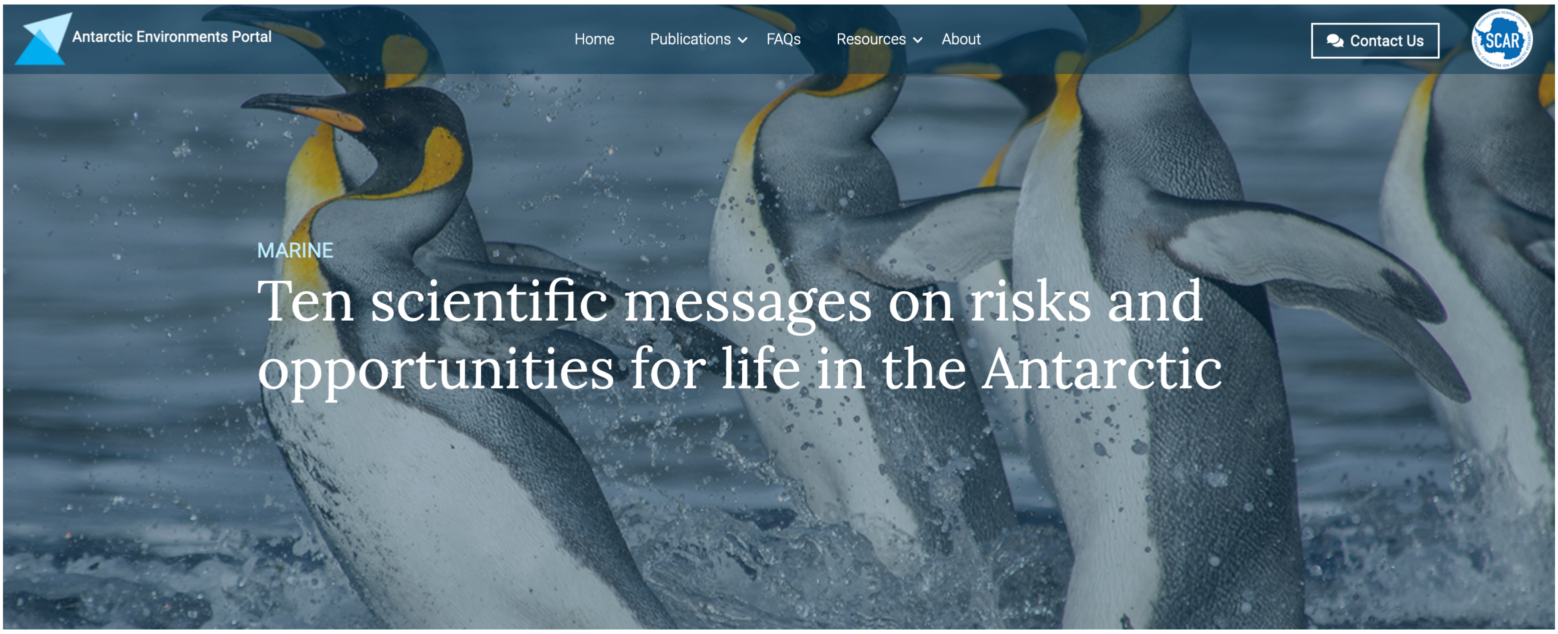

MARINE

Ten scientific messages on risks and opportunities for life in the Antarctic

PEER REVIEWED:

FIRST PUBLISHED: 21 Feb 2022

PRINT:

Author/s

Julian Gutt (1), Enrique Isla (2), José C. Xavier (3,4), Byron J. Adams (5), In-Young Ahn (6), C.-H. Christina Cheng (7), Claudia Colesie (8), Vonda J. Cummings (9), Huw Griffiths (4), Ian Hogg (10, 11), Trevor McIntyre (12), Klaus M. Meiners (13), David A. Pearce (14), Lloyd Peck (4), Dieter Piepenburg (1), Ryan R. Reisinger (15), Grace K. Saba (16), Irene R. Schloss (17, 18, 19), Camila N. Signori (20), Craig R. Smith (21), Marino Vacchi (22), Cinzia Verde (23) and Diana H. Wall (24)

(1) Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany.
(2) Institute of Marine Sciences-CSIC, Barcelona, Spain
(3) University of Coimbra, MARE – Marine and Environmental Sciences Centre, Faculty of Sciences and Technology, Portugal
(4) British Antarctic Survey, Natural Environmental Research Council, Cambridge, UK
(5) Department of Biology and Monte L. Bean Museum, Brigham Young, University, Provo, USA
(6) Korea Polar Research Institute, Incheon, Republic of Korea
(7) University of Illinois, Department of Evolution, Ecology and Behavior, Urbana, USA
(8) School of GeoSciences, University of Edinburgh, Edinburgh, UK
(9) National Institute of Water and Atmosphere Research Ltd (NIWA), Wellington, New Zealand
(10) School of Science, University of Waikato, Hamilton, New Zealand
(11) Canadian High Antarctic Research Station, Polar Knowledge Canada, Nunavut, Canada
(12) Department of Life and Consumer Sciences, University of South Africa, Florida, South Africa
(13) Australian Antarctic Division, University of Tasmania, Battery Point, Australia
(14) Department of Applied Science, Northumbria University at Newcastle, Newcastle-upon-Tyne, UK
(15) Centre d'Etudes Biologique de Chizé, La Rochelle Université, Villiers en Bois, France
(16) Center for Ocean Observing Leadership, Rutgers University, New Brunswick, NJ, USA
(17) Instituto Antártico Argentino, Buenos Aires, Argentina
(18) Centro Austral de Investigaciones Científicas, Ushuaia, Argentina
(19) Universidad Nacional de Tierra del Fuego, Ushuaia, Argentina
(20) Oceanographic Institute, University of São Paulo, São Paulo, Brazil
(21) Department of Oceanography, University of Hawaii at Manoa, Honolulu, HI, USA
(22) Institute for the study of the anthropic impacts and the sustainability of the marine environment (IAS), National Research Council of Italy (CNR), Genoa, Italy
(23) Institute of Biosciences and BioResources (IBBR), National Research Council (CNR), Naples, Italy
(24) Department of Biology and School of Global Environmental Sustainability, Colorado State University, Fort Collins, USA

