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Ant-ICON - '*Integrated Science to Inform Antarctic and Southern Ocean Conservation*': a new SCAR Scientific Research Programme

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Abstract: Antarctic and Southern Ocean environments are facing increasing pressure from multiple threats. The Antarctic Treaty System regularly looks to the Scientific Committee on Antarctic Research (SCAR) for the provision of independent and objective advice based on the best available science to support decision-making, policy development and effective environmental management. The recently approved SCAR Scientific Research Programme Ant-ICON - '*Integrated Science to Inform Antarctic and Southern Ocean Conservation*' - facilitates and coordinates high-quality transdisciplinary research to inform the conservation and management of Antarctica, the Southern Ocean and the sub-Antarctic in the context of current and future impacts. The work of Ant-ICON focuses on three research themes examining 1) the current state and future projections of Antarctic systems, species and functions, 2) human impacts and sustainability and 3) socio-ecological approaches to Antarctic and Southern Ocean conservation, and one synthesis theme that seeks to facilitate the provision of timely scientific advice to support effective Antarctic conservation. Research outputs will address the most pressing environmental challenges facing Antarctica and offer high-quality science to policy and advisory bodies including the Antarctic Treaty Consultative Meeting, the Committee for Environmental Protection and the Scientific Committee of the Commission for the Conservation of Antarctic Marine Living Resources.

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Introduction

The Scientific Committee on Antarctic Research (SCAR) is a thematic organization of the International Science Council (ICS) charged with 1) initiating, developing and coordinating high-quality international scientific research in the Antarctic region, including the Southern Ocean, and 2) providing objective and independent scientific advice to the Antarctic Treaty Consultative Meeting (ATCM) and other bodies on issues of science and conservation that affect the governance and management of the region. Policy-relevant scientific information is delivered to policymakers, including those within the ATCM, the Committee for Environmental Protection (CEP) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) through SCAR's Standing Committee on the Antarctic Treaty System (SC-ATS). SC-ATS was established in 2004 as part of a restructuring of SCAR, replacing the Group of Specialists on Environmental Affairs and Conservation (GOSEAC), which until then had primarily been responsible for the provision of scientific advice to the Antarctic Treaty System (ATS), and the ATCM and CEP in particular. However, since that time, and in parallel with the ongoing expansion of the CEP's work, requests to SCAR have increased, putting some strain on existing capacity (Walton *et al.* 2018, p. 182). Furthermore, increasing awareness of the diverse conservation challenges facing Antarctic marine and terrestrial environments makes the provision of policy-relevant research all the more urgent.

To develop further expertise in conservation issues relevant to Antarctica and thereby provide support to SC-ATS, SCAR has established a Scientific Research Programme (SRP) called Ant-ICON: '*Integrated Science to Inform Antarctic and Southern Ocean Conservation*'. SRPs are large, overarching programmes that are often multidisciplinary and have a lifespan of up to 8 years. Ant-ICON commenced its work in 2021 and coordinates and delivers Antarctic science relating to the conservation and management of Antarctica and the Southern Ocean, and it focuses on research to inform international decision-making and policy change. Human impacts are becoming increasingly evident within marine, terrestrial, ice and freshwater environments, and Ant-ICON's scope includes research across all of these realms. Here, we set out the role of Ant-ICON in further integrating Antarctic research and policy to deliver conservation and management benefits across the region.

Human impacts affecting Antarctica

Antarctica, the Southern Ocean and its islands have long been considered as pristine and largely unimpacted compared to other areas of the globe, and this remains largely the case for more remote regions. However, to differing degrees, many areas are under increasing threat from human impacts that manifest through biological invasions, pollution, the exploitation of marine living resource and an increasing human footprint (e.g. Frenot *et al.* 2005, Jansen van Vuuren et al. 2007, Lee *et al.* 2009, Braun *et al.* 2012, Tin *et al.* 2013, Amaro *et al.* 2015, Coetzee & Chown 2015, Hughes *et al.* 2015, Stark *et al.* 2015, Pertierra *et al.* 2017, Avila *et al.* 2020, Cárdenas *et al.* 2020). The construction and operation of research stations impact a wide range of environmental values (Brooks *et al.* 2019), fisheries are increasing and extending into new areas (Santa Cruz *et al.* 2018) and a decline of pristine wilderness areas has been reported (Leihy *et al.* 2020). Chown *et al.* (2017) assessed conservation trajectories in Antarctica compared with those identified in the Strategic Plan for Conservation developed under the aegis of the Convention on Biological Diversity for the rest of the globe. The authors concluded that despite Antarctica's isolation and apparent pristine state, the biodiversity outlook is similar to that for the rest of the planet, leaving considerable scope for mitigating action.

