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Antarctic marine biodiversity: challenges and future outlook

Toni Wi

Student ID: 56617477

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Abstract: The conservation of biodiversity is an issue of global importance, especially in response to widespread global change as a result of human activity. In Antarctica, the Protocol on Environmental Protection to the Antarctic Treaty has been in operation since 1991. Even though the continent and surrounding Southern Ocean is designated as an area devoted to peace and science, there is a significant lack of cohesive biodiversity management in both terrestrial and marine ecosystems.

In 2015 a group of experts on Antarctica and biodiversity convened in Monaco to discuss the biodiversity outlook for Antarctica and the Southern Ocean. The resulting strategy is known as the Monaco Assessment, and aims to conserve the biodiversity of Antarctica in accordance with the global Strategic Plan for Biodiversity for 2011-2020.

The purpose of this report is to understand the challenges facing the management and conservation of biodiversity, as human activity in Antarctica is increasing along with the effects of climate change, ocean acidification, and invasive species. What do we know about marine biodiversity in Antarctica? Can biodiversity targets be set in the Southern Ocean? Where do we need to focus our efforts, and why? A Biodiversity Strategy for Antarctica can help prioritise research in areas where there are gaps in the knowledge base, and align with the framework of the Convention on Biological Diversity for more effective management.

+ Introduction

Antarctica and the surrounding Southern Ocean is a globally significant region that is governed by the Antarctic Treaty System and the Protocol on Environmental Protection. However, conservation challenges facing the region are putting pressure on the Antarctic Treaty System and policy makers to respond.[1] Human activity in Antarctica is increasing due to tourism, science, and fisheries in the Southern Ocean. The potential consequences of increased activity are the introduction of non-indigenous species, point-source pollution, and over-exploitation of marine resources.[2] Stressors such as these may be exacerbated by the ecosystem effects of anthropogenic impacts, such as climate change and ocean acidification.[3]

The Southern Ocean has a critical role to play in the circulation of water throughout the global ocean, and is an important regulator of climate and atmospheric carbon dioxide.[4] Conserving marine biodiversity is a key priority considering the importance of biodiversity in maintaining ecosystem services, such as provisioning and regulating services in the marine environment[5]. The conservation of biodiversity underpins the UN Convention on Biological Diversity, as seen in the Strategic Plan for Biodiversity 2011-2020.[6] This plan includes 20 targets, known as Aichi Biodiversity Targets, with a range of strategic goals that together act as an overarching framework for biodiversity management.[7]

The strategic goals are to:

A. Mainstream biodiversity across government and society
B. Reduce direct pressures on biodiversity and promote sustainable use
C. Safeguard ecosystems, species, and genetic diversity
D. Enhance the benefits from biodiversity and ecosystem services

[1] S. L. Chown et al., "Challenges to the Future Conservation of the Antarctic," *Science (New York, N.Y.)* 337, no. 6091 (2012).
[2] Monaco Assessment Document (2015).
[3] Huw J. Griffiths, "Antarctic Marine Biodiversity--What Do We Know About the Distribution of Life in the Southern Ocean?," *PloS one* 5, no. 8 (2010).
[4] nd Mahlon C. Kennicutt et al., "Polar Research: Six Priorities for Antarctic Science," *Nature* 512, no. 7512 (2014).
[5] Philippe Goulletquer et al., *Biodiversity in the Marine Environment* (Cham: Springer, 2014).
[6] Convention on Biological Diversity Strategic Plan for Biodiversity https://www.cbd.int/sp/ (accessed 4/3/16).
[7] Convention on Biological Diversity Aichi Targets https://www.cbd.int/sp/targets/ (accessed 4/3/16).

E. Enhance implementation through planning, knowledge management, and capacity building

In 2015, a group of Antarctic and biodiversity experts met to discuss the biodiversity outlook for Antarctica, and the extent to which it was achieving targets under the Strategic Plan for Biodiversity 2011-2020. The outcome of this meeting is the Monaco Assessment, which states that although the outlook for Antarctica appears to be no better than elsewhere in the world, effective action in the coming years has the prospect to significantly improve the biodiversity outlook for Antarctica[8]. This would be through the implementation of a specialized Antarctic Biodiversity Strategy and Action Plan, with Biodiversity targets in accordance with framework of the Convention on Biological Diversity.[9]

The aim of this paper is to investigate the outlook, issues, and developments within the realm of Antarctic marine biodiversity, including the challenges of creating and implementing a Biodiversity Strategy for the Southern Ocean. A brief overview of Antarctic marine biodiversity projects will be followed by critical issues in assessing marine biodiversity and a discussion on creating Antarctic biodiversity targets that can be assessed in a global context.