Brief Overview

- Initiated by the SCAR scientific research programme "Antarctic Thresholds – Ecosystem Resilience and Adaptation" (AnT-ERA, 2013-2021), 26 experts synthesized knowledge on impacts and risks of climate-change on biological processes and ecosystem functions in the Antarctic[1].
- The ten main scientific messages that emerged addressed (1) accelerating marine and terrestrial biogeochemical cycles, (2) response to ocean acidification, (3) ecological changes in climate change hot spots, (4) unexpected dynamism of marine seafloor communities, (5) biodiversity shifts, (6) low temperature limitation of protein synthesis, (7) life

intrinsically linked to changing sea ice conditions, (8) pollution, (9) genetically distinct terrestrial populations under threat, and (10) newly discovered habitats.

- Two-thirds of the literature included in this synthesis was published between 2010 and 2020 and only one-third was published earlier.
- The fast mounting, recent decadal evidence indicates various Antarctic biological communities now experience climate stress, or will experience such stress in the coming decades.
- The responses of organisms, ecosystem functions and services to environmental changes are complex and varied. Key knowledge gaps remain and need addressing to adequately assess future prospects for life in the Antarctic.

Detailed Overview

Twenty-six experts, representing the breadth of Antarctic scientific disciplines, identified the most relevant research on biological and ecological processes and functions, across all levels of biological organization in marine, terrestrial and limnetic ecosystems in the Antarctic[1] (Figure 0). The identified research spans from molecule biosynthesis playing an important role in adaptation and plasticity of organisms, shaping biodiversity[2]; to ecosystems, including their resilience (or self-repair capacity); biological interactions, such as prey-predator relationships; biogeochemical cycles; and ecosystem services[3,5,6]. Results with a wider scientific significance, of particular novelty and with obvious stakeholder relevance were clustered into ten main messages. Here we present a condensed description of these key messages. Since only the overarching literature is cited herein, please refer to Gutt et al.[1] for the comprehensive list.

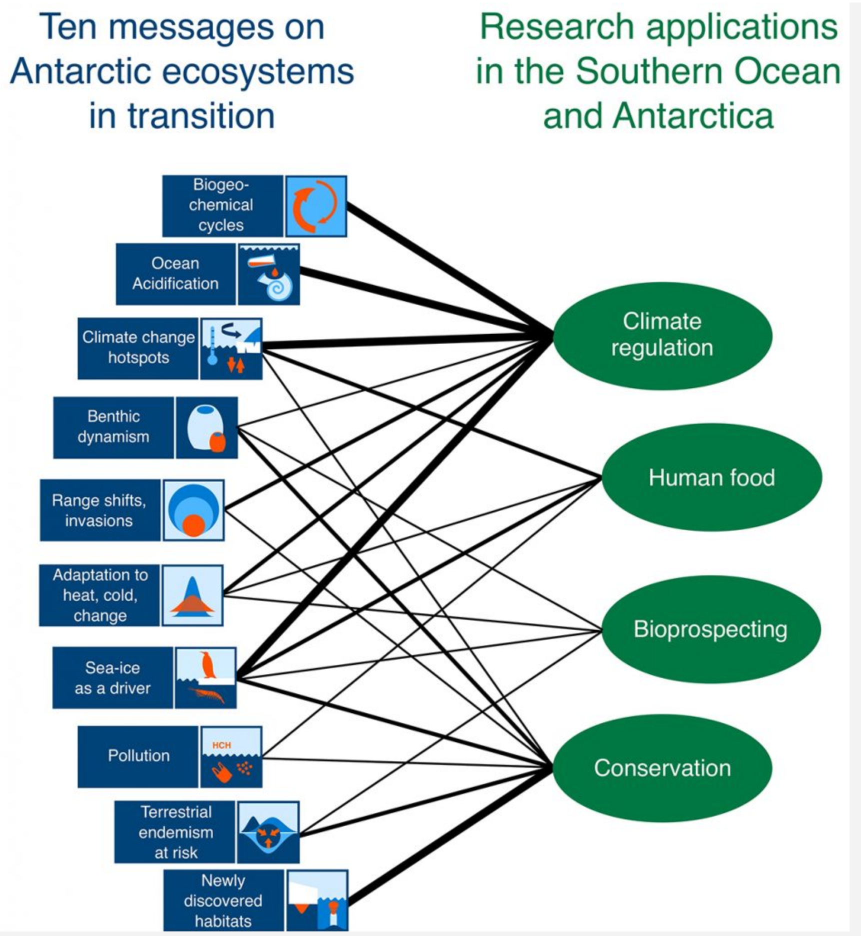

Figure 0. Links between the ten scientific key messages from the Antarctic continent and Southern Ocean (abbreviated) and fields of applied research comprising mostly ecosystem goods and services (nature's contributions to people). Thicker lines indicate stronger relationships.

