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SCAR Annual Report to the Antarctic Treaty System, 2015/16

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1. Background

The Scientific Committee on Antarctic Research (SCAR) is a non-governmental, Interdisciplinary Scientific Body of the International Council for Science (ICSU), and Observer to the Antarctic Treaty and the UNFCCC.

SCAR's Mission is (i) to be the leading, independent, non-governmental facilitator, coordinator, and advocate of excellence in Antarctic and Southern Ocean science and research and (ii) to provide independent, sound, scientifically-based advice to the Antarctic Treaty System and other policy makers, including the use of science to identify emerging trends and bring these issues to the attention of policy makers.

2. Introduction

SCAR's scientific research adds value to national efforts by enabling researchers to collaborate on large-scale scientific programmes to accomplish objectives not easily obtainable by any single country. SCAR's Members currently include 39 countries and nine ICSU Scientific Unions.

SCAR's success depends on the quality and timeliness of its scientific outputs and the volunteer time of world's leading researchers. Descriptions of SCAR's activities and scientific outputs are available at: *http://www.scar.org/*. Highlights of recent scientific publications by the SCAR research community since the last Antarctic Treaty Meeting are listed in Appendix 1. Papers submitted to ATCM XXXIX / CEP XIX 2016 are available at: *http://www.scar.org/treatypapers/atcm39*. Some papers from 2015 are also referenced and these are available at: *http://www.scar.org/treatypapers/atcm38*.

3. SCAR Highlights (2015/16)

SCAR has a number of subsidiary bodies and programmes that focus on science or science-related activities in the Antarctic region. Here we highlight and provide updates on SCAR activities that we believe to be of particular interest to Treaty Parties.

Standing Committee on the Antarctic Treaty System (SCATS)

(http://www.scar.org/antarctic-treaty-system/scats)

SCATS is the body tasked with developing SCAR's scientific advice to the Antarctic Treaty. In addition to providing and co-ordinating scientific advice for SCAR, SCATS members are also actively involved in research. SCAR supports the Antarctic Environments Portal where the SCATS Chief Officer sits on the Editorial Board, and SCAR's Executive Director sits on the Management Board. SCAR, in collaboration

with several partners, continued its development of the Antarctic Conservation for the 21st Century Strategy.

The Monaco Assessment

(http://www.scar.org/monaco-assessment/document)

In 2015, SCAR was represented at the meeting of global biodiversity and Antarctic experts entitled '*Antarctica and the Strategic Plan for Biodiversity 2011-2020: The Monaco Assessment*'. The central purpose of the meeting was to examine the extent to which conservation of the biodiversity of Antarctica and the Southern Ocean is realizing the set of ambitions agreed for the world as part of the Strategic Plan for Biodiversity 2011-2020. The meeting also aimed to provide guidance for action that can effectively help deliver further conservation successes for Antarctica and the Southern Ocean. See IP038 (*Antarctica and the Southern Ocean in the context of the Strategic Plan on Biodiversity 2011-2020*) submitted by SCAR and Monaco summarizing the workshop.

Southern Ocean Acidification

(http://www.scar.org/ssg/physical-sciences/acidification)

SCAR has undertaken a synthesis of the scientific understanding of Southern Ocean acidification. This landmark report was highlighted at the ATCM XXXVIII - CEP XVIII and was the topic the Treaty Lecture (see 2015 BP001). The report will be launched at the SCAR Open Science Conference in Kuala Lumpur, Malaysia, 22-26 August 2016.

Follow Up to The SCAR Science Horizon Scan

(http://www.scar.org/horizonscanning/)

In 2014, the 1st SCAR Antarctic and Southern Ocean Science Horizon Scan identified the most important scientific questions that should be addressed over the next two decades and beyond (see 2015 IP020). With SCAR's assistance, COMNAP has led a second stage in the process with the Antarctic Research Challenges (ARC) Project in order to assist national Antarctic programmes to understand, and develop ways to address the challenges, and share any innovation or access to technology (see IP051, submitted by COMNAP, http://www.ats.aq/). The topic of this year's SCAR Lecture will address both the science priorities from the SCAR Horizon Scan and results from the ARC project and discuss the steps needed to address those science priorities (see BP003, *Abstract of the SCAR Lecture: Exploring the future if scientific research in Antarctica*).

Antarctic Climate Change and the Environment

(http://www.scar.org/ssg/physical-sciences/acce)

The climatic, physical and biological properties of Antarctica and the Southern Ocean are closely coupled to other parts of the global environment by the oceans and the atmosphere. In 2009, SCAR published the landmark Antarctic Climate Change and

the Environment (ACCE) Report and since then has provided annual updates. See IP035 for the 2016 update.

Recommendations for activity within terrestrial geothermal areas

After a broad and extensive consultation, including the SCAR relevant subsidiary bodies and COMNAP, the *SCAR Code of Conduct for Activity within Terrestrial Geothermal Environments in Antarctica* has been developed (see WP023).

Geoheritage and Geoconservation

(http://www.scar.org/ssg/geosciences/geoconservation)

The SCAR Geological Heritage and Geoconservation Action Group was created to consider emerging concerns on the recognition, protection and ongoing management of geological and geomorphological sites of significance within the Antarctic, including fossils. Among the goals is to develop a paper for submission to the CEP in 2018. Advances in this matter are shown in IP031 (*Antarctic Geoconservation: a review of current systems and practices*).

