestrial and marine ecosystems directly and indirectly; e.g. it affects the greening of the continent (Hill et al. 2011); results in a shift from nutritious krill to gelatinous slaps, which is further associated with a variety of complex reasons ranging from micronutrients to apex predators (Atkinson et al. 2008, 2012), and a turnover from larger to smaller organisms in the Southern Ocean (Moline et al. 2004). This climate-change-induced variability is superimposed by the natural phenomenon of the Southern Annular Mode (Lovenduski and Gruber 2005). However, the warming along the Antarctic Peninsula (Domack et al. 2013) seems to have been interrupted during the most recent decade, but this phenomenon is considered to be part of the variability within the long-term warming process (Turner et al. 2016).

Over a shorter term a shift to seemingly more polar conditions (e.g. to more sea-ice cover) has been observed off East Antarctica, but the reasons are poorly understood, if at all (Massom et al. 2013). In future, further environmental changes attributed to anthropogenic global climate change are predicted for larger areas of the Southern Ocean than what was been affected up until now, e.g. in terms of sea-ice reduction, warming and glacier melting, with potentially high relevance for the Antarctic biosphere (Gutt et al. 2015; Constable et al. 2016). Ocean acidification, the "climate's step sister", might develop to another big problem for marine ecosystems, especially in the Southern Ocean. Besides atmospheric warming, changes in precipitation, UV radiation, wind patterns and deglaciation could become the most important climate-change-related drivers on land (Convey and Smith 2006; Krinner et al. 2007; Fretwell et al. 2011). Furthermore, the introduction of "alien" species might be amplified by climate change, particularly (although not exclusively) in terrestrial ecosystems (Chown et al. 2011).

The response of organisms to such environmental changes is not well known. However, valuable results on selected marine species show that thermal thresholds are close to the warming conditions predicted for the end of the century (Peck 2011). Also, exceptions of species with clearly higher phenotypic plasticity seem to exist (e.g. Franklin and Seebacher 2009). Observations on the ecosystem-level vulnerability are rare, but few studies show an above-global average sensitivity to environmental changes (Rogers et al. 2012; Saba et al. 2014; Chown et al. 2015). Studies on their resilience (self-repair capacity) are important to understand and maintain ecosystem services (Oliver et al. 2015). It is unclear whether the lack of evidence for climate-induced community shifts is due to the weakness of the climate-change impact or, alternatively, whether such shifts are especially difficult to be separated from "background-noise" in the Antarctic, due to a high spatial patchiness and temporal variability in ecosystem dynamics (Convey et al. 2014; Gutt et al. 2016).

Science to understanding the response of our biosphere to climate change can be classified into independent academic approaches mainly housed in universities and traditionally in museums, and conditional contract research awarded by governmental, non-governmental, profitable or non-profit institutions or funding agencies. In many countries the freedom of (the arts and) sciences is guaranteed by their constitution. However, in terms of essential resources, all such science depends on political decision-making processes. Applied research projects are a priori conditional with regard to content and funding, e.g. associated with a wider, defined programme for a limited period. Most of the climate research falls under applied research, because either it is carried out by large national research centres with a more or less applied mission or it depends on third-party funds. Irrespective of research approaches, climate change is obviously the biggest research complex in terms of funds and personnel within Antarctic-specific research, especially under the "roof" of SCAR. Additional applied biological foci include natural resources and nature protection, which eventually also connects to climate-change issues. Fundamental research generally covers a broad variety of themes, including studies on biological structures and processes, single species and bulk parameters, long- and short-term observations, new biomolecular technologies, as well as experiments. The *Census of Antarctic Marine Life* supported for a limited period (2005–2010) such marine research issues, especially biodiversity, taxonomy and systematics including genetic approaches (Gutt et al. 2010; Kaiser et al. 2013; de Broyer et al. 2014).

An instinctive idea to accommodate political and societal demands, and reduce destructive impacts on habitats, is to protect them. However, global or other large-scale climate change cannot be prevented from affecting Antarctic terrestrial and marine (and any other) habitats by the designation of protected areas. Nonetheless, the protection of refuge areas and the reduction of additional local stress, e.g. by fishing or pollution in areas experiencing climate change, do not only reduce the directly manageable impacts, but can also reduce synergistic (negative) effects including climate change (Keppel et al. 2012).