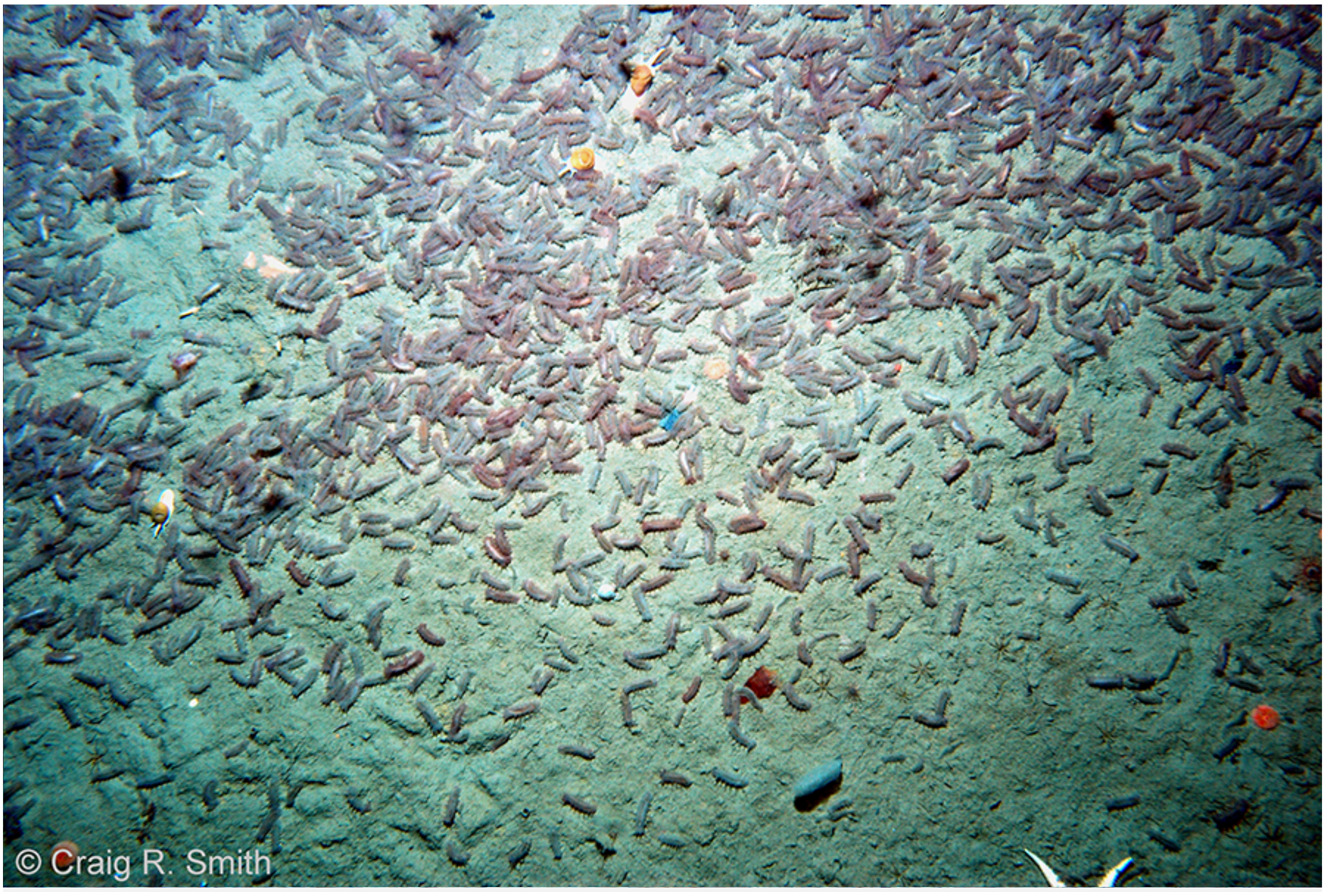

Figure 1. Sea cucumbers usually colonize the deep-sea floor but can also occur on Antarctic shelves in high densities, especially if food is abundant. They contribute considerably to the remineralization of organic particles, which sink from the upper water column to the seabed. © Craig R. Smith

(1) Climate stress intensifies the transfer of elements among organisms and the environment (biogeochemical cycling).

Melting ice increases the release of nutrients into terrestrial and marine ecosystems (Figure 1). Ice mass loss also results in the appearance of new terrestrial and marine habitats, which, due in part to increased nutrient inputs, results in greater net photosynthesis and biomass. Under exceptional periods of increased water turbidity or particular weather conditions, biological activity may be inhibited.