SCAR at the UNFCCC COP21

(http://www.scar.org/srp/ant-era#COP21)

SCAR played an active role at the historic 2015 UNFCCC COP21 held in Paris, highlighting changes in the Antarctic that have global ramifications and promoting Antarctic science in general. SCAR partnered with the International Cryosphere Climate Initiative (ICCI) for two official events on Antarctica Day (December 1st) and promoted the 2015 ACCE update presented to ATCM XXXVIII (See 2015 IP092) and information on the Antarctic Environments Portal.

SCAR Data and Products

(http://www.scar.org/data-products)

SCAR promotes free and unrestricted access to Antarctic data and information through open and accessible archives, managed by its Standing Committees on Antarctic Data Management (SCADM) and Antarctic Geographic Information (SCAGI). SCAR also has several products of relevance to the Antarctic community, such as Quantarctica, the Antarctic Map Catalogue, and the Biogeographic Atlas of the Southern Ocean among others.

Antarctic Sea Ice Underway Observation Platform v2

(http://aspect.antarctica.gov.au/)

The Antarctic Sea Ice Process and Climate (ASPeCt) digital underway ice observation method, v.2, has been launched. Voyages from October 2015 to March 2016 have uploaded near-real time data, pending networking from vessel to central server, and automatic cameras were implemented on some research cruises to take images that

currently supplement ASPeCt visual observations. Ships going to the Antarctic are encouraged to participate in data collection.

SCAR Strategic Plan 2017-2022

(http://www.scar.org/about/futureplans)

SCAR's current Strategic Plan expires at the end of 2016 and efforts are underway for the development of a new plan to meet future needs. SCAR is consulting widely in its development and welcomes comments from all interested in the future direction of the organization and its activities. The new plan will be discussed at the XXXIV SCAR Delegates Meeting in Kuala Lumpur, Malaysia, on 29-30 August 2016, and finalized later this year.

Celebrating Women in Antarctic Research

(http://www.scar.org/outreach/women)

In the 1950s, most countries did not allow women to work in Antarctica and there were few female Antarctic scientists. Today females are playing leading and influential roles in Antarctic research. To help acknowledge this, SCAR is hosting a Wikibomb event to promote and celebrate the achievements of female Antarctic scientists by increasing their presence in Wikipedia at the next Open Science Conference. The aim is to increase the visibility of models for younger female researchers and to stimulate girls around the world to pursue science careers.

4. SCAR Fellowships and Prizes

In order to expand capacity within all its Members, SCAR runs several Fellowship and prize schemes (*http://www.scar.org/awards*):

- ***SCAR/COMNAP Fellowships*** focus on early-career researchers and aim to build new connections and further strengthen international capacity and cooperation in Antarctic research. The fellowships are advertised in tandem with the CCAMLR Scholarships. In 2015, four SCAR fellowships, including the new Prince Albert II of Monaco Biodiversity Fellowship, and one SCAR/COMNAP fellowship were awarded. A mini-symposium to highlight the SCAR/COMNAP fellowships will be held during the 2016 SCAR Open Science Conference. *http://www.scar.org/awards/fellowships*
- ***SCAR Visiting Professor Scheme*** provides mid- to late-career scientists with the opportunity to undertake short-term visits to a facility in, or operated by, other SCAR member countries, to provide training and mentoring. Two Visiting Professorships were awarded in 2015. *http://www.scar.org/awards/visitingprofs*
- ***Tinker-Muse Prize for Science and Policy in Antarctica***, funded by the Tinker Foundation and facilitated by SCAR, is a USD $100,000 unrestricted award presented to an individual in the fields of Antarctic science or policy. Dr. Valérie Masson-Delmotte was awarded the 2015 Tinker-Muse Prize for her work on the characterization, quantification and understanding of past changes in climate and water cycle, translating the isotopic data to paleo-temperature records. *www.museprize.org*

5. Other News

In an effort to continue to improve, a structural review was conducted last year resulting in several recommendations for streaming the SCAR organisational structure and meetings. This year, five of the six SCAR Scientific Research Programmes (SRPs) are also undergoing external review, as is the Southern Ocean Observing System (See IP032 for the SOOS update). SCAR itself is also being reviewed by ICSU this year. For more information, see *http://www.scar.org/about/reviews*.

In July 2015, Dr. Jenny Baeseman was appointed as the new SCAR Executive Director, replacing Dr. Mike Sparrow.

6. Major SCAR Meetings

- ***XII International Symposium on Antarctic Earth Sciences (ISAES) 2015***. 13-17th July 2015, Goa, India. *http://www.isaes2015goa.in*
- ***XXXIV SCAR Meetings and Open Science Conference***. 20-30 August 2016, Kuala Lumpur, Malaysia. *http://scar2016.com*
- ***XII SCAR Biology Symposium.*** 3-9 July 2017, Leuven, Belgium.
- ***The XXXV SCAR Meetings and Open Science Conference***, 15-27 June 2018 in Davos, Switzerland. The Open Science Conference will cover both polar regions, being organized jointly with the International Arctic Science Committee (IASC). *http://www.polar2018.org/*

Appendix 1: Selected Science Highlights for 2015/16

1. Background

This section highlights some recent key science papers published since the last Treaty meeting. Although not highlighted below, the latest ACCE update (see IP035) should also be consulted as it contains reference to recent studies on climate change in the Antarctic and Southern Ocean region. It should also be noted that this is not a complete list (there have been many highly significant papers published over the last year) but represents some of the key science papers highlighted by SCAR groups.