Climate change in the Antarctic Peninsula has resulted in profound and widespread changes in the environment (Convey 2011), including the retreat of glaciers and partial or complete collapse of ice shelves (Cook *et al.* 2005, Mulvaney *et al.* 2012). Warming is now being recorded across other areas of Antarctica (Robinson *et al.* 2020), including, for example, long-term warming at the South Pole (Clem *et al.* 2020). Under a business-as-usual scenario of continued greenhouse gas emission increases, Antarctic surface temperatures are expected to increase by ~4°C by 2100 compared to temperatures at the end of the 20th century. Atmospheric and/or ocean warming is predicted to result in decreases in sea-ice extent, marked increases in precipitation and expansion of ice-free ground at the continent's fringes with potentially substantial impacts upon biological communities and ecological balance (Lee *et al.* 2017, Convey & Peck 2019, Jenouvrier *et al.* 2021, Wang *et al.* 2022). As an indirect impact, warming is likely to reduce barriers to non-native species invasion and establishment, resulting in negative though poorly understood impacts on native species (Duffy *et al.* 2017, Jansen van Vuuren *et al.* 2019, Hughes *et al.* 2020). Current and predicted levels of human footprint and climate change in Antarctica differ regionally, resulting in different levels of change and impact across the continent (Pertierra *et al.* 2017, Brooks *et al.* 2019, IPCC 2019). Thus, the combined and potentially synergistic impacts of climate change and regional human impacts on the Antarctic environment are an increasing cause for concern (Chown *et al.* 2012, Kennicutt *et al.* 2014, Hughes *et al.* 2021).

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International agreements on Antarctic conservation

Antarctica's unique history of continent-wide environmental protection began with the Agreed Measures for the Conservation of Antarctic Fauna and Flora (1964) and continues today under the 1991 Protocol on Environmental Protection to the Antarctic Treaty (hereafter the Madrid Protocol) that came into force in 1998. The Madrid Protocol regulates human activities in Antarctica with the aim of minimizing environmental impacts from such activities within a framework of high protection goals. The Madrid Protocol includes a ban on mineral resource activities (other than for scientific research), strict regulations on the intentional introduction of non-native species and disturbance to native species, waste management controls, a requirement for environmental impact assessments and the designation of specially protected and managed areas.

While the Madrid Protocol applies predominantly to the area south of 60°S latitude (although it does take into consideration dependent and associated ecosystems that lie outside this area), the management of the Southern Ocean is largely enacted under the provisions of the 1980 Convention on the Conservation of Antarctic Marine Living Resources (CAMLR Convention; entry into force in 1982) as it governs the most prominent extractive human activity that takes place there (i.e. fishing). The primary objective of this agreement is the conservation of Antarctic marine living resources (Article II(1)), both in the area south of 60°S and also in the area between this latitude and the Polar Convergence. To achieve this overarching objective, CCAMLR promotes an ecosystem-based and precautionary approach to marine conservation, whereby species interactions are fully accounted for in management decisions. Furthermore, Article II of the CAMLR Convention specifically mandates the prevention of change or minimization of risk to marine ecosystems that are not potentially reversible within two to three decades. CCAMLR has implemented measures that support the conservation and management of Antarctic living resources, including a mechanism for establishing species-specific catch limits and a framework for establishing marine protected areas in the Southern Ocean.

Policymakers' call for science

The Madrid Protocol and CAMLR Convention themselves are significant statements of Parties' commitment to Antarctic conservation. Moreover, international will to improve conservation and management across the region through these international agreements has been repeatedly confirmed and reinforced by the Parties, such as through the ATCM's Santiago Declaration of 2016 (ATCM XXXIX), the ATCM's Prague Declaration of 2019 (ATCM XLII), the ATCM's Paris Declaration of 2021 (ATCM XLIII) and the CCAMLR Conservation Measure CM 91-04 to establish a network of marine protected areas.