+ Antarctic marine biodiversity projects

In order to meet biodiversity targets in the Southern Ocean a baseline must first be established for progress to be measured against.[10] This is where Antarctic marine biodiversity projects and initiatives are particularly beneficial. Such projects include the Census of Marine Life (CoML), the Census of Antarctic Marine Life (CAML), and the data component, the Marine Biodiversity Information Network of the Scientific Committee on Antarctic Research (SCAR MarBin).[11] CAML cruises collected biodiversity data as part of the International Polar Year 2007-2009, with over 18,000 taxa identified and more than 700

[8] Monaco Assessment Document (2015).
[9] Ibid.
[10] Huw J. Griffiths, Bruno Danis, and Andrew Clarke, "Quantifying Antarctic Marine Biodiversity: The Scar-Marbin Data Portal," *Deep-Sea Research Part II* 58, no. 1 (2011).
[11] Claude De Broyer and Bruno Danis, "How Many Species in the Southern Ocean? Towards a Dynamic Inventory of the Antarctic Marine Species," ibid.

species discovered that were new to science.[12] The Register of Antarctic Marine Species (RAMS) was established thereafter to provide an easily accessible taxonomic database. RAMS encompasses all Antarctic marine species in a comprehensive range of habitats such as the seafloor, the water column, and the sea ice, and covers the entire geography of the Antarctic region, from the continental coast to sub-tropical fronts.[13]

The core idea behind CAML was to integrate knowledge on the *Known, Unknown,* and *Unknowable* diversity of marine life across all regions of the Southern Ocean, with a specific set of goals for different habitats and size classes.[14] As part of the CAML legacy new projects and products have been developed, including the Biogeographic Atlas of the Southern Ocean, and the Antarctic Biodiversity Information Facility.[15] Coordinating and integrating available knowledge improves understanding on biodiversity in the Southern Ocean, and allows for more detailed evaluation of the distribution and evolution of marine biota.[16]

The SCAR Southern Ocean Continuous Plankton Recorder Survey (SO-CPR) is a monitoring program producing a comprehensive data set on Zooplankton in the Southern Ocean.[17] Because zooplankton are particularly sensitive to environmental change they can be used as indicators. Mapping the current distribution in the Southern Ocean is important again in providing a baseline to monitor future impacts, such as climate change. Data collected from the survey has been used to validate the CPR, develop modelling protocols, and to test modelling for research on bioregionalisation.[18] Bioregionalisation is a type of analysis that identifies boundaries between distinct habitats, and is a useful first step for developing a representative network of marine protected areas.[19] The resulting bioregions have a set of predictable ecosystem properties and can be used as discrete management units for the conservation of marine resources and the management of marine activity, as regulated by

[12] Huw Griffiths Angelika Brandt, Julian Gutt, Katrin Linse, Stefano Schiaparelli, Tosca Ballerini, Bruno Danis, Olaf, Pfannkuche, "Challenges of Deep-Sea Biodiversity Assessments in the Southern Ocean," *Advances in Polar Science* 25, no. 3 (2014).
[13] De Broyer and Danis, "How Many Species in the Southern Ocean? Towards a Dynamic Inventory of the Antarctic Marine Species."
[14] Guido Di Prisco, Cinzia Verde, and Corporation Ebooks, *Adaptation and Evolution in Marine Environments: The Impacts of Global Change on Biodiversity* (New York;Heidelberg;: Springer, 2013).
[15] Ibid.
[16] Griffiths, "Antarctic Marine Biodiversity--What Do We Know About the Distribution of Life in the Southern Ocean?."
[17] David J. McLeod et al., "Zooplankton Atlas of the Southern Ocean: The Scar So-Cpr Survey (1991–2008)," *Polar Science* 4, no. 2 (2010).
[18] Ibid.
[19] WWF http://www.wwf.org.nz/what_we_do/marine/antarctic/marine_protected_areas/ (accessed 4.3.16).