2. Selected Antarctic and Southern Ocean Science Highlights (2015/16)

Ice sheet mass balance, sea level, and past climate and earth sciences:

During the last two years, the Marine Ice Sheet Instability (MISI) was incorporated in simulations of ice sheet models allowing the investigation of the impact of global warming on ice dynamics. Several articles proposed projections of the contribution of Antarctica to sea level rise on the century to millennial time scales focusing on various aspects. Cornford et al. (2015) highlighted the importance of initial conditions, Gomez et al. (2015) showed that the sea level feedback has a stabilizing influence and (Ritz et al., 2015) used an ensemble method and a statistical approach constrained by observation to assess probability distribution of sea level contribution due to MISI.

- *Cornford, S. L., Martin, D. F., Payne, et al. (2015). Century-scale simulations of the response of the West Antarctic Ice Sheet to a warming climate. The Cryosphere. doi:10.5194/tc-9-1579-2015.*
- *Gomez, N., Pollard, D. and Holland, D. (2015). Sea-level feedback lowers projections of future Antarctic ice-sheet mass loss. Nature Communications. doi:10.1038/ncomms9798.*
- *Ritz, C., Edwards, T. L., Durand, G., Payne, A. J., Peyaud, V., and Hindmarsh, R. C. A. (2015). Potential sea-level rise from Antarctic ice-sheet instability constrained by observations. Nature. doi:10.1038/nature16147.*

Other simulations aimed at assessing the role of backstresses exerted by ice shelves in this instability. For instance, (Fürst et al., 2016) delineated the vulnerable regions and (Mengel et al., 2015) indicated that the response of the Weddel sea sector is almost linear and does not display a strong MISI feedback. Recent improvements on ice sheet modelling highlighted the dramatic processes linked to hydrofracturing and ice cliff failure (Pollard et al. 2015a).

- *Fürst, J.J., Durand, G., Gillet-Chaulet, F., et al. (2016). The safety band of Antarctic ice shelves. Nature Climate Change. https://dx.doi.org/10.1038/nclimate2912.*
- *Mengel, M., Feldmann, J. and Levermann, A. (2015). Linear sea-level response to abrupt ocean warming of major West Antarctic ice basin. Nature Climate Change, doi:10.1038/nclimate2808.*

- *Pollard, D., DeConto, R. M. and Alley, R.B. (2015a). Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure. Earth Plan. Sci. Lett.. doi:10.1016/j.epsl.2014.12.035.*

Agosta et al. (2015) evaluate the current climate in 41 climate CMIP5 models with the aim of regional modelling of the Antarctic surface mass balance. Trusel et al. (2015) assess the twenty-first-century evolution of surface melt across Antarctica under intermediate and high emissions climate scenarios and show that under the high emissions pathway by 2100, melt on several ice shelves approaches or surpasses intensities that have historically been associated with ice shelf collapse.

- *Agosta, C., Fettweis, X. and Datta, R. (2015). Evaluation of the CMIP5 models in the aim of regional modelling of the Antarctic surface mass balance. The Cryosphere. doi:10.5194/tc-9-2311-2015.*
- *Trusel, L. D., Frey, K. E., Das, S. B., et al. (2015). Divergent trajectories of Antarctic surface melt under two twenty-first-century climate scenarios. Nature Geoscience. doi:10.1038/ngeo2563.*

A new, highly detailed ice core retrieved by researchers with the National Science Foundation (NSF)-funded West Antarctic Ice Sheet (WAIS) Divide project revealed a consistent pattern of climate changes that started in the Arctic and spread across the globe to the Antarctic during planet Earth's last glacial period, tens of thousands of years ago. Representing more than 68,000 years of climate history, data extracted from the core - a cylinder of ice that represents a cross-section of the ice sheet - is helping scientists understand past, rapid climate fluctuations between warm and cool periods that are known as Dansgaard-Oeschger events. Published in the journal *Nature*, the new research illustrates how sudden climate changes that began in the North Atlantic around Greenland circulated southward, appearing in the Antarctic approximately 200 years later. Further, the new findings show how ocean currents were largely responsible for redistributing the heat between the Northern and Southern hemispheres in a process called the bipolar seesaw.

- *WAIS Divide Project Members. (2015). Precise interpolar phasing of abrupt climate change during the last ice age. Nature. doi:10.1038/nature14401.*

Sea-level rise in the next century will become increasingly dominated by glacier and ice sheet contributions, and threshold behaviour could bring unwelcome surprises. Of particular concern is the 'marine ice sheet instability', where initial retreat of an ice margin into a deepening valley leads to progressive, unstable ice loss. This study used results from Beryllium-10 dating to show that Mackay Glacier, an outlet of the East Antarctic Ice Sheet, underwent rapid thinning around 7,000 years ago, in a climate similar to present. This is the first study to unambiguously link geological evidence of rapid ice surface lowering to the marine ice sheet instability. It also shows that glacier thinning events, similar to those observed by satellites in rapidly changing parts of Antarctica today, may continue unabated for centuries.