The use of the best available science for decision-making is enshrined in the Madrid Protocol (Article 10.1: 'Antarctic Treaty Consultative Meetings shall, drawing upon the best scientific and technical advice available: (a) define, in accordance with the provisions of this Protocol, the general policy for the comprehensive protection of the Antarctic environment and dependent and associated ecosystems; and (b) adopt measures under Article IX of the Antarctic Treaty for the implementation of this Protocol') and CAMLR Convention (Article IX.1 (f): 'The function of the Commission shall be to give effect to the objective and principles set out in Article ii of this Convention. To this end, it shall formulate, adopt and revise conservation measures on the basis of the best scientific evidence available …'). The establishment of both an advisory body to the ATCM (the CEP) and the Scientific Committee to CCAMLR (SC-CAMLR) further exemplify the recognized need to incorporate high-quality research into decision-making, particularly around issues of environmental protection and marine conservation (e.g. Hughes *et al.* 2018, ATCM Resolution 7 (2019)).

In the context of the CEP, a mechanism has been developed to communicate policymakers' scientific and information needs to SCAR and the wider research community through the 'CEP list of science knowledge and information needs' (see https://documents.ats.aq/ATCM43/att/ATCM43_att054_e.docx). Identified research needs include:

- Work to support the current management, future designation and implementation of Antarctic and Southern Ocean protected areas;
- Input into assessments of and response strategies for threatened species, ecosystems or environments; and
- Monitoring to assess and mitigate anthropogenic impacts.

In contrast, CCAMLR (which is the decision-making body for the Convention) communicates its needs for scientific advice to its own integrated Scientific Committee (SC-CAMLR) during the annual boreal autumn meetings. In response to these requests, the SC-CAMLR tasks its Working Groups, which meet during the boreal summer, to develop the scientific knowledge with which SC-CAMLR can then respond to the requests from the Commission during the following autumn meeting. Many of the requests revolve around the analysis and assessment of commercial-in-confidence information owned by its Members, precluding its wider dissemination to SCAR. While the relationship between SCAR and the CEP is enshrined in the Articles of the

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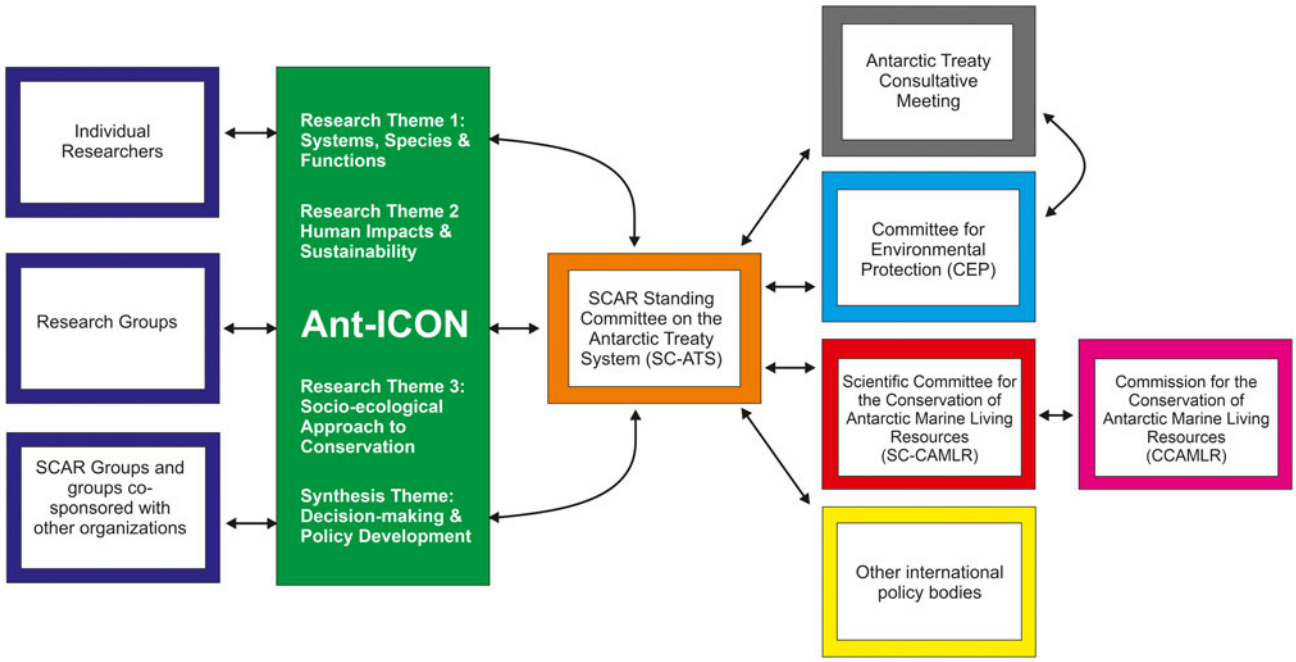