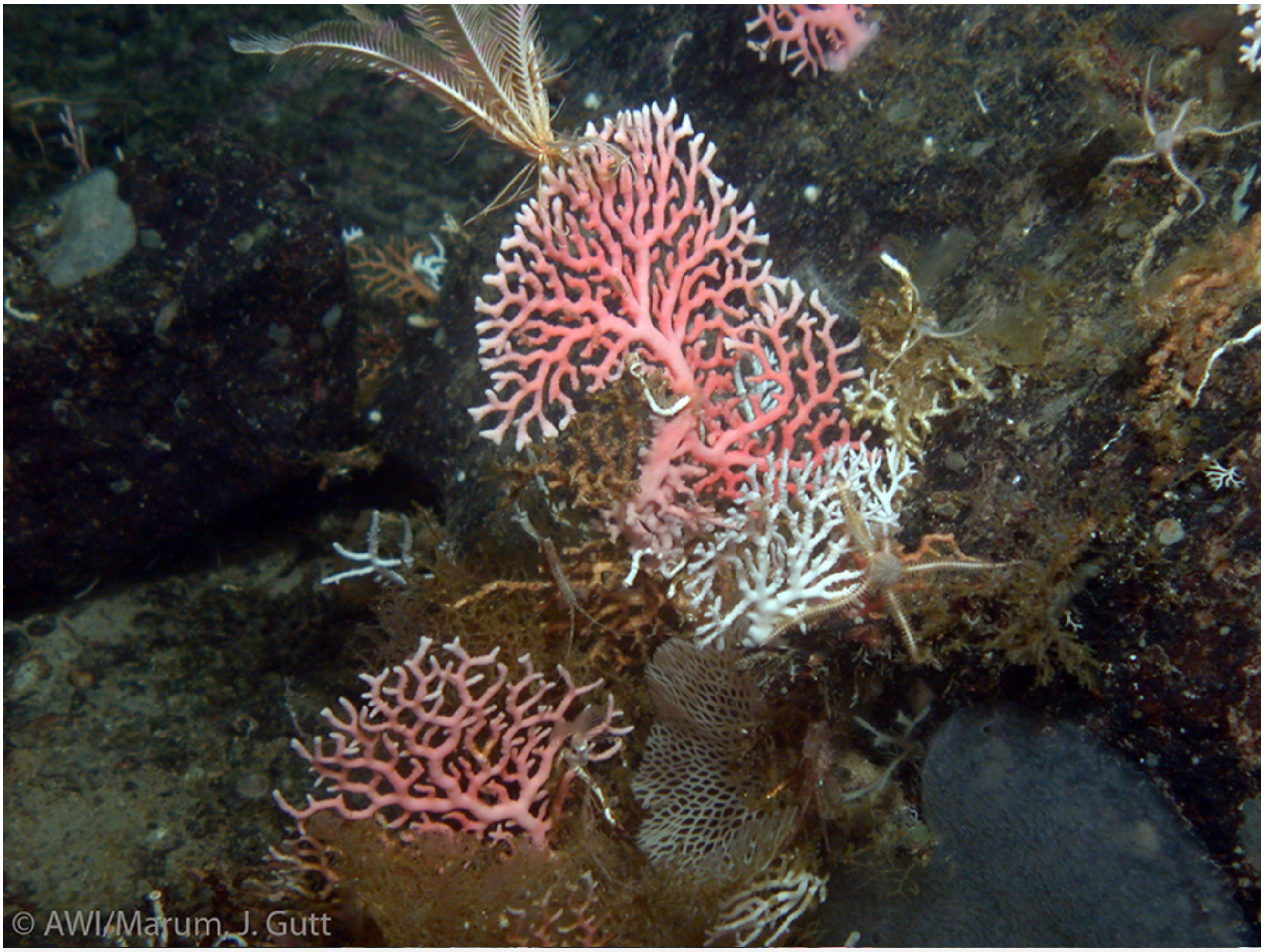

Figure 2. Corals can occur in high abundances at several places in the Southern Ocean. They are particularly vulnerable to ocean acidification because of their calcareous skeletons. © J. Gutt & W. Dimmler, AWI/MARUM

(2) Species respond differently to ocean acidification: some may acclimatise, but ecosystem responses are unknown.

Responses, including growth and photosynthesis, of primary producers vary among species and with duration of exposure. Early life-history stages are generally more vulnerable (e.g. krill hatching, shell development). Long-term studies reveal the potential for compensatory responses to acidification. Predictions of changes at the community and ecosystem level require knowledge of which key species and functional groups will and will not be impacted by acidification, in combination with other stressors, and particularly, their ability to adapt in the long term.