## The opinion survey, structure and results

The survey offered researchers a choice to vote for:

- (A) *More applied climate-related research recommended.*
- (B) *Better ecosystem understanding under climate change and improved predictions needed.*
- (C) *Novel concepts to be developed.*
- (D) *No changes necessary.*

The respondents could choose a maximum of two out of the four options, for full text of the opinion survey see *Electronic Supplementary Material,* Online Resource 1 (ESM.pdf).

*Metainformation*

The survey was released 17 February 2016 and ended 13 May 2016 using LimeSurvey 2.05+ software. It was promoted through the mailing list of the Scientific Research Programme *Antarctic Thresholds-Ecosystem Resilience and Adaptation* (AnT-ERA) of the *Scientific Committee on Antarctic Research* (SCAR) with approximately 510 members, of which more than 480 were biologists. The survey was also advertised on the public AnT-ERA website (subpage of SCAR: http://www.scar.org/srp/ant-era; accessed 21 November 2016), which is mainly used by biologists within the Antarctic community and to the participants of the *SCAR Barcelona cross-program workshop* organised by AnT-ERA in cooperation with other biological and non-biological Antarctic research programmes (http://www.scar.org/srp/ant-era#CPW, accessed 21 November 2016). The main focus of AnT-ERA is biological processes on ecological timescales in the Antarctic, especially, but not exclusively, related to climate change. The survey was purposely advertised only through these media for a relatively good non-personal traceability of the participants. Ninety answers were received, of which 21 were early career, 39 mid-career and 28 late-career scientists. Sixty-three of the participants were marine biologists, 20 terrestrial biologists, while five additional answers came from scientists other than biologists and one was not from a scientist. Fifty-two of the participants worked for an institution which is mainly involved in applied research, and 37 were doing mainly fundamental academic research, e.g. in a university or museum. Sixty-seven respondents revealed their identity, which increases the certainty of the sincerity of the survey and allowed further simple analyses: the majority of answers came from countries with a long tradition in Antarctic science and a relatively large national programme, while a minority of approximately 20% were from countries with an emerging or small national Antarctic programme. Only three of the non-anonymous answers came from the same institute as the author of this paper.

*Answers to the key question (Fig. 1)*

The majority of the respondents voted for option B (*Better ecosystem understanding under climate change and improved predictions needed*), followed by option D (*No changes necessary*) and option A (*More applied climate-related research recommended*). The fewest voted for option C (*Novel concepts to be developed*).

In terms of the stage of career, an above-average proportion of early career scientists voted *More applied climate-related research recommended* (option A) and had a relatively low priority for *No changes necessary* (option D). Late-career scientists responded in the opposite direction and formed the majority for the *No changes necessary* scenario (option D). The mid-career scientists were representative of the overall average responses. Most answers came from marine scientists and followed the general trend. None of the 13 terrestrial experts voted for *Novel concepts to be developed* (option C), and they had a higher preference for *More applied climate-related research recommended* (option A) and lower support for *No changes necessary* (option D) compared to the overall response. Scientists who worked within a third-party-funded project or for an institution with an applied mission, indicated relatively little support for *Novel concepts to be developed* (option C) and voted more fore *More applied climate-related research recommended* (option A) and also the *No changes necessary* scenario (option D). In contrast, scientists from more independent institutions, such as universities and museums, voted with a high priority for *Novel concepts to be developed* (option C) and a relatively low agreement with *More applied climate-related research recommended* (option A).

## Discussion—future direction of research on climate change in the Southern Ocean and Antarctica

Here we discuss the scientists opinions and allocate these to actual science questions, primarily from the *1st SCAR Horizon Scan,* especially the *Antarctic Life on the Precipice* cluster. Such a designation is artificial, since the questions rather represent gradients from applied to fundamental and from current approaches to really novel ideas. However, it aids in identifying opinions that groups of researchers have in common, overcoming details and elaborating on top priorities of the Antarctic scientific community for future research directions.