- *Jones, R. S., Mackintosh, A. N., Norton, K. P., et al. (2015). Rapid Holocene thinning of an East Antarctic outlet glacier driven by marine ice sheet instability. Nature Communications. doi: 10.1038/ncomms9910.*

New information from the ANDRILL-2A drill core and a complementary ice sheet modelling study show that polar climate and Antarctic ice sheet (AIS) margins were highly dynamic during the early to mid-Miocene. Changes in extent of the AIS inferred by these studies suggest that high southern latitudes were sensitive to relatively small changes in atmospheric CO_2 (between 280 and 500 ppm). Importantly, reconstructions through intervals of peak warm temperatures indicate that the AIS retreated beyond its terrestrial margin under atmospheric CO_2 conditions that were similar to those projected for the coming centuries.

- *Levy, R., Harwood, D., Florindo, F., et al. (2016). Antarctic ice sheet sensitivity to atmospheric CO_2 variations in the early to mid-Miocene. PNAS. doi:10.1073/pnas.1516030113.*

Atmospheric concentrations of carbon dioxide are projected to exceed 500 ppm in the coming decades. It is likely that the last time such levels of atmospheric CO_2 were reached was during the Miocene, for which there is geologic data for large-scale advance and retreat of the Antarctic ice sheet. Simulating Antarctic ice sheet retreat is something that ice sheet models have struggled to achieve because of a strong hysteresis effect. Here, a number of developments in modelling approaches allowed the authors to simulate large-scale variability of the Antarctic ice sheet for the first time. These results are also consistent with a recently recovered sedimentological record from the Ross Sea at ANDRILL-2A site, presented in the above article.

- *Gasson, E., DeConto, R., Pollard, D. and Levy, R. (2016). Dynamic Antarctic ice sheet during the early to mid-Miocene. PNAS. doi:10.1073/pnas.1516130113.*

A special issue of the journal *Global and Planetary Change*, edited by Maldonado et al. (2015), presents new works that summarize significant recent research results and synthesize the current state of knowledge for the Scotia Arc. The Scotia Arc, situated between South America and Antarctica, is one of the Earth's most important ocean gateways and former land bridges. Understanding its structure and development is critical for the knowledge of tectonic, paleoenvironmental and biological processes in the southern oceans and Antarctica. As the basins opened, formation of first shallow sea ways and then deep ocean connections controlled the initiation and development of the Antarctic Circumpolar Current, which is widely thought to have been important in providing the climatic conditions for formation of the polar ice sheets. The evolution of the Scotia Arc is therefore of global palaeoclimatic significance. The Scotia Arc has been the focus of increasing international research interest. Many recent studies have stressed the links and interactions between the solid Earth, oceanographic, paleoenvironmental and biological processes in the area. This special issue contains 17 papers from many authors of different countries, and provides an updated view of the knowledge of this region.

- *Maldonado, A., Dalziel, I. W. D. and Leat, Ph. (Eds). (2015). Special Issue of Global and Planetary Change, 123-125, A1–A8.*

Ecology and Biology:

Marine:

Ground counts during 1959-1968 compared with counts using high-resolution satellite imagery during 2008-2012 indicated many fewer Weddell seals (*Leptonychotes weddellii*) at two major moulting areas in the western Ross Sea. This reduction is consistent with an altered food web, the reasons for which are complex. In the context of a recent industrial fishery targeting a seal prey species, the authors suggest a large-scale seal monitoring programme is required to increase understanding of seal population changes.

- *Ainley, D. G., Larue, M. A., Stirling, I., Stammerjohn, S. and Siniff, D. B. (2015). An apparent population decrease, or change in distribution, of Weddell seals along the Victoria Land coast. Marine Mammal Science 10.1111/mms.12220.*

Bost et al. (2015) tracked breeding king penguins (Aptenodytes patagonicus) from Crozet islands (South Indian Ocean) for 16 years and monitored their population and change in breeding success. They found that changes associated with an increased sea surface temperature of just 1°C pushed the polar front southward, and significantly increased both the distances penguins travelled to forage and the depths to which they dived to find food. Population numbers also decreased. Climate models predict that the polar front will continue to shift southwards, which may threaten king penguins and other predators in the region.

- *Bost, C. A., Cotté, C., Terray, P., et al. (2015). Large-scale climatic anomalies affect marine predator foraging behaviour and demography. Nature Communications. doi:0.1038/ncomms9220.*

Using conventional and isotopic measures of dietary overlap, this study showed that the trophic structure of the Antarctic seabird community was unaffected by annual changes in availability of different types of prey, including Antarctic krill. Even though resource abundance changed, the various seabird species maintained roughly the same position in the food web.

Moreno, R., Stowasser, G., McGill, R. A. R., Bearhop, S., and Phillips, R. A. (2016). Assessing the structure and temporal dynamics of seabird communities: the challenge of capturing marine ecosystem complexity. Journal of Animal Ecology. doi: 10.1111/1365-2656.12434.

A catch-based macrobenthos study and a sea-bed imaging survey on ascidians were carried out off the tip of the Antarctic Peninsula, an area with steep natural gradients in the environment and in climate-induced changes. The multidisciplinary analyses showed large-scale faunistic differences between the Drake Passage, Bransfield Strait and western Weddell Sea. They can partially be explained by differences in sea-ice, primary production, water depth, water masses and bottom rugosity. A possible reason for difficult to explain intermediate-scales patterns might be a high between-station heterogeneity and high small-scale variability in ascidian composition. This high species turnover shaped by unknown biological interactions may mask existing intermediate-scale physical and chemical drivers.