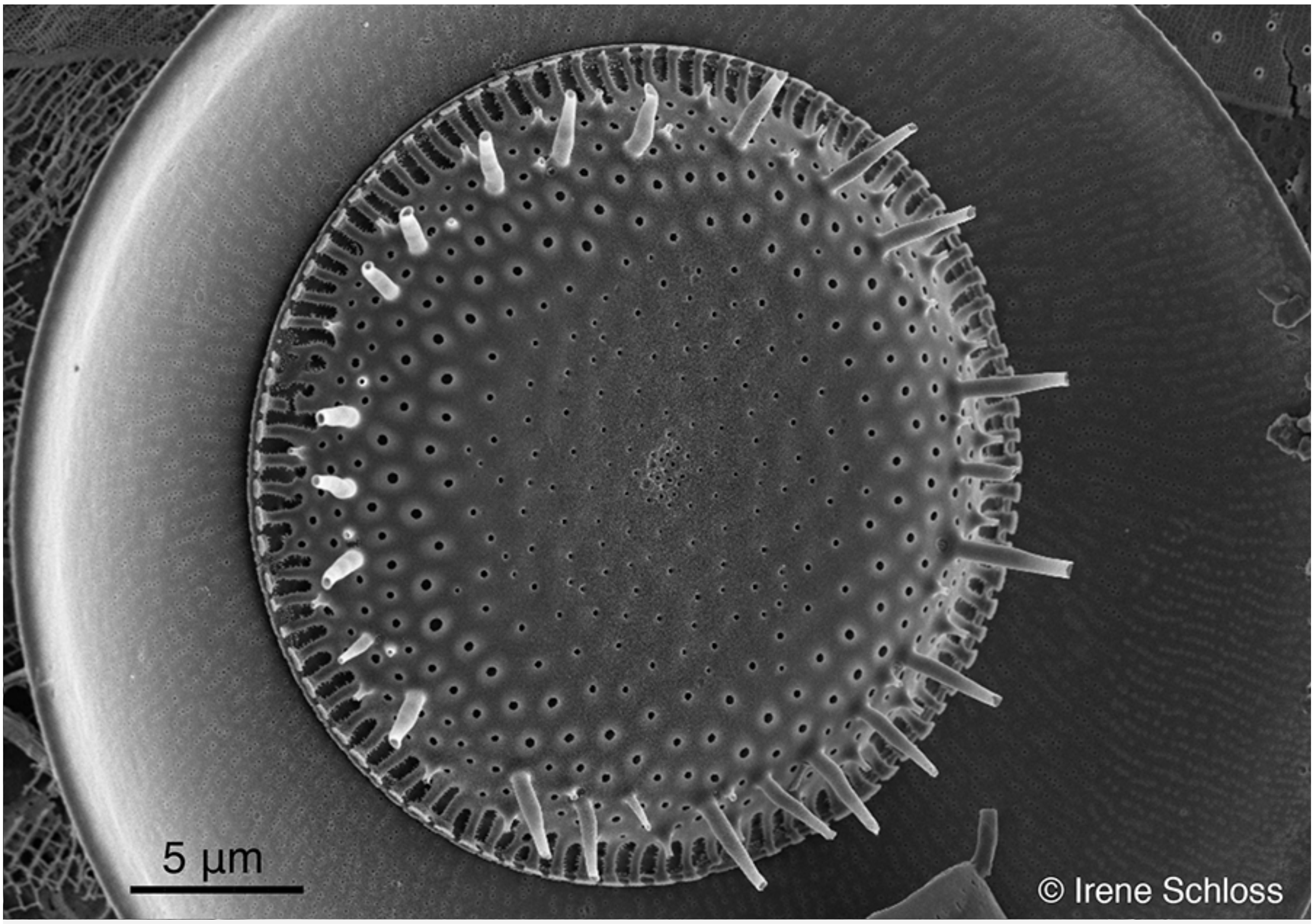

Figure 3. Microalgae such as the diatom species Thalassiosira scottia respond sensitively in their composition and growth to changes in temperature and sea-ice dynamics. © Irene Schloss

(3) Marine and terrestrial ecosystem changes are occurring rapidly in climate change hotspots.

The Western Antarctic Peninsula (WAP) region may represent a harbinger of the fate of other Antarctic areas of climate-influenced biological hotspots. Changes in local features, as well as in regional winds, ice quality and extent, and water column stratification, modulate the occurrence of WAP algal blooms (Figure 3). Coastal areas, such as fjords along the WAP, harbour high krill and whale biomass, and unique seafloor species assemblages. These rich areas may be under threat from climate change, especially where glaciers retreat.