the Commission for the Conservation of Marine Living Resources (CCAMLR), and also the Committee for Environmental Protection (CEP).[20]

Another significant project that has contributed to a greater understanding of the biodiversity and biogeography of the Southern Ocean is the Antarctic benthic DEEP-sea biodiversity (ANDEEP) project, which ran from 2002-2005.[21] The objectives of the surveys were to conduct a comprehensive survey of deep-water communities in the Scotia and Weddell seas, investigate similarities between Atlantic basin and Antarctic shelf taxa, determine the influence of habitat diversity on species diversity and genetic diversity over different spatial scales, determine the importance of life history strategies and larval biology, and lastly, to investigate evolutionary processes resulting in present-day biodiversity.[22] The ANDEEP project found high levels of biodiversity in the Southern Ocean deep-sea, and challenged the assumption of declining biodiversity in this area.[23] It also made possible the ability to compare fauna to other deep-sea ocean basins by using similar sampling strategies and operational gear.[24]

CAML was a 5-year operation that resulted in a wide array of knowledge on the biodiversity and biogeography of the Southern Ocean, but there are a host of challenges to consider if progress is to be made in conserving and managing biodiversity in such a remote and globally significant region.

+ Issues, outcomes, and developments

Oceanic research, and deep-sea research in particular, is expensive, time-consuming, and logistically challenging, which may help to explain why there are such large gaps in the knowledge base.[25] Although the deep-sea is the largest benthic habitat in the world it is the

[20] Grant, S., Constable, A., Raymond, B. and Doust, S., "Bioregionalisation of the Southern Ocean: Report of Experts Workshop", Hobart, WWF-Australia and ACE CRC (September 2006).
[21] Angelika Brandt and Brigitte Ebbe, "Southern Ocean Deep-Sea Biodiversity—from Patterns to Processes," *Deep-Sea Research Part II* 56, no. 19 (2009).
[22] Angelika Brandt et al., "Introduction to Andeep (Antarctic Benthic Deep-Sea Biodiversity: Colonization History and Recent Community Patterns)—a Tribute to Howard L. Sanders," ibid.51, no. 14 (2004).
[23] Angelika Brandt and Brigitte Ebbe, "Southern Ocean Deep-Sea Biodiversity—from Patterns to Processes," ibid.56, no. 19 (2009).
[24] Ibid.
[25] Brandt and Ebbe, "Southern Ocean Deep-Sea Biodiversity—from Patterns to Processes."

least studied, especially in the Southern Ocean.[26] Within the wider region there are also areas that are underrepresented, and the Antarctic Peninsula is one data poor area in the Southern Ocean Continuous Plankton Recorder data set.[27] This is an issue because of the rapid warming and associated physical, biological, and ecological effects observed in the Peninsula region. The possibility of the CPR data to detect future change would therefore be disadvantaged by a lack of information.[28]

In a paper published in Science Magazine, the challenges facing science programs in Antarctica are briefly described.[29] One point raised is that postponed projects due to financial constraints, among other reasons, leave gaps that result in missing data. In biodiversity monitoring this loss can be particularly damaging. It is also difficult to gain access to various locations, especially when scientist only visit for a few months during a single season any given year. There is an opportunity for autonomous vehicles to be developed that can reach hard to access places, such as under-sampled areas and deep sea habitats in the Southern Ocean.[30]

The intensity of sampling changes with location, with a greater sampling effort occurring in the immediate vicinity of national bases.[31] Sampling in the open water is more often carried out along the routes of vessels that visit the bases due to the high cost of ship-based research.[32] Also in terms of a depth profile and the logistics of deep-sea sampling, most benthic samples come from less than 500m depth, with most of the Antarctic seafloor far deeper than 500m.[33] Gaps in sampling observed in the SCAR-MarBIN data portal are the deep sea, the western Weddell Sea, which is mostly ice-covered, and the Amundsen Sea, which is geographically remote and thus difficult to sample.[34] Another factor to consider is the kind of sampling undertaken, as benthic sampling efforts record all species collected but with targeted sampling only the species of interest is recorded rather than a complete