### More applied climate-related research recommended

The stimulus to offer this option was that, at least in Europe, scientists realise that calls for third-party EU-funding increasingly prioritise the development of nature or ecology-based solutions, including the investigation of socio-economic pathways of emission and economic measures as well as instruments. Therefore, scientists involved actively in such projects will become implementation assistants with the mission to solve large environmental or other

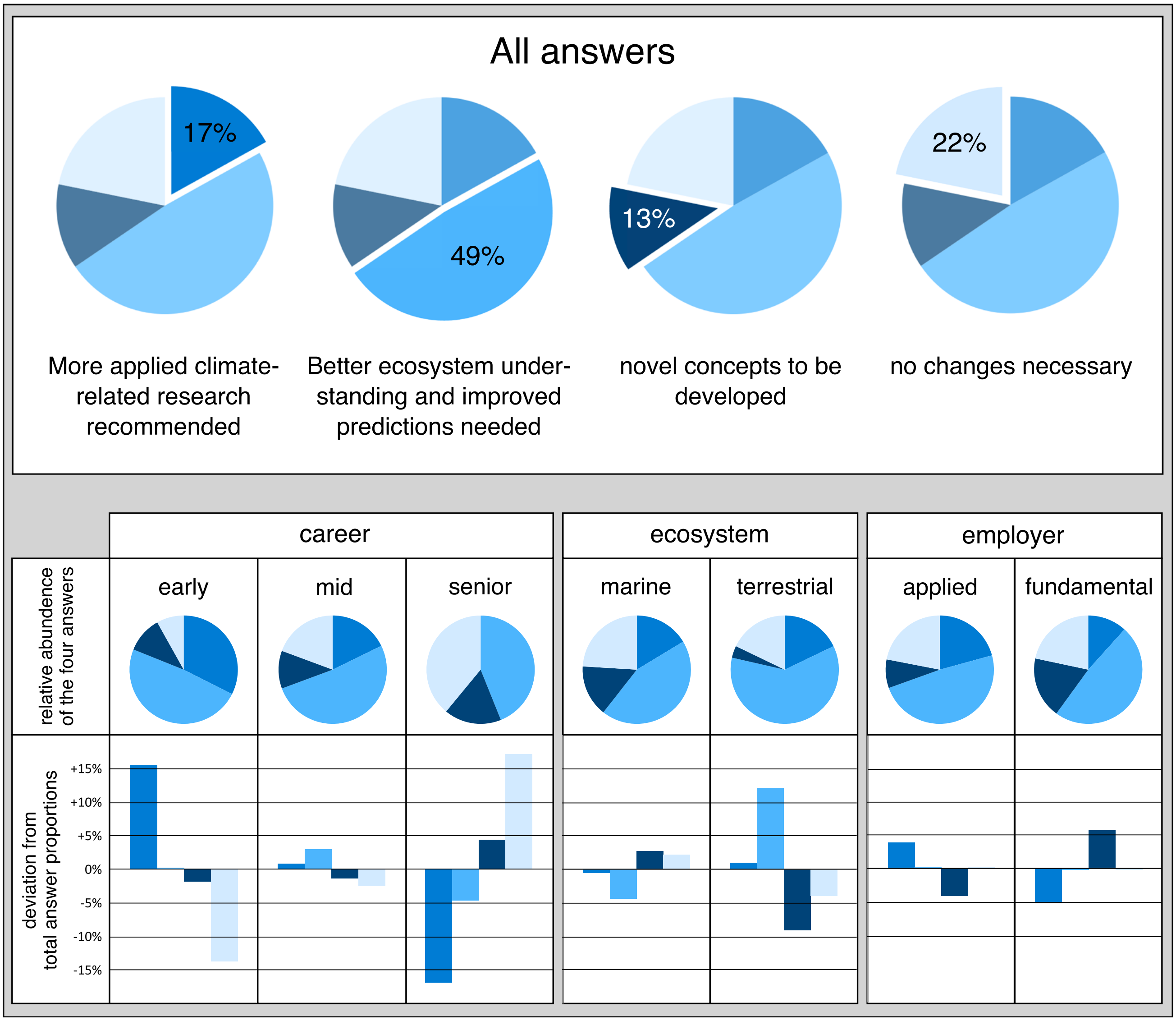


**Fig. 1** Relative proportions of the answers of the opinion survey; all answers (*above*) and answers split into clusters referring to the respondents with respect to their stage of "career", the "ecosystem" for which they are specialised and the general research concept of their "employer" (*bottom*)