Fig. 1. Ant-ICON will closely support the Standing Committee on the Antarctic Treaty System (SC-ATS) as it works at the interface between science and policy to facilitate the conservation of Antarctica and the Southern Ocean. SCAR = Scientific Committee on Antarctic Research.

Madrid Protocol, the CAMLR Convention is less specific regarding the formal relationship between CCAMLR and SCAR (see Article XXIII(3)). Indeed, SCAR only holds Observer status during the annual meetings of CCAMLR and SC-CAMLR, and it has no independent representation at any of the Working Group meetings. However, scientific knowledge and advice are provided by SCAR to CCAMLR on an *ad hoc* basis when requested (*sensu* the SCAR Krill Action Group; SKAG) or when an issue of potential importance has been identified by SCAR.

Ant-ICON: delivering policy-relevant research to stakeholders

As highlighted earlier, the SC-ATS is the body within SCAR tasked with developing SCAR's scientific advice to the ATS, but the ability of SC-ATS to directly facilitate research is limited. As such, there can be a mismatch (both temporally and in substance) between the research that is required and the advice that can be delivered. Ant-ICON was established specifically to provide the best available science to facilitate the improved conservation of Antarctic and Southern Ocean ecosystems, species and environments. Ant-ICON works closely with SC-ATS, key policy and management entities and other stakeholders to deliver science that will underpin SCAR's advice in a form suitable for policy forums and decision-makers. In recognizing the ongoing threats to the Antarctic region, Ant-ICON aims to facilitate and coordinate high-quality transdisciplinary research that brings together input from researchers and policymakers (see also Knapp *et al.* 2019) to support and inform conservation and management.

The role of SCAR as a provider of independent and objective scientific advice is recognized and utilized within the ATS (see the 2021 Paris Declaration (ATCM XLIII)). Ant-ICON outputs will support this role, with the ATCM, CEP and SC-CAMLR being amongst the key stakeholders (see Fig. 1). Research outputs are also relevant to National Antarctic Programmes (NAPs), the Council of Managers of National Antarctic Programs (COMNAP), managers of sub-Antarctic Islands, the International Association of Antarctica Tour Operators (IAATO) and non-governmental organizations (NGOs) such as the Antarctic and Southern Ocean Coalition (ASOC). Ant-ICON will liaise with SC-CAMLR and its Working Groups to identify how it can best engage with CCAMLR to deliver relevant scientific needs. Ultimately, Ant-ICON's membership comprises volunteers from the Antarctic research community who will determine the group's approach to planning its work, undertaking research and engaging with stakeholders in an effective and useful manner.

SCAR produces 5-yearly strategic plans to set the goals and direction for the organization. Ant-ICON is strongly aligned with the SCAR Strategic Plan 2017–2022 and will

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Table I. Examples of Scientific Committee on Antarctic Research (SCAR) Horizon Scan questions relevant to Ant-ICON (see Kennicutt *et al.* 2014, 2015).

Question no.	SCAR Horizon Scan questions
48	Can we identify vulnerable ecosystems and food webs?
49	What will be the impact of future environmental conditions on ecosystem functioning?
50	What will be the synergistic effects of multiple stressors and environmental change drivers on Antarctic and Southern Ocean biota?
52, 53	What will be the impact of contaminants and pollutants on Antarctic environments and ecosystems?
54, 55	Can we identify and mitigate non-native species pathways and associated impacts?
56, 57, 58	What will be the range and extent of climate-mediated impacts on Antarctic and Southern Ocean biota?
75	What will be the impacts of large-scale, direct human modification of the Antarctic environment?
80	How will diseases and pathogens impact and adapt to the extreme Antarctic environment?