[26] Ibid.
[27] McLeod et al., "Zooplankton Atlas of the Southern Ocean: The Scar So-Cpr Survey (1991–2008)."
[28] Ibid.
[29] Kennicutt et al., "Polar Research: Six Priorities for Antarctic Science."
[30] Angelika Brandt, "Challenges of Deep-Sea Biodiversity Assessments in the Southern Ocean."
[31] Griffiths, "Antarctic Marine Biodiversity--What Do We Know About the Distribution of Life in the Southern Ocean?."
[32] Ibid.
[33] Ibid.
[34] Griffiths, Danis, and Clarke, "Quantifying Antarctic Marine Biodiversity: The Scar-Marbin Data Portal."

inventory.[35] The sampling strategy used can influence the overall pattern of observed biodiversity and must be considered in future assessments.[36]

An additional sampling bias is body size, as less is known about smaller sized species due to challenges in identification for particular species and a lack of taxonomic expertise.[37] The Microbial Antarctic Resource System is one attempt to rectify the knowledge gap for bacterial diversity in the Southern Ocean, and targeted efforts such as this could be employed for other data-poor taxon in the future[38]. There is a need to improve sampling strategies and develop statistical methods in order to avoid and remove the effect of sampling biases.[39] It is also important to consider different spatial scales to better distinguish patterns in abundance and distribution.[40] In terms of species extinctions it is difficult to comment on the conservation status of different species if many are known from only single recorded specimens.[41] Likewise, the ability to identify whether a species is new or invasive may be restricted due to the high rate of discovery of species in the deep shelf and abyssal depths.[42]

The assessment of unknown biodiversity has been greatly improved through the use of molecular taxonomic techniques, such as DNA barcoding. DNA barcoding was supported as part of the CAML initiative as a way to further investigate the distribution of biodiversity in the Southern Ocean.[43] The Antarctic Barcoding Campaign was hosted in a database specially designed for barcode information, with data for the COI gene as used in the Marine Barcode of Life Project (MarBOL), as well as other non-COI barcodes.[44] Out of a total of 34 marine phyla, 18 have at least one Antarctic barcode sequence, with the number of Antarctic barcode sequences increasing from 432 to 20,355.[45] A major outcome of DNA barcoding in Southern Ocean fauna is the identification of a large number of cryptic species that are

[35] Ibid.
[36] Ibid.
[37] Angelika Brandt, "Challenges of Deep-Sea Biodiversity Assessments in the Southern Ocean."
[38] Ibid.
[39] Griffiths, Danis, and Clarke, "Quantifying Antarctic Marine Biodiversity: The Scar-Marbin Data Portal."
[40] Angelika Brandt, "Challenges of Deep-Sea Biodiversity Assessments in the Southern Ocean."
[41] Griffiths, "Antarctic Marine Biodiversity--What Do We Know About the Distribution of Life in the Southern Ocean?."
[42] Ibid.
[43] Rachel A. Grant et al., "Antarctic DNA Barcoding; a Drop in the Ocean?," *Polar Biology* 34, no. 5 (2011).
[44] Ibid.
[45] Ibid.

morphologically very similar but exhibit a high level of genetic divergence.[46] Cryptic species are often hard to discern, which is why DNA barcoding has been so beneficial in the Antarctic realm where cryptic species complexes seem to be common.[47] DNA barcoding has also changed interpretations of species distributions, with certain circumpolar species now found to be made up of previously unknown species described through the use of genetic analysis, with subsequent narrower depth and geographic distributions.[48] However, knowledge gaps remain, such as a lack of barcoding data for groups such as the nemertines, bryozoans, ascidians, brachiopods, and sponges.[49] Molecular taxonomists must aim to cover a representative geographic area, as well as depths, to improve overall coverage in addition to focusing on data-poor taxon.[50]

One finding of the Southern Ocean Continuous Plankton Recorder survey was of increased zooplankton abundance in a particular area of the Kerguelen Plateau region, indicating a potential hotspot of productivity likely related to iron enrichment.[51] The discovery of biodiversity hotspots is of particular interest in conservation for setting biodiversity targets. It may also be useful knowledge to consider when designing a representative network of marine protected areas.