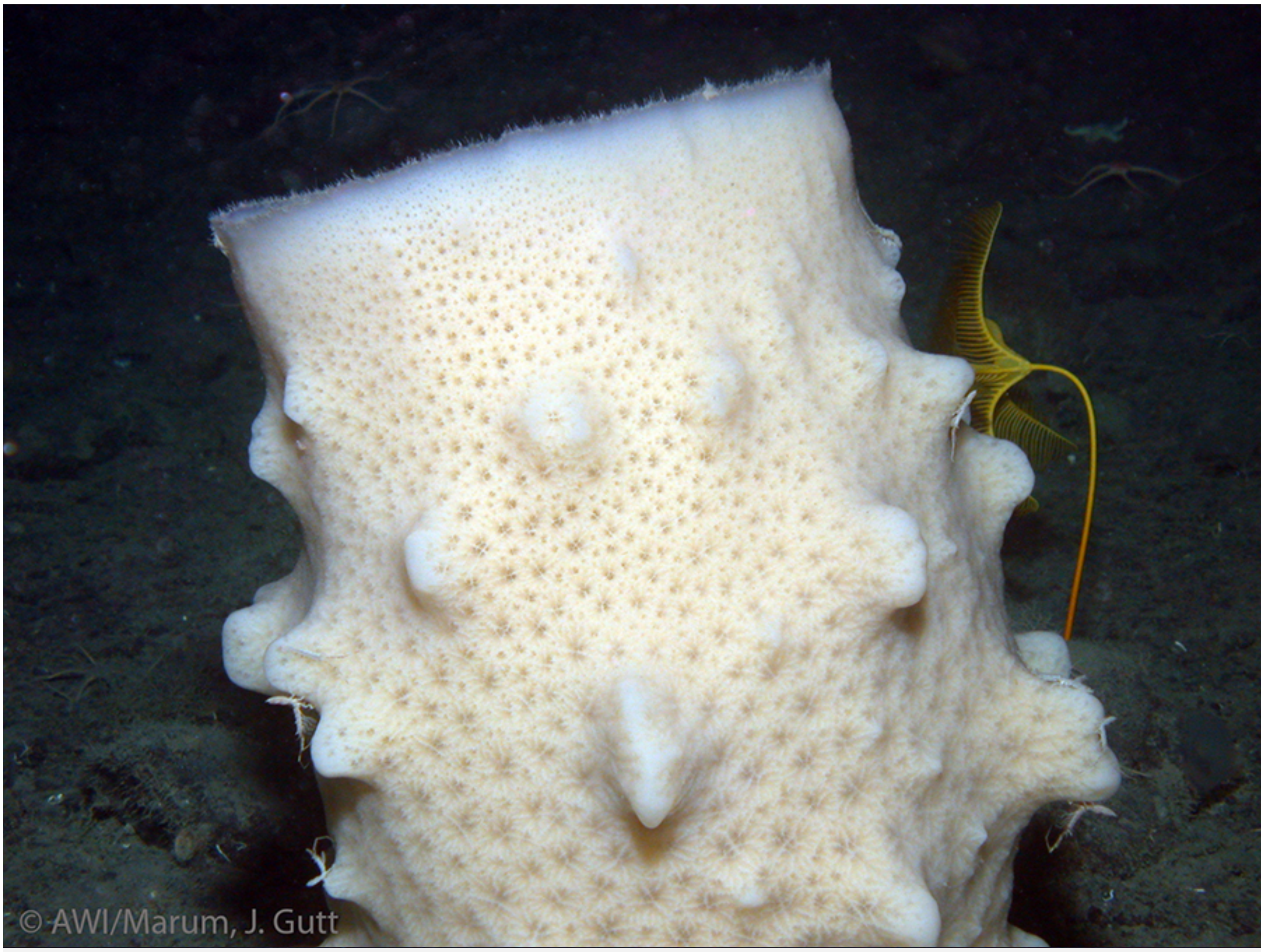

Figure 4. Glass sponges are sensitive to fluctuating environmental conditions. Some species grow faster than previously thought, but are also affected by high mortality rates. © J. Gutt & W. Dimmler, AWI/MARUM

(4) Sea-bed communities exhibit unexpected dynamism – from explosive growth to mass mortality.

Antarctic sea-bed organisms and communities were considered for decades to be slow growing (Figure 4). However, some recent surveys covering several years to a few decades show that sponges and ascidians can grow faster than expected, and can also experience high mortality rates due to climate-induced changes to ice shelf and sea-ice conditions and glacier retreat.

Figure 5. Vegetation on the Antarctic continent consists mostly of lichens and mosses, whose distribution is expanding regionally due to warming. © Claudia Colesie

(5) Environmental changes and an increased human footprint trigger shifts in species distribution, and invasions.

The distributions of most marine species are expected to move poleward and contract, but some species show evidence for contraction in the north. On land, habitat availability increases with glacier retreat. Under favourable conditions, such as along the Antarctic Peninsula, this could result in increased terrestrial plant productivity, also called “Greening of Antarctica” (Figure 5). Non-indigenous species, predominantly terrestrial, imported by human visitors, can become established and change original ecosystem functions.