problems of humanity. The needs for such solutions are, among others, determined by policy-makers and are caused by forces outside the world of science, e.g. by the industry or land-use practices, also in the oceans. This can, when successful, be a highly valuable societal mission to which biologists can contribute in the future. However, scientists would also lose their partial independency and primarily support political visions. One reason early career scientists might have shown a priority for this option is simply because of their expectancy of life. They will very likely experience the problems of the next decades and need climate solutions more exigently than late-career scientists, independent of their affiliation and field of scientific interest. However, all who voted for this option must be aware that the Southern Ocean, and even more Antarctica, cannot solve global climate-change environmental problems.

Theoretically, the climate problem generated in other parts of the world and having a large impact in the Antarctic could be solved if the Southern Ocean with its high nutrient-low chlorophyll regions at the margin is used to dump atmospheric $CO_2$ through ocean fertilisation (Smetacek et al. 2012). However, this approach is controversial (Chisholm et al. 2001; Strong et al. 2009; Vaughan and Lenton 2011; McCormack et al. 2016). There is no evidence that it provides a carbon dioxide reduction, which contributes significantly and, thus, efficiently to the global $CO_2$ budget. In addition, a negative impact on the pelagic and benthic ecosystems and its ecosystem services, including $CO_2$ uptake itself, must be assumed. This is not yet understood and not sufficiently assessed, suggesting that more research might be needed before recommendations can be made. Furthermore, the area south of 60 ° is protected from anthropogenic impact by the *Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol*, http://www.ats.aq/e/ep.htm). Even if the strict protection of Antarctica and the Southern Ocean will be eased when a renewal of the *Madrid Protocol* is to be discussed in the mid of this century (2048) and permissions for large-scale fertilisation are issued under economic and political pressure, it has to be considered that climate change is considered irreversible (Solomon et al. 2009). Also, the globally valid *London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* and of the *International Maritime Organization* (*IMO*) and the *Convention on Biological Diversity* (*CBD*) argued that large-scale operations to mitigate the $CO_2$ are currently not justified and should not be allowed (www.cbd.int/decisions/?m=COP-09&id=11659&lg=0, www.maritimeconnector.com/NewsDetails/2203/lang/.wshtml, www.ioccp.org; both accessed 21 November 2016). Direct measures to protect the Antarctic marine environment from anthropogenic impact are Marine Protected Areas (MPAs). Examples of these include the recently designated approximately 1.6 $km^2$ large MPA in the Ross Sea and the protection of areas of ice shelf disintegration, as well as planned additional MPAs, e.g. in the Weddell Sea. Such action primarily bans commercial fishing from relatively large areas, while it also provides refuge areas for species under climate stress without additional anthropogenic disturbance.

Reasons why late-career scientists did not vote for this option might have been because they noticed these constraints or because they already experienced too much guidance by non-experts in their career without general success and, thus, prefer their partial independency.

The relatively high priority for this option is not directly reflected by the *1st SCAR Horizon Scan* questions. This is not a surprise because the identification of climate problems to be solved primarily does not fall into the responsibilities of Antarctic biologists. Five questions from the *1st SCAR Horizon Scan* centre on applied aspects, e.g. the use of natural resources, technology-driven themes and also conservation measures, but not exclusively in a climate context. A reason why these questions do not aim primarily at climate-change mitigation actions and (other) product- or technology-driven research is that such attempts need a wider scope of disciplines. Experts in humanities, process engineering and biotechnology are needed at least to learn from the Antarctic for an implementation elsewhere, since solutions cannot be found within the Antarctic. The low representation of such applied research aspects in the *1st SCAR Horizon Scan* was maybe also due to the dominance of late-career scientists in this initiative. Scientists working for an employer with a more applied mission were slightly more in favour of *More applied climate-related research recommended*, in contrast to scientists working in more independent institutions who showed a slight avoidance of such research aspects. This might demonstrate the somewhat conservative spirit of scientists preferring to stay in the professional environment they are used to and by which they are paid.