continue to 1) facilitate high-quality science to underpin SCAR's independent and objective advice, 2) strengthen and expand collaborations across disciplinary and geographical boundaries and 3) effectively communicate research and raise public awareness of Antarctic issues. Recognizing and mitigating human influences were included in the six top priorities to emerge from the SCAR Horizon Scan initiative (Kennicutt *et al.* 2014, 2015; see Table I for relevant questions). Progress in answering some of the questions highlighted in Table I has been made through the previous suite of SCAR SRPs (and other ongoing SCAR-related groups and initiatives), but many remain unanswered, reinforcing the need for future scientific research on these important questions that will be facilitated by Ant-ICON (Kennicutt *et al.* 2019).

Connecting expertise and innovation across SCAR and beyond

The Antarctic research community is a productive source of ideas and innovative methods, many of which are relevant to improving environmental protection and achieving conservation outcomes. Due to the complex interactions among the threats facing Antarctica, understanding these threats, forecasting future states, developing strategies for mitigating impacts and communicating the findings to policymakers require input from a range of disciplines. A key challenge in informing environmental governance is that it often requires long-term commitments that should be designed with future rather than present conditions and scenarios in mind. Given that impacts on the Antarctic integrate economic, socio-cultural, climatological and biological processes, even minimally adequate forecasts will require coordinated integrated research.

Ant-ICON research will complement and integrate with the other SRPs (i.e. Near-term Variability and Prediction of the Antarctic (AntClimNow) and Instabilities and Thresholds in Antarctica (INSTANT)), existing SCAR groups and other related initiatives such as the SKAG, Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED), Integrated Science for the Sub-Antarctic (ISSA) and Input Pathways of Persistent Organic Pollutants to Antarctica (ImPACT). Ant-ICON is also generating strong links to SCAR-related monitoring groups, including the Southern Ocean Observing System (SOOS; see Newman *et al.* 2019) and the developing Antarctic and Nearshore and Terrestrial Observing System (ANTOS). This complementarity is being achieved through cross-membership on Steering Committees, the establishment of the Ant-ICON Advisory Group and the identification of collaborative research opportunities (the Ant-ICON membership list is available at https://www.scar.org/science/ant-icon/members/). Furthermore, potential external collaborative partners include the tourism industry (e.g. IAATO), NGOs (e.g. WWF, the Pew Foundation, ASOC), fishing industry bodies (e.g. the Association of Responsible Krill harvesting companies (ARK), the Coalition of Legal Toothfish Operators (COLTO)) and philanthropic groups.

Humans play a fundamental role in impacting and managing the Antarctic environment. Therefore, understanding environmental issues in the context of socio-cultural factors, such as environmental values, ethics, justice, economics, law and geopolitics, is crucial for the successful and effective conservation of the Antarctic environment (e.g. Nuno *et al.* 2014, Gruby *et al.* 2016, Mair *et al.* 2018, Moon *et al.* 2019, Yates *et al.* 2019). Ant-ICON brings together researchers from the humanities and social sciences to work with those from the life, physical and earth sciences to facilitate 1) our understanding of the interactions between humans and the Antarctic environment and 2) how these interactions shape conservation and management decisions (see Folke 2006, Howkins *et al.* 2021).

The Ant-ICON research and synthesis themes

Ant-ICON promotes or contributes to research that assesses current states, forecasts change across temporal and spatial scales, identifies at-risk species, ecosystems and environments, identifies and quantifies multiple stressors and threats and informs the development of practical mitigation strategies. The Programme is underpinned by three primary research themes (R1–R3) and one synthesis theme (S1).

The research in both research themes 1 and 2 builds on the legacy of previous SCAR SRPs in the spirit of multidisciplinary collaborations (e.g. Gutt *et al.* 2018). Key

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areas of research from these previous SRPs (including species abundance and distributions, ecosystem vulnerabilities, non-native species impacts, biogeographical insights, climate predictions and functional responses of species) form an important foundation for much of the research of Ant-ICON. Moreover, Ant-ICON is developing connections and linkages between the research themes to deliver broad and integrated research knowledge through the synthesis theme.