- *Gutt, J., Alvaro, M. C., Barco, A. Böhmer, A., et al. (2015). Macro-epibenthic communities at the tip of the Antarctic Peninsula, an ecological survey at different spatial scales. Polar Biology. doi:10.1007/s00300-015-1797-6*

The most recent knowledge on the cold limit to adaptation of marine species was comprehensively reviewed in an opinion paper by Peck (2016). It seems likely that problems with protein synthesis or protein folding are important in the slowing of rates of a wide range of physiological processes beyond the expected effects of temperature on biological systems.

- *Peck, L. S. (2016). A cold limit to Adaptation in the Sea. Trends in Ecology and Evolution. doi:10.1016/j.tree.2015.09.014*

Xavier et al. (2016) evaluates the habitats and distributions of Southern Ocean cephalopods (octopuses, squid, cuttlefish and nautiluses), which may be commercially exploited in the future. They used net-catch data to develop habitat suitability models for 15 of the most common species in the Southern Ocean. The individual habitat suitability models were overlaid to generate a ''hotspot'' index of species richness, which showed higher numbers of squid species associated with various fronts of the Antarctic circumpolar current.

- *Xavier, J. C., Raymond, B., Jones, D. C. and Griffiths, H. (2016). Biogeography of cephalopods in the Southern Ocean using habitat suitability prediction models. Ecosystems. doi:10.1007/s10021-015-9926-1.*

The uptake of anthropogenic CO_2 is altering the carbonate chemistry and pH of the world's oceans with changes for the polar oceans predicted to be amongst the most severe. This study carried out ocean acidification (OA) manipulations of natural Arctic and Southern Ocean pelagic communities. A key finding was that all copepod species preferentially grazed on dinoflagellates, compared to other phytoplankton species, when in elevated pCO_2 conditions. This demonstrates that changes in food quality and altered grazing selectivity may be a major consequence of the predicted chemical changes to the polar oceans. Such altered trophodynamic interactions will impact how carbon is channelled through polar food webs, and the extent to which future anthropogenic CO_2 emissions can be absorbed.

- *Tarling G, Peck, V., Ward, P., et al. (2016). Response of polar pelagic food-webs to predicted changes in ocean chemistry. Deep-Sea Research II. doi: 10.1016/j.dsr2.2016.02.008.*

Understanding the key drivers of population connectivity is essential for effective management of natural marine resources. Here, a seascape genetics approach, combining oceanographic modelling and microsatellite analyses, was used to understand the influences on the population genetic structure of two Antarctic fishes with contrasting life histories. Inter-annual variability in oceanographic currents strongly influenced the projected genetic structure, suggesting that shifts in circulation patterns due to climate change are likely to impact future genetic connectivity and opportunities for local adaptation, resilience and recovery from perturbations.

- *Young, E. F., Belchier, M., Hauser, L., et al. (2015). Oceanography and life history predict contrasting genetic population structure in two Antarctic fish species. Evolutionary Applications. doi: 10.1111/eva.12259.*

Quantifying the strength of biological feedbacks in Southern Ocean air-sea CO_2 flux is an important aspect of understanding the effects of a changing climate. This study compared a number of global biogeochemical models under different climate change scenarios projected to the end of this century, focusing on vertical carbon flux and changes in plankton community structure. The models agreed that the biological carbon pump may be responsible for increased CO_2 uptake in a future more acidic ocean.

- *Hauck, J., Völker, C., Wolf-Gladrow, D., et al. (2015). On the Southern Ocean CO_2 uptake and the role of the biological carbon pump in the 21st century. Global Biogeochemical Cycles. doi: 10.1002/2015GB005140.*

Terrestrial:

The Antarctic Peninsula is one of three regions of the planet that have experienced the highest rates of climate warming over recent decades. Based on a comprehensive large-scale resurvey, allowing comparison of new (2009) and historical data (1960s), these authors show that the two native Antarctic vascular plant species have exhibited significant increases in number of occupied sites and percent cover since the 1960s: *Deschampsia Antarctica* increasing in coverage by 191% and in number of sites by 104%. *Colobanthus quitensis* increasing in coverage by 208% and number of sites by 35%. These changes likely occurred in response to increases of 1.2°C in summer air temperature over the same time period.

- *Cannone, N., Guglielmin, M., Convey, P., Worland, M. R., and Longo, S. F. (2016). Vascular plant changes in extreme environments: effects of multiple drivers. Climatic Change. doi:10.1007/s10584-015-1551-7.*

The role of aerial dispersal in shaping patterns of biodiversity remains poorly understood, mainly due to a lack of coordinated efforts in gathering data at appropriate temporal and spatial scales. It has been long known that the rate of dispersal to an ecosystem can significantly influence ecosystem dynamics, and that aerial transport has been identified as an important source of biological input to remote locations. With the considerable effort devoted in recent decades to understanding atmospheric circulation in the south polar region, a unique opportunity has emerged to investigate the atmospheric ecology of Antarctica, from regional to continental scales. SCAR has facilitated the bringing together of a consortium of polar aerobiologists with a common interest in the airborne dispersion of microbes and other propagules in the Antarctic, with opportunities for comparative studies in the Arctic.