## Better ecosystem understanding under climate change and improved predictions needed

The background for this option was that (1) advanced research in the Southern Ocean and Antarctica became especially successful in recent decades because of the use of efficient research platforms, such as ships, stations, aircrafts, satellites and modern equipment deployed from some of these. During this period the climate-change discussion shaped numerous smaller and a few very large research activities and facilities. (2) A critical view on our fundamental knowledge provides a diversity of valuable single results based on the success mentioned above. However, answers to the "big" questions on the response of Antarctic ecosystems to climate change, including systemic approaches and ecological predictions, are still rare. The specific environment, its partial isolation and its difficult accessibility might be the reasons that overarching findings on the impact of climate change are less abundant and less clear than in some other parts of the world and, thus, especially needed in the Antarctic.

The preference of late-career scientists for this option was slightly lower, compared to the other respondents. On the one hand, this result in combination with the lower preference for *More applied climate-related research recommended* might be based on the opinion that the *No changes needed* option is considered sufficient for the continued successful development of climate-related biological research. On the other hand, there is an increasing pressure to develop permanently novel approaches, ideas and solutions, especially when third-party-funded projects are planned. However, the frequency of such innovations has a limit.

The higher preference of terrestrial experts, compared to the below-average proportion of marine experts, for this option might be due to the better visibility of effects on land, e.g. the Antarctic greening. The complexity of life in a huge, dark and deep ocean might be seen as challenging difficulties to deal with "uncountable" species, their ecological role as well as the goods and services they provide.

A majority of the 25 questions of the *1st SCAR Horizon Scan* cluster *Antarctic Life on the Precipice* can be directly or indirectly linked to the problem of climate change, independently of whether the detailed ideas are really novel. Some of these questions centre on a better ecosystem understanding and can "improve our knowledge on HOW climate change impacts Antarctic ecosystems and improve predictions" (from the questionnaire of the opinion survey).

While most of the *1st SCAR Horizon Scan* questions are primarily and predominantly of academic scientific interest, a few others might directly agree with the requirements of stakeholders. A good example of the latter is the question on the Southern Ocean as a carbon sink, which can be considered as one of the above-mentioned unanswered "big" question. More such simple, but difficult to answer, questions could be added; e.g. how much oxygen is produced by the SO autotrophs, and how will this change under ongoing climate change? What is the capacity of SO benthic macro- and microorganisms to recycle or bury nutrients at various water depths, and what are the consequences for the entire global ocean ecosystem under climate change? How much does Antarctic and Southern Ocean biodiversity contribute to a global biodiversity including the deep sea (Brandt et al. 2014), and how will this proportion change under climate change? The diversity of such questions in combination with the dominance of votes for a *Better system understanding under climate change and improved predictions needed* underlines the ambition of scientists to contribute to answer societally relevant questions at a high level of scientific quality.

## Novel concepts to be developed

This option received the lowest interest overall, with only 13% of all answers. The support by early career scientists, terrestrial experts and scientists working in institutes with an applied mission was even lower. One reason for this might be that early career scientists rather work along guidelines as priority, which gives certainty to their career planning, despite not contributing as much to a fascinating but uncertain renewal of scientific developments. This low support may also reflect honest self-assessment, resulting in a low number of scientists, especially at the beginning of their career, regarding themselves as having enough creativity to develop really novel concepts. It is beyond the scope of this study to assess how many scientists with particularly creative minds are needed to maintain a perfect science system to the benefit of a prosperous societal development, and how much practical work is to be done by busy, executing researchers. However, it should not be overlooked that, against the result of this opinion survey in the "academic world", the most innovative ideas are usually ascribed to the younger generation. A general indolence to develop novel ideas and concepts would mean an unfortunate standstill in science. The low support could also be affected by an assumed higher probability to get a job in a scientific field when doing more prudent research. In this regard, it is generally well accepted and established that some public employers and funding agencies are not forward-looking enough to provide employment for research that is willing to take risks and address "crazy" questions. Researchers of relatively independent institutions were more open to *novel concepts needed* maybe because they are more used to thinking in different directions, without the pressure to demonstrate relevance to any societal group already at the start of projects. A third reason why the support for this option was low might be the same as for the partial below-average acceptance of option B (*Better ecosystem understanding under climate change and improved predictions needed).* Scientists already use all their creativity to focus on new or so far unanswered climate-related questions, especially for fund-raising purposes. If in this respect a realistic optimum is reached, there is no need and no justification for an additional stimulus to develop even more novel ideas. However, it must also be noted that the question of the opinion survey did not aim to ask for new questions but just whether (permanent) development and brainstorming about new ideas is necessary.