Recent developments and new initiatives have the potential to greatly improve understanding of biodiversity and address some of the challenges faced in the assessment and management of marine biodiversity in Antarctica. The SCAR program State of the Antarctic Ecosystem (AntEco) aims to increase the knowledge of biodiversity for the conservation and management of Antarctic ecosystems, and encompasses five different sectors of research.[52] Multidisciplinary approaches and collaboration between the different sectors is encouraged.[53] Antarctic Thresholds – Ecosystem Resilience and Adaptation (AnT-ERA) is a platform designed to support science on the resilience of Antarctic ecosystems in the face of global environmental change. This includes research on the likelihood of crossing

[46] Rachel Anne Grant and Katrin Linse, "Barcoding Antarctic Biodiversity: Current Status and the Caml Initiative, a Case Study of Marine Invertebrates," *Polar Biology* 32, no. 11 (2009).
[47] Rachel A. Grant et al., "Antarctic DNA Barcoding; a Drop in the Ocean?," ibid.34, no. 5 (2011).
[48] Ibid.
[49] Grant and Linse, "Barcoding Antarctic Biodiversity: Current Status and the Caml Initiative, a Case Study of Marine Invertebrates."
[50] Rachel A. Grant et al., "Antarctic DNA Barcoding; a Drop in the Ocean?," ibid.34, no. 5 (2011).
[51] McLeod et al., "Zooplankton Atlas of the Southern Ocean: The Scar So-Cpr Survey (1991–2008)."
[52] SCAR State of the Antarctic Ecosystem http://www.scar.org/anteco/anteco-about (accessed 4/3/16).
[53] State of the Antarctic Ecosystem (AntEco) Implementation Plan (2013).

thresholds. An ecosystem threshold is often referred to as a tipping point, where an ecosystem experiences a rapid change in state.[54] The objectives of AnT-ERA and AntEco will complement each other, with AntEco providing an evolutionary context for AnT-ERA research.[55] Specific outcomes of the AnT-ERA platform are publications, outreach, capacity building, and recommendations, including the flow of data through servers and networks to decision makers.

AnT-ERA is not an isolated platform, but rather seeks to maintain collaborations with other organizations and initiatives such as CCAMLR, the CEP, the SO Continuous Plankton Recorder, and the Southern Ocean Observing System (SOOS). SOOS is an initiative of SCAR and the Scientific Committee on Oceanic Research (SCOR), and aims to facilitate the collection and delivery of observations on changing Southern Ocean systems to relevant stakeholders.[56] Observations are required in order to detect and respond to change, and long-term biological monitoring across different habitats, or even bioregions, will mean a substantial commitment in terms of funding and international cooperation.[57] Although the marine environment is not a specific focus of AnT-ERA and AntEco, targeted research on marine biodiversity in the Southern Ocean can still be extremely relevant to the goals and targets of both initiatives; for example, research investigating the relationship between biodiversity and ecosystem resilience in the marine environment and the importance of marine biodiversity for the provision of Southern Ocean ecosystem services. Greater collaboration and coordination with similar research initiatives can help to address challenges posed by expensive oceanic research and gaps in the knowledge base, and broaden understanding of Antarctic marine biodiversity.

+ Biodiversity targets in the Southern Ocean

In order to create a biodiversity strategy for the Southern Ocean a framework must be established. A framework is a broad overview that supports a particular approach to a

[54] SCAR Antarctic Thresholds – Ecosystem Resilience and Adaptation http://www.scar.org/antera/antera-about (accessed 4/3/16).
[55] SCAR Antarctic Thresholds – Ecosystem Resilience and Adaptation http://www.scar.org/antera/antera-about (accessed 4/3/16).
[56] Southern Ocean Observing System http://www.soos.aq/about-us/mission (accessed 4/3/16).
[57] Griffiths, "Antarctic Marine Biodiversity--What Do We Know About the Distribution of Life in the Southern Ocean?."

specific objective.[58] In this instance a clear objective is needed. The mission statement for the Strategic Plan for Biodiversity 2011-2020 is to halt the loss of biodiversity, which is ensured by the five strategic goals. These goals are conservation aspirations by which national or regional targets can then be set.[59] A specific set of targets can therefore be developed under the objective of the Strategic Plan for Biodiversity, which is specifically to halt the loss of biodiversity, or more broadly, to conserve biodiversity.