- *Pearce, D. A., Alekhina, I. A., Terauds, A., et al. (2016). Aerobiology Over Antarctica - A New Initiative for Atmospheric Ecology. Frontiers in Microbiology. doi:10.3389/fmicb.2016.00016.*

Human activity in Antarctica has the potential to cause disturbance to wildlife. In some cases, human disturbance to wildlife can cause declines in breeding success, physical harm and even sometimes, direct mortality. Human disturbance can also induce physiological stress responses, which can manifest as behavioural responses like increased vigilance or fleeing behaviour, or avoidance of disturbed areas. The

meta-analysis undertaken in this study highlights that human disturbance effects vary in response to a range of extrinsic factors such as the type of disturbance, its form, magnitude and frequency. It also shows that different species, and even different populations of the same species can show widely differing responses to human disturbance. This variability means that generalisations of the impact of human disturbance to Antarctic wildlife cannot yet be made.

- *Coetzee, B. W., and Chown, S. L. (2015). A meta‐analysis of human disturbance impacts on Antarctic wildlife. Biological Reviews. doi:10.1111/brv.12184.*

Biological invasion is one of the key threats to the conservation of the broader Antarctic region. This study provides an evidence-based assessment of the status of biological invasion in the region as a basis for future monitoring and management. The authors adapted the indicator framework for global biological invasion monitoring by collating information on (i) numbers of alien species and those invasive species impacting biodiversity (ii) trends in the extinction risks of native species impacted by invasive species and (iii) trends in relevant agreements, management intention and species eradications. The Antarctic Biological Invasions Indicator (ABII) provides a system for information exchange across the region and a vehicle for targeted monitoring and surveillance. It also enables inclusion of the region in global efforts to track both invasive alien species and interventions for managing the threat.

- *McGeoch, M. A., Shaw, J. D., Terauds, A., Lee, J. E., and Chown, S. L. (2015). Monitoring biological invasion across the broader Antarctic: A baseline and indicator framework. Global Environmental Change-Human and Policy Dimensions. doi:10.1016/j.gloenvcha.2014.12.012.*

Conservation and Management:

The prohibition of commercial mineral resource extraction through the Antarctic Treaty System has removed one significant source of potential damage to Antarctica's geological and geomorphological values. However, given the ongoing increase in Antarctic tourism and scientific footprint, some high-quality geological features may be vulnerable to human impact, such as damage due to the construction of infrastructure, unregulated collection of geological specimens or oversampling for scientific purposes. These authors suggest that further implementation of existing management tools may be required to protect the diverse range of vulnerabilities, qualities and spatial scales represented in the geology and geomorphology of the continent. At sites where high-quality mineralogical or palaeontological specimens exist in limited quantities, considerations of how best to prevent oversampling and manage access to remaining material may be supported by assessment of cumulative impacts.

- *Hughes, K. A., Lopez-Martinez, J., Francis, J., et al. (2016). Antarctic geoconservation: a review of current systems and practices. Environmental Conservation. doi:10.1017/S0376892915000387.*

Vegetation is sparsely distributed over Antarctica's ice-free ground, and distinct plant communities are present in each of the continent's 15 recently identified Antarctic Conservation Biogeographic Regions (ACBRs). With rapidly increasing human

activity in Antarctica, terrestrial plant communities are at risk of damage or destruction by a range of factors. Using remote sensing to assess vegetation in Antarctic Specially Protected Areas, these authors suggest that there are large omissions in the protection of Antarctic botanical diversity.

- *Hughes, K. A., Ireland, L. C., Convey, P. and Fleming, A. H. (2016). Assessing the effectiveness of specially protected areas for conservation of Antarctica's botanical diversity. Conservation Biology. doi:10.1111/cobi.12592.*

Antarctic krill fishing vessels can collect acoustic data that could be used in future management of the commercial fishery. With increasing costs and demands on time, the use of research vessels to undertake regular Antarctic krill biomass surveys is becoming more difficult to justify. Here we describe the work undertaken by CCAMLR to assess how Antarctic krill fishing vessels may be used to collect more extensive scientific data sets. Through a 'proof of concept' study started in 2013, trial data have now been received from half the fishing fleet and protocols are being developed to enable Antarctic krill fishing vessels to collect quantitative acoustic data along transects. The willingness of the fishing industry to participate in this process has already been demonstrated by several fishing companies, and Norwegian- and Chinese-flagged vessels are undertaking krill biomass surveys in two key fishery areas in the South Atlantic sector of the Southern Ocean.

- *Watkins, J. L., Reid, K., Ramm, D., et al. (2015). The use of fishing vessels to provide acoustic data on the distribution and abundance of Antarctic krill and other pelagic species. Fisheries Research. doi: 10.1016/j.fishres.2015.07.013.*

The Arctic and Antarctic polar regions are subject to multiple environmental threats, arising from both local and ex-situ human activities. This study reviews the major threats to polar ecosystems including the principal stressor, climate change, which interacts with and exacerbates other threats such as pollution, fisheries overexploitation, and the establishment and spread of invasive species. Given the lack of progress in reducing global atmospheric greenhouse-gas emissions, the authors suggest that managing the threats that interact synergistically with climate change, and that are potentially more tractable, is all the more important in the short to medium term for polar conservation. They show how evidence-based lessons learned from scientific research can be shared between the poles on topics such as contaminant mitigation, biosecurity protocols to reduce species invasions, and the regulation of fisheries and marine environments. They suggest that applying these trans-polar lessons in tandem with expansion of international cooperation could substantially improve environmental management in both the Arctic and Antarctic.