Aiming at actionable requirements for research supporting technologies, logistics and infrastructure, the output of the *1st SCAR Horizon Scan* in combination with the *Antarctic Road Map Challenge* (Kennicutt et al. 2016) confirms the conclusion that scientists are already quite active in brainstorming and development of novel scientific questions (Xavier et al. 2016). Such questions can be roughly classified into (a) new applied aspects, e.g. on new contaminants or conservation issues, (b) fundamental science, e.g. on various topics ranging from very small to very large spatial scales, e.g. from molecules to ecosystem approaches, (c) background knowledge for further climate-change-related research, e.g. the need of up- and downscaling for a better system understanding and for obtaining representative results and conclusions. Novel scientific approaches and new technologies can be developed hand in hand (Brandt et al. 2016).

The high abundance of *1st SCAR Horizon Scan* themes which could be attributed to *Novel concepts to be developed* is in contrast to the low support for the development of novel ideas in the opinion survey. The number of such novel concepts was even higher among the originally submitted questions of the *1st SCAR Horizon Scan*. However, all final questions had to be democratically supported by scientists of all disciplines and exceptional and "crazy" questions (in the sense of novelty) therefore had only a reduced chance of general acceptance.

### No changes necessary

The difference in the representation of this option between early- and late-career scientists is most obvious. This is not surprising, because seniors are responsible for at least part of the research strategies in the past. Thus, it is evident that they might consider past developments as sufficient and good enough to be continued without major changes. However, such an opinion might only reflect the state and developments within the scientific community and does not consider significant impacts from outside, like the *Paris Agreement*. It can be expected that this unambiguous and internationally accepted statement on the existence and impact of anthropogenic global change will affect the opinion and decisions of taxpayers, politicians, funding agencies and eventually with a delay also of scientists. It is not a surprise that most scientists do not prefer a business as usual scenario as a consequence of the COP21 and its results. It was also foreseeable that early career scientists, assumed to be more dynamic on average, do not favour a strict long-term consistency in research priorities. However, the possible reasons for a shift towards more applied, to the disadvantage of more independent research, are outlined above. Another reason for the nevertheless, notable agreement with this *No changes necessary* option especially among late-career scientists could be the same as for the generally low agreement with the need for novel ideas—that a permanent search for novel ideas is presently already a feasible maximum. This argument is supported by the pressure within fund-raising processes and the development of research programmes, which permanently demand novel approaches, independently of whether this is feasible in monthly to yearly intervals or not.

Logic would suggest that there are no associations of any novel questions to this "business as usual" option. However, since the output of brainstorming events such as the *1st SCAR Horizon Scan* did not yield discrete and independent clusters but rather represent a gradient, few "novel" questions could be associated with this *No changes necessary* option. The authors and the editors of *Nature* journal selected from the *Antarctic Life on the Precipice* biology cluster the question on the adaptation of Antarctic organisms to the polar-specific conditions as almost the only biological question other than ones dealing with nature conservation issues. This theme has a long and successful tradition. It has formerly been approached using conservative physiological and biomolecular methods. However, extraordinarily fast-developing technological advances keep this adaptation theme fascinating (Verde et al. 2016). Thus, some detailed questions aiming at polar adaptation could be associated with the *No changes necessary* option. Another reason why this scientific issue is still very attractive and challenging in the Antarctic community might be that the pace of applications of this perpetually advancing technology is not as fast in Antarctic studies as for other ecosystems or habitats. Also, the implementation of results from some existing modern biomolecular techniques (e.g. genomics) in ecosystem-level models is generally still very challenging (Gutt et al. 2012). Since such ideas already exist no true changes are necessary, although increased research networking would be beneficial.