Research theme 1: Current state and future projections of Antarctic, Southern Ocean and sub-Antarctic systems, species and functions

Research theme 1 (R1) focuses on the current status of and future projections for Antarctic ecosystems. Because so many biodiversity data have already been collated under the auspices of prior efforts (e.g. the Global Biodiversity Information Facility (GBIF), SOOS), the focus of R1 is to identify knowledge gaps as well as datasets that already exist but may be undigitized or underutilized (e.g. from NAPs). After an initial assessment of biodiversity and related environmental data, the focus will shift to spatial and temporal assessments (e.g. species distribution and habitat suitability models), integrated forecasting based on *in situ* and experimental observations (including climate change impacts on species/ecosystems and physiological responses to climate change) and data from remote sensing and state-of-the-art ecological surveys and experiments. Key questions include:

- How vulnerable are the different species, ecosystems and environments?
- How will they change over multiple time scales (years to decades) and spatial scales?
- What are the projected impacts of multiple stressors (e.g. human activities, climate change, non-native species) on Antarctic and Southern Ocean species, ecosystems and environments?
- What are the key drivers of change - can tipping points, resilience, thresholds and irreversibility be identified?
- What are the roles of Antarctic species/ecosystems and environments in mitigating global change and how might that change under future projections?

Research theme 2: Human impact and sustainability

Research theme 2 (R2) recognizes that robust monitoring strategies are required to measure change in established and emerging baselines (in conjunction with R1) and to clarify the relationship of this change to key stressors, including emerging and increasing infrastructure, human visitation, climate change, non-native species and other anthropogenic stressors in the marine ecosystem (e.g. fishing). Ant-ICON will not focus on routine monitoring and reporting for regulatory or compliance purposes, but it will facilitate the collection of science-based long-term observations of the environment, such as establishing trends and variability, to enable better understanding of the underlying processes (SCAR 2009, Walton *et al.* 2018, p. 185). Results from new and existing initiatives (e.g. ANTOS, SOOS) will be combined with forecasting and projecting risks and impacts using quantitative techniques (e.g. ecosystem assessments) and conservation planning tools (such as the implementation of systematic conservation planning frameworks). Through R2, Ant-ICON will coordinate evidence-based research on interacting biophysical and social factors to develop sustainable approaches to managing human activities in Antarctica (including the concept of ecosystem services; Cavanagh *et al.* 2021, Pertierra *et al.* 2021) and to engage with a range of stakeholders to help develop practical mitigation strategies and mechanisms where such needs are identified. Key questions include:

- What is the current and projected future extent of human activities (*inter alia*, science, science support, tourism, bioprospecting and fisheries)?
- What are the risks related to these human activities?
- What are the synergistic and cumulative impacts of human activities combined with other change drivers (including climate change)?
- How can risks and impacts be mitigated?

Research theme 3: Socio-ecological approaches to Antarctic and Southern Ocean conservation

Research theme 3 (R3) is examining the interplay between human activities, perceptions, perspectives and behaviours in the Antarctic, their geopolitical and socio-economic drivers and Antarctic ecosystem dynamics within the context of complex and tightly interconnected socio-ecological systems research. Drawing in particular on emerging research in the field of critical physical geography (Lave *et al.* 2018) as well as biocultural and comparative approaches (Merçon *et al.* 2019, Hanspach *et al.* 2020), R3 is developing alternative integrated frameworks to assess and understand the multitude of interactions between Antarctic and Southern Ocean environments, human engagement with these places over time and shifting management practices and cultural values. R3 is investigating the socio-economic implications and cultural dimensions of change or management strategies, gaining a better understanding of the intrinsic values mentioned in the Madrid Protocol (e.g. aesthetic or wilderness), describing and anticipating the drivers of change in socio-ecological systems and clarifying the implications of political, economic and socio-cultural changes on current and future activities. The research also addresses questions that have been raised regarding the efficacy of environmental management across the region (Shaw *et al.*

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2014, Hughes *et al.* 2016, Coetzee *et al.* 2017) and builds on lessons learnt in other parts of the world (Soutullo *et al.* 2022). Key questions include:

- Taking into consideration socio-ecological connectivity, what are the socio-political and economic impacts and consequences of environmental change in Antarctica?
- What are the characteristics and implications of responsible and ethical governance for Antarctica in the 21st century?
- What does socio-ecological resilience look like in Antarctica and the Southern Ocean?
- What are the potential implications of global social, health and economic shifts for Antarctic activities?