- *Bennett, J. R., Shaw, J. D., Terauds, et al. (2015). Polar lessons learned: long-term management based on shared threats in Arctic and Antarctic environments. Frontiers in Ecology and the Environment. doi:10.1890/140315.*

Do krill fisheries compete with macaroni penguins? Management of the krill fishery at South Georgia includes a closed season during the summer to minimise spatial overlap of predators during the breeding season. It opens in winter on the assumption that predators disperse away from the island and overlap will be minimal, but this remains untested. We equipped macaroni penguins on Bird Island with geolocators

and tracked their winter distribution. They dispersed widely across the Southern Ocean, with some feeding hotspots associated with oceanic fronts. During this time, the krill fisheries were concentrated on three small areas of shelf break off South Georgia, South Orkneys and South Shetlands and spatial overlap of fishery catches and penguin foraging was minimal. We conclude that competition under current management is low and recommend our methods are extended to other species on South Georgia that forage closer to the island and to other krill fisheries that remain open during the breeding season.

- *Ratcliffe, N., Hill, S. L., Staniland, I. J., Brown, R., Adlard, S., Horswill, C. A., and Trathan, P. N. (2015). Diversity and Distributions. doi:10.1111/ddi.12366.*

This 10-year synthesis reconstructs population trajectories and assesses the recovery status of all Southern Hemisphere humpback whale populations**.** It also details methodological advances and the significant challenges overcome during the assessment and identifies key data gaps and avenues for future work. Southern Hemisphere humpback whales are now at roughly 70% of pre-exploitation abundance, but recovery levels vary substantially between oceans, with strong recovery in the Indian Ocean but still low recovery in the southwest Atlantic and Oceania.

- *Jackson, J. A., Ross-Gillespie, A., Butterworth, D., et al. (2015). Synthesis review of the status of Southern Hemisphere humpback whales. 67th Annual Meeting of the International Whaling Commission (IWC). Document SC/66a/SH3 submitted to the IWC Scientific Committee.*

Astronomy and Astrophysics:

In August 2015, the IceCube Collaboration announced a new observation of high-energy neutrinos that originated beyond our solar system. This study, which looked for neutrinos coming from the Northern Hemisphere (i.e. neutrinos that reached the detector after passing all the way through the Earth), confirms their cosmic origin as well as the presence of extragalactic neutrinos. The first evidence for astrophysical neutrinos was announced by the collaboration in November 2013. This new, independent observation confirms that the detection rate of astrophysical neutrinos is close to the maximum rate based on potential cosmic ray sources. The intensity of this flux shows that cosmic ray sources are also efficient generators of neutrinos and, therefore, that these tiny particles are further endorsed as the perfect tools to explore the extreme universe.

- *Aartsen, M. G., Abraham, K., Ackermann, M. (2015). Evidence for Astrophysical Muon Neutrinos from the Northern Sky with IceCube. Phys. Rev. Lett. doi:10.1103/PhysRevLett.115.081102.*

The direct detection of gas clouds in our Galaxy via observations of carbon was made using the HEAT telescope at Ridge A in Antarctica. Ridge A is the driest location on the Earth, allowing routine study of the universe at terahertz frequencies through atmospheric windows not accessible from warmer locations. One third of the molecular gas along the sightline studied was estimated to be in "dark" form, a form of cold gas that can only be traced by observation of the carbon atoms by terahertz instruments such as HEAT.

- *Burton, M. G., Ashley, M. C. B., Braiding, C., et al. (2015). Extended Carbon Line Emission in the Galaxy: Searching for Dark Molecular Gas along the G328 Sightline. The Astrophysical Journal. doi:10.1088/0004-637X/811/1/13.*

Magnetic monopoles are thought to have been created during the early stages of the universe. These monopoles would have been accelerated by intergalactic magnetic fields and could reach relativistic velocities, i.e. velocities near the speed of light (c). Similar to electrically charged particles, magnetic monopoles produce Cherenkov light when traveling through ice at such high speeds. IceCube, with its large instrumented volume, is an excellent detector for searches for exotic particles. The IceCube Collaboration presented a search for relativistic (>0.75c) and mildly relativistic (>0.51c) monopoles using two years of data. No monopole candidate was observed, allowing IceCube to set very stringent limits for the abundance of such particles in the range of velocities studied.

- *Aartsen, M. G., Abraham, K., Ackermann, M. (2016). Searches for relativistic magnetic monopoles in IceCube. Eur. Phys. J. C. doi:10.1140/epjc/s10052-016-3953-8.*

History, Humanities, Social Sciences and Multidisciplinary:

A new multi-disciplinary book catering to students and those who want to have a more critical look behind the scenes of Antarctic science has recently been published. This book takes a systems approach to providing insights into Antarctic ecosystems and the geophysical environment. Further, the book links these insights to a discussion of current issues, such as climate change, bio prospecting, environmental management and Antarctic politics. It is written and edited by experienced Antarctic researchers and scientists from a wide range of disciplines. Academic references are included for those who wish to delve deeper into the topics discussed in the book.