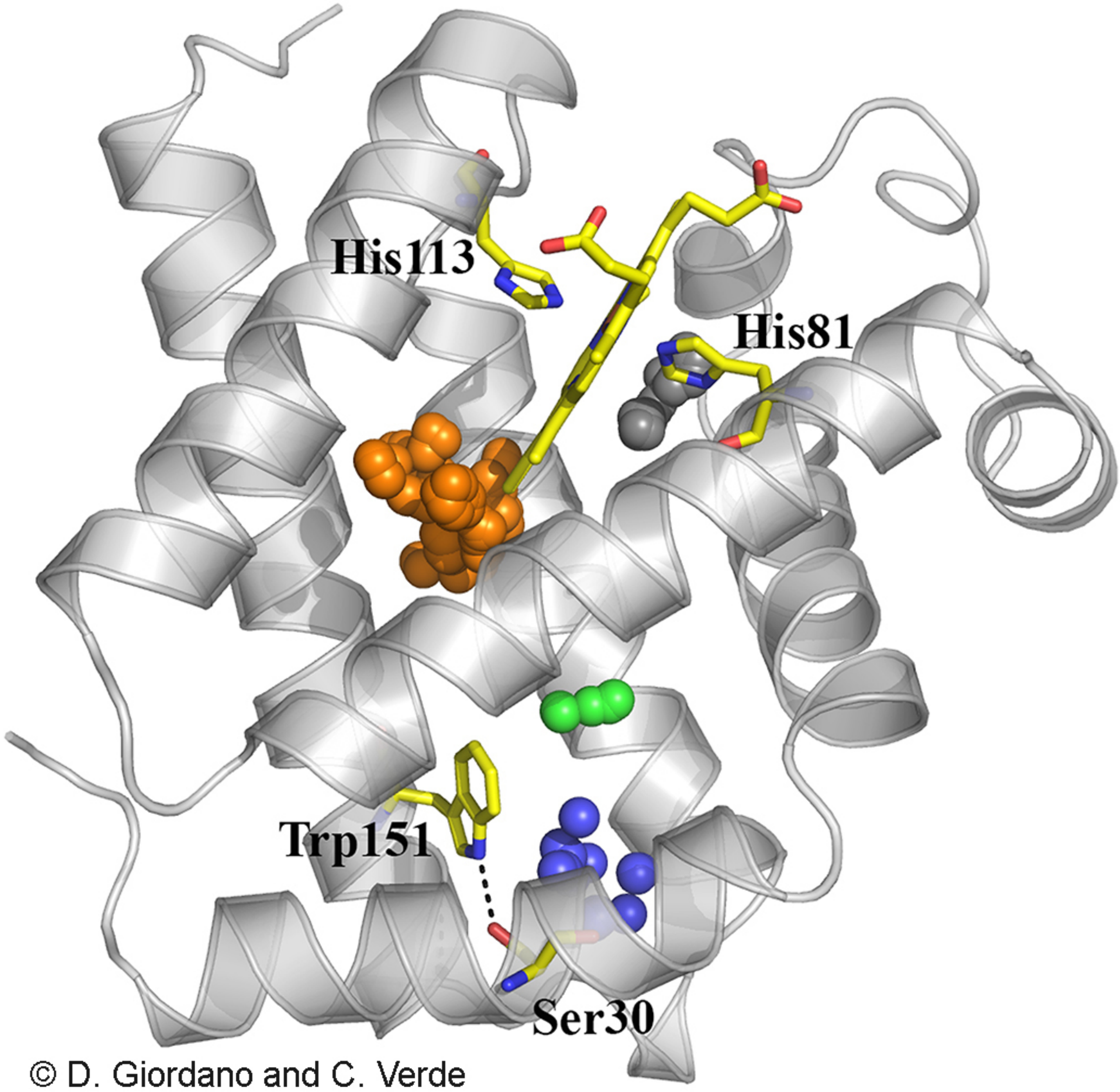

Figure 6. Structure of the protein cytoglobin of the Antarctic toothfish Dissostichus mawsoni, Cytoglobins are important in oxygen supply and control of protein damage in Antarctic fishes. © Daniela Giordano and Cinzia Verde

(6) Thermal resilience responses of species are poor, complex and variable.

Terrestrial species have significant abilities to survive warming, while marine species do not. However, terrestrial species are vulnerable to freeze-thaw cycles. Genetic adaptations are unlikely to keep pace with rapid environmental changes because of the typically long generation times of most species. Both high and low temperatures can cause proteins to unravel or be damaged. In marine species at low temperatures this affects organismal function, including slow growth rates and impacts on oxygen supply where cytoglobins help to control damage (Figure 6). Low temperature limitations may also drive protein functional innovation, and low temperature proteins. Especially cold-active enzymes may be amongst the most promising targets for bioprospecting.

Figure 7. Crabeater seals live in the pack-ice zone and are, thus, sensitive to changes in the extent and dynamics of the sea-ice. © Ryan Reisinger

(7) Sea-ice strongly controls the functioning of almost all marine ecosystem components.

Changing sea-ice conditions, including extent, concentration and duration, have major impacts on marine food webs, including the diatom – krill – top predator system, as well as seafloor communities (Figure 7). Sea-ice variability also affects the availability and quality of foraging and breeding grounds for predator groups such as penguins and seals.

Figure 8. Seabirds, such as the black-browed albatross, suffer from water-borne pollutants and debris, e.g., microplastics and lost fishing gear. © José Xavier

(8) Known and new pollutants are increasingly found in the Antarctic environment, but responses of organisms and communities remain under-surveyed.

Antarctic ecosystems are sinks for anthropogenic bioaccumulative persistent organic pollutants (POPs) and heavy metals. Also, macro- and microplastics are increasingly found in terrestrial and marine habitats and organisms in the Antarctic.

Figure 9. Increased retreat of ice on land and on lakes leads to the mixing of previously isolated populations of nematodes due to glaciation. © Byron Adams

(9) Continental biota are highly endemic and, thus, at risk from climate change.

Increasing terrestrial habitat connectivity by melting ice increases the dispersion of organisms and mixes populations which are genetically more distinct than previously thought (Figure 9). Consequently, competition for resources among populations and species may increase, particularly as habitats become more connected. Novel niches and/or favourable habitats for invasive species are also likely to develop.

Figure 10. This many-armed starfish (Freyella fragilissima) lives only under ice shelves and in the deep sea. As ice shelves break up due to climate warming, the survival of such species is threatened. © J. Gutt & W. Dimmler, AWI/MARUM

(10) Recently-discovered rare, patchy and small assemblages thriving under particular environmental conditions are especially vulnerable to climate risks.

Highly adapted biota, characterized by a unique biodiversity and performing unique ecosystem functions, were discovered in special habitats. These include subglacial lakes; the subsurface or under ice shelves; hydrothermal vents and seeps; as well as geothermal habitats on land; coral aggregations; and seamounts (Figure 10).

Challenges

The research of the previous years provides sharply increasing evidence that a number of important ecosystem components in the Antarctic and Southern Ocean are already under environmental stress or are expected to be at even more risk in the future [7,8,9,10,11]. Improving projections on how life in the Antarctic will respond to climate change demands a combination of additional basic information on long-term natural variability in patterns and processes and a better understanding of ecosystem functioning[12]. To achieve this aim, more year-round and multi-year observations need to be carried out. Cross-disciplinary synoptic ecological surveys should have a high temporal and spatial resolution and provide the basis to analyze and detect the impact of multiple stressors[13]. In addition, sound information on the adaptive capacities of key species and ecological functions, including interactions, can provide a basis on which to develop reliable future scenarios.

A few research themes are under-represented in the scientific literature including for example, remineralization of dead biomass to new nutrients (recycling) at the sea-floor and response of organisms to pollution, which are recognised as being important in an environmental context, and essential knowledge for answering urgent questions. Techniques with a high potential to advance scientific progress in this field include, among others, an increased use of autonomous sampling platforms (e.g., robotic floats, unmanned aerial and underwater vehicles), rapidly improving non-invasive imaging and acoustic methods for biological surveys, analyses of environmental DNA, and ecological modelling. These can assist not only in developing spatially explicit projections for the future, but also identifying key ecological functions.

Conclusion

The past decade was very successful for research on biological and ecological processes and functions in Antarctica and the Southern Ocean. We now know that climate change will result in winners and losers among ecologically key species, increasing and decreasing biodiversity and primary production, as well as changed biogeochemical functions [14,15,16].

We conclude that our current knowledge on the human footprint is essential to inform Antarctic Treaty policy and national legislation to ensure healthy Antarctic ecosystems. It already justifies an extended protection of Antarctic biota from the risks of climate change, pollution and other anthropogenic disturbances[17,18].