The development of regionally specific biodiversity targets must take into account national needs and priorities.[60] However, Antarctica is not governed by one national body, but through the Antarctic Treaty System. Priorities for a biodiversity strategy, and also contributions to global targets, must be discussed through appropriate channels within the ATS, and may include multiple bodies, such as CCAMLR and the CEP. Chown and colleagues note that most parties with an interest in Antarctic activities have a national biodiversity strategy under the CBD, but the Antarctic is rarely considered and there is no comparable regional plan.[61] They also compared the relevance of Antarctica to the Aichi Biodiversity Targets, and found that some of them are not immediately relevant to the Antarctic and some were only relevant in the marine environment, such as resource use and climate change mitigation. On the final target, the authors state that there is currently no mechanism for the mobilization of financial resources in support of a strategic plan for biodiversity in Antarctica and the Southern Ocean. This further emphasizes the need for not only an Antarctic biodiversity strategy, but one targeted for the marine environment.

In setting biodiversity targets, establishing comprehensive baseline data is crucial in order to understand the current state of biodiversity in the Southern Ocean and the actions required to meet the objective of the biodiversity strategy. Taxonomic inputs must be maintained and improved to describe new and unknown biodiversity, and further supporting taxonomic databases, web-ID tools, and molecular taxonomy may help to achieve this goal.[62] Indicators are also necessary for biodiversity targets, and as part of the Strategic Plan for

[58] Business Dictionary http://www.businessdictionary.com/definition/framework.html (accessed 4/3/16).
[59] Convention on Biological Diversity Strategic Plan for Biodiversity Key Elements https://www.cbd.int/sp/elements/default.shtml (accessed 4/3/16).
[60] Convention on Biological Diversity Strategic Plan for Biodiversity Key Elements https://www.cbd.int/sp/elements/default.shtml (accessed 4/3/16).
[61] Steven L. Chown et al., "The Changing Form of Antarctic Biodiversity," *Nature* 522, no. 7557 (2015).
[62] De Broyer and Danis, "How Many Species in the Southern Ocean? Towards a Dynamic Inventory of the Antarctic Marine Species."

Biodiversity 2011-2020 indicators are specified as trends broken down into the relevant operational indicators.[63] Ongoing monitoring is required in order to evaluate trends, and collaboration with monitoring initiatives such as the Southern Ocean Observing System is imperative.

One final point to consider is the hierarchical structure of biodiversity, which comprised of four main components: genetic diversity, species diversity, ecosystem diversity, and functional diversity.[64] Functional diversity, the array of biological processes or functions of an ecosystem, may be a convenient way of assessing biodiversity without the need to catalogue species.[65] Similarly, the assessment of diversity within bioregions might be possible when considering different scales. It is important to note however that no single measurement of biodiversity is sufficient and the linkages between them need to be understood, as one component may be inappropriate in evaluating the effect of biodiversity at a particular spatial scale.[66]

The state of biodiversity is a consequence of ecological, evolutionary, environmental, and human pressures, and monitoring biodiversity can lead to progress towards achieving management objectives.[67] Creating a biodiversity strategy for the Southern Ocean allows for the prospect of targeted conservation action within a specific timeframe, assessed in a global context under the Convention on Biological Diversity.

+ Conclusion

Understanding of marine biodiversity in Antarctica has been greatly improved due to census, observing, and barcoding initiatives undertaken in recent years. Although these projects do not come without challenges, such as sampling biases and gaps in the knowledge base, collaboration and coordination of current projects have the potential to broaden the scope of research in the Southern Ocean. There is great potential for an Antarctic biodiversity strategy with targets specific to the Southern Ocean, but baseline data and ongoing

[63] 11th meeting of the Conference of the Parties for the Convention on Biological Diversity (5th December 2012).
[64] Goulletquer et al., *Biodiversity in the Marine Environment*.
[65] Ibid.
[66] Ibid.
[67] Ibid.

monitoring is required in order to assess progress made using indicators. Overall, the outlook for the state of biodiversity in the Southern Ocean can be greatly improved and build on the success and legacy of past initiatives, such as the Census of Antarctic Marine Life. The Southern Ocean is a globally significant region, and conserving and managing biodiversity into the future is a key priority in an era of rapid environmental change.