- *Liggett, D., Storey, B., Cook, Y. and Meduna, V. (Eds.) (2016). Exploring the Last Continent: An Introduction to Antarctica. Springer. 597p. doi:10.1007/978-3-319-18947-5.*

A recent publication on the environmental history of both polar regions, covering both the Arctic and Antarctic over the long durée, makes an important argument for the links between physical geography, culture, and politics. The book builds on the author's many years of study of Antarctic politics, including pioneering studies of British and Latin American Antarctic research in the mid-20th century.

- *Howkins, A. (2016). The Polar Regions: An Environmental History. Cambridge: Polity Press.*

Climate Terror brings a critical geopolitics perspective to climate change debates. The authors argue that the geographical politics of global warming are highly differentiated. They critique the way in which climate change has been framed as a challenge for and threat to the West, neglecting the perspective of and impact on the global South. They ask: "Can climate, as a set of discourses, be utilized for emancipatory ends or, ultimately, is the climate story … a discourse now captured by the affluent North to control the development of the global South?" This important

and timely book is relevant to international policy makers as well as researchers from a wide range of disciplines.

- *Chaturvedi, S. and T. Doyle. (2015). Climate Terror: A Critical Geopolitics of Climate Change. Houndsmills, Basingstoke; New York: Palgrave Macmillan. doi:10.1057/9781137318954.*

Deary and Tin (2015) offer a thoughtful and well-informed review of the Antarctic Treaty Parties' engagement with the concept of wilderness in Antarctica and the governance of wilderness areas. Comparing different Parties' domestic wilderness legislation and their level of engagement with Antarctic wilderness protection leads the authors to conclude that Parties' engagement with issues around the governance of Antarctic wilderness is more closely aligned with their overall patterns of engagement within the Antarctic Treaty System than with the extent to which they have put in place legislation protecting wilderness areas in their domestic territories.

- *Deary, H. and Tin, T. (2015). Antarctic Treaty Consultative Parties' engagement in wilderness protection at home and in Antarctica. The Polar Journal. doi:10.1080/2154896X.2015.1068537.*

The product of the fruitful collaboration within the SCAR Humanities and Social Sciences Expert Group (HASSEG), this paper illustrates the challenges arising from the presence and practice of nationalism in the Antarctic. The authors suggest that nationalism in Antarctica is present in a form that is different to what is typically understood as nationalism in the rest of the world – it may play out in a virtual realm or may be mediated through social or cultural habits, events, celebrations, or even through the diverse sets of human activities in the Antarctic themselves. As Hemmings et al. (2015) argue, "[I]n Antarctica, the intersection of nationalism with resources poses a particular challenge to the regional order and its commitments to shareable public goods such as scientific research and environmental protection".

- *Hemmings, A. D., Chaturvedi, S., Leane, E., Liggett, D., and Salazar, J. F. (2015). Nationalism in Today's Antarctic. The Yearbook of Polar Law. doi:10.1163/2211-6427_020.*

Shibata (2015) offers an astute analysis of the legal order in both polar regions and concludes that, despite a multitude of geographical, socio-cultural and physical differences, some fundamental principles determining the legal order and the process of creating legal order in the Arctic and the Antarctic are very similar. These core foundational principles upon which the making of legal order rests have been applied differently in the two polar regions, highlighting that the same core principles can lead to different end projects. Shibata points out, for example, that an analysis of the core foundational principles of legal order-making does not necessarily and unambiguously support the creation of an Arctic Treaty System. However, such an analysis does enable the identification of important interactions between the Arctic and Antarctic regimes and emphasizes the opportunity for processes enabling the sharing of experiences and mutual learning between these regimes.

- *Shibata, A. (2015). Japan and 100 Years of Antarctic Legal Order: Any Lessons for the Arctic? The Yearbook of Polar Law. doi:10.1163/2211-6427_002.*

Appendix 2: List of Acronyms

ABII	Antarctic Biological Invasion Indicator
ACBR	Antarctic Conservation Biogeographic Region
ACCE	Antarctic Climate Change and the Environment
AIS	Antarctic ice sheet
ANDRILL	Antarctic Geological Drilling
ARC	Antarctic Research Challenges project
ASPA	Antarctic Specially Protected Area
ASPeCt	Antarctic Sea-Ice Processes and Climate
ATCM	Antarctic Treaty Consultative Meeting
ATS	Antarctic Treaty System
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CMIP	Coupled Model Intercomparison Project
CO_2	carbon dioxide
COMNAP	Council of Managers of National Antarctic Programs
COP	Conference of Parties (UNFCCC)
HASSEG	Humanities and Social Sciences Expert Group
HEAT	High Elevation Antarctic Terahertz telescope
IASC	International Arctic Science Committee
ICCI	International Cryosphere Climate Initiative
IceCube	the South Pole Neutrino Observatory
ICSU	International Council for Science
ISAES	International Symposium on Antarctic Earth Sciences
MISI	Marine Ice Sheet Instability
NSF	National Science Foundation (USA)
OA	(Southern) Ocean Acidification
pCO_2	Partial Pressure of Carbon Dioxide
ppm	parts per million
SCADM	Standing Committee on Antarctic Data Management
SCAGI	Standing Committee on Antarctic Geographic Information
SCATS	Standing Committee on the Antarctic Treaty System
SCAR	Scientific Committee on Antarctic Research
SOOS	Southern Ocean Observing System
SRP	Scientific Research Programme
UNFCCC	United National Framework Convention on Climate Change
WAIS	West Antarctic Ice Sheet