We also gained a significantly better understanding of which processes, regions or organisms in the Antarctic we have to look at to elucidate the future of all Antarctic ecosystems and to design novel integrative studies of ecosystem research[4,19].

Finally, our synthesis also highlights that major advances in question-driven Antarctic research depend on a good balance between applied scientific approaches, such as solving climate-, conservation- and ecosystem-management problems, and the academic freedom to carry out fundamental research, which in turn informs the applied approaches.

Other information:

REFERENCES | PORTALGRAPHIC

1. J. Gutt, E. Isla, J. Xavier, B. Adams, et al, Antarctic ecosystems in transition – life between stresses and opportunities. *Biological Reviews* (2020). Doi: 10.1111/brv.12679
2. L.S. Peck, Antarctic marine biodiversity: adaptations, environments and responses to change. *Oceanography and Marine Biology: An Annual Review* **56**, 105–236 (2018)
3. G.K. Saba, W.R. Fraser, V.S. Saba, R.A. Iannuzzi, et al, Winter and spring controls on the summer food web of the coastal West Antarctic peninsula. *Nature Communications* **5**, 4318 (2014). Doi: 10.1038/ncomms5318
4. A.J. Constable, D.P. Costa, O. Schofield, L. Newman, et al, Developing priority variables ("ecosystem Essential Ocean variables" – eEOVs) for observing dynamics and change in Southern Ocean ecosystems. *Journal of Marine Systems* **161**, 26–41 (2016). Doi: 10.1016/j.jmarsys.2016.05.003.
5. C.K. Lee, D.C. Laughlin, E.M. Bottos, T. Caruso, et al, Biotic interactions are an unexpected yet critical control on the complexity of an abiotically driven polar ecosystem. *Communications Biology* **2**, 62 (2019). Doi: 10.1038/s42003-018-0274-5
6. A.D. Rogers, B.A.V. Frinault, D.K.A. Barnes, N.L. Bindoff, et al, Antarctic futures: an assessment of climate-driven changes in ecosystem structure, function, and service provisioning in the Southern Ocean. *Annual Review of Marine Science* **12**, 87–130 (2020). Doi: 10.1146/annurev-marine-010419-011028
7. J. Turner, N.E. Barrand, T.J. Bracegirdle, P. Convey, et al, Antarctic climate change and the environment: an update. *Polar Record* **50**, 237–259 (2014). Doi: 10.1017/S0032247413000296
8. P. Convey, L.S. Peck, Antarctic environmental change and biological responses. *Science Advances* **5**, eaaz0888 (2019). Doi: 10.1126/sciadv.aaz0888
9. M. Meredith, M. Sommerkorn, S. Cassotta, C. Derksen, et al, Polar regions. In: H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M., Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J., Petzold, B. Rama and N. M. Weyer (eds) *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* (2019), pp 203–320.
10. S.L. Chown, C.M. Brooks, The state and future of Antarctic environments in a global context. *Annual Review of Environment and Resources* **44**, 1–30 (2019). Doi: 10.1146/annurev-environ-101718-033236
11. S.A. Morley, D. Abele, D.K.A. Barnes, C.A. Cárdenas, et al, Global drivers on Southern Ocean ecosystems: changing physical environments and anthropogenic pressures in an earth system. *Frontiers in Marine Science* **7**, 1–24 (2020). Doi: 10.3389/fmars.2020.547188
12. M.C. II Kennicutt, D. Bromwich, D. Liggett, B. Njåstad, et al, Sustained Antarctic research: a 21th century imperative. *One Earth* **1**, 95–113 (2019). Doi: 10.1016/j.oneear.2019.08.014
13. J. Gutt, N. Bertler, T.J. Bracegirdle, A. Buschmann, et al, The Southern Ocean ecosystem under multiple climate stresses – an integrated circumpolar assessment. *Global Change Biology* **21**, 1434–1453 (2015). Doi: 10.1111/geb.12794
14. H.J. Griffiths, A.J.S. Meijers, T.J. Bracegirdle, More losers than winners in a century of future Southern Ocean seafloor warming. *Nature Climate Change* **7**, 749–755 (2017). Doi: 10.1038/NCLIMATE3377
15. M.A. Hindell, R.R. Reisinger, Y. Ropert-Coudert, L. Hückstädt, et al, Tracking of marine predators to protect Southern Ocean ecosystems. Nature **580**, 87–92 (2020). doi: 10.1038/s41586-020-2126-y
16. S.F. Henley, E.L. Cavan, S.E. Fawcett, R. Kerr, et al, Changing biogeochemistry of the Southern Ocean and its ecosystem implications. *Frontiers in Marine Science* **7**, 581 (2020). Doi: 10.1098/rsta.2017.0168
17. H. Flores, A. Atkinson, S. Kawaguchi, B.A. Krafft, et al, Impact of climate change on Antarctic krill. *Marine Ecology Progress Series* **458**, 1–19 (2012). Doi: 10.3354/meps09831
18. K.A. Hughes, A. Constable, Y. Frenot, J. López-Martínez, et al, Antarctic environmental protection: strengthening the links between science and governance. *Environmental Science & Policy* **83**, 86–95 (2018). Doi: 10.1016/j.envsci.2018.02.006
19. J. Gutt, E. Isla, N. Bertler, G.E. Bodeker, et al, Cross-disciplinarity in the advance of Antarctic ecosystem research. *Marine Genomics* **37**, 1–17 (2018). Doi: 10.1016/j.margen.2017.09.006