Not only method-driven approaches, but research for a better understanding of the Southern Ocean ecosystem is already successfully underway. This can therefore not be considered as really new, but reasonable. Comparative studies between the deep-sea (Brandt et al. 2014) and shelf ecosystems or polar comparisons are especially useful, but remain very rare. A comprehensive ecological understanding of Antarctic ecosystems will eventually be gained not only through the persistence of long-term questions, but also by the development of new field methods, better computer-based concepts and cross-disciplinary cooperation, simply more resources or a change in research priorities.

## Conclusion and recommendations

It can be assumed that the urgency with which stakeholders need further evidence for anthropogenic climate-change processes will decrease after the *Paris Agreement*, while questions on how to mitigate effects of climate change will become more pressing. However, politicians not only are in charge of plans how to reduce greenhouse gas emissions and temperature increases, but must also ensure the success of the implementation of the *Paris Agreement*. Even if the atmospheric temperature and its increase will be the major parameters to be measured, an evaluation of biosphere responses will be even more important. The latter provides ecological goods and services, including climate feedback effects, and directly shapes the human well-being.

Also, the interest of the general public, of communities under specific climate stress and of NGOs in the success of the COP21 will continue (Boucher et al. 2016). While the past focus was to detect any changes that provide evidence for climate change and its impact, it now becomes more important to observe how the changes develop in the next decades, e.g. whether amplification, a linear increase, buffering or general weakening happens (Constable et al. 2014). Scientists can meet such requirements if they continue to observe phenomena, for which baselines exist in the Antarctic and Southern Ocean. New analytical methods and observations must be able to detect long-term changes in a number of significant processes and correlative techniques should separate background noise from true climate-change impacts. This can refer to all levels of biological organisation such as biodiversity and community patterns, biological productivity, physiological plasticity and thresholds. Phenomena, which are representative for either a larger area or a larger component of the ecosystem, should have the highest priority. Examples could be repeated large-scale surveys on krill and fish in areas where their stocks are largest or dynamics of benthic suspension feeders in areas from which data already exist, or selected transects of *Continuous Plankton Recorder* operation. In addition to the nationally and internationally funded research projects, initiatives under the roof of SCAR stimulate the communication on and coordination of such approaches embedded in different research directions. There is no internationally and topically wider community than SCAR representing Antarctic-specific research. Specifically, its Scientific Research Programme *Antarctic Thresholds-Ecosystem Resilience and Adaptation* (AnT-ERA) is in charge of stimulating research and collaboration on a broad variety of climate-driven and other biological processes and contributes considerably to a permanent process of brainstorming. Most, if not all, of these studies must be carried out in close cooperation with physicists. The international initiative *Southern Ocean Observing System* (SOOS, http://www.soos.aq/; accessed 21 November 2016), endorsed by SCAR and the *Scientific Committee on Oceanic Research* (SCOR), could be the best suited platform for such an interdisciplinary approach. Another institution that brings experts on polar ecosystems from different disciplines together is the *Gordon Research Conferences on Polar Marine Science*, which has a slightly different scope than SCAR. An intellectual exchange with the "Arctic equivalent" to SCAR, the *International Arctic Science Committee* (IASC) is a permanent challenge for scientists working in the polar regions.

Analyses in a wider scientific and societal context can only be carried out by consortia comprising natural and social scientists as well as engineers and economists (Knapp et al. 2017). New cross-disciplinary academic study courses and even degrees would foster the efficiency of such trans-disciplinary approaches. They would foster the cooperation between specific specialists based on a common sense and a well-developed communication.

Independently of the actual pressure to head for new directions in applied climate-change research, scientists and students might be reminded that they traditionally contributed to develop new research issues and strategies in any larger context. They should continue to identify and accept scientific challenges, independently of actual and temporary problems.

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