Synthesis theme 1: Science synthesis to inform decision-making and policy development

Synthesis theme 1 (S1) aligns with SCAR's fundamental role to provide independent scientific advice to the ATS. Outputs from this theme can inform, for example, systematic conservation planning, the designation of specially protected species, the designation and management of protected areas, the identification of vulnerable marine ecosystems, state-of-the-environment reporting and the effective management of human activities. S1 is investigating ways to foster mutual understanding between research and policy communities to improve the delivery of relevant and tailored research outputs to decision-making forums. This includes identifying ways of communicating and clarifying policy needs to the research community. A future-focused approach will be key, as well as building partnerships and working in collaboration with the whole SCAR community (particularly SC-ATS) and other knowledge providers and Antarctic experts, including NAPs (and the COMNAP), international research agencies and non-governmental bodies. Key questions include:

- How can research address key Antarctic conservation goals?
- What outputs can be most effectively integrated to inform decision-making?
- How can research and monitoring be used to evaluate the effectiveness of management strategies?
- How can we assist in quantifying and dealing with scientific biases and uncertainties in decision-making?
- How can we foster connection, mutual understanding and forward-planning between research and policy communities?
- How can science be targeted and communicated to increase uptake by decision-makers?

Ant-ICON outputs

Publications in peer-reviewed journals are a key deliverable for Ant-ICON-affiliated researchers, and the Steering Committee encourages and supports collaborations across disciplines and groups to prepare and progress these papers. The primary mechanisms for Ant-ICON to report to SCAR are 1) the annual report to the SCAR Executive Committee and 2) biennial reports to the SCAR Delegates. Ant-ICON will work closely with SC-ATS to enable it to submit a range of relevant scientific papers to the ATCM, CEP, SC-CAMLR and its Working Groups and workshops organized by these bodies. These will be facilitated through an annual Ant-ICON report to SC-ATS, detailing current and developing outputs of interest to key policy stakeholders. Crucially, the Ant-ICON Steering Committee works closely with SC-ATS to stay informed of the priorities of key policy representatives, and it will work with the other SRPs (i.e. INSTANT and AntClimNow) to ensure submissions are thorough and targeted most appropriately and effectively. Although publications in peer-reviewed journals and submissions to international bodies (as described above) form the majority of Ant-ICON outputs, other reports and grey literature will be prepared as required. Future outputs could take the form of policy-ready summary documents or emerging issues syntheses for initiatives such as the Antarctic Environments Portal (www.environments.aq) or reports to NAPs, government bodies or institutions.

Inclusion, capacity building, education and training

Policy meetings differ greatly from scientific meetings. While high-quality science can provide the foundation for strong management decisions, it must be communicated effectively (Evans & Cvitanovic 2018, Gluckman *et al.* 2021, Press 2021). Therefore, capacity building and developing expertise in science-policy communication is an Ant-ICON priority. In cooperation with the SCAR Capacity Building, Education and Training (CBET) Advisory Group, Ant-ICON is investigating opportunities for early- and mid-career researchers (EMCRs) and researchers from countries with nascent Antarctic research programmes. Ant-ICON leaders have assisted EMCRs to make important contributions to Ant-ICON through the provision of opportunities for engagement and mentorship (e.g. Remedios-De León *et al.* 2021). Ant-ICON has facilitated the presentation of EMCR scientific work to advisory and management organizations such as the CEP and will extend this into the scientific bodies of CCAMLR via its Scientific Committee and associated Working Groups. In conjunction with SC-ATS and the SCAR Executive Committee, mechanisms for the potential inclusion of EMCRs on SCAR Delegations to ATCM/CEP Meetings are being explored, including the provision of funding to support participation. Throughout its lifespan, Ant-ICON plans to host or

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co-convene sessions, workshops and mini-symposia targeted at EMCRs for the purpose of empowering researchers at all levels to create policy impact through their work (see SCAR Open Science Conference 2022 mini-symposium: 'How SCAR informs and guides Antarctic policy and conservation').

In conjunction with the Ant-ICON Steering Committee, the Communications Officer is facilitating outreach and education through different social media accounts. Ant-ICON will budget for and host webinars and produce training or educational videos and guides to increase education and outreach within and beyond the SCAR community.

How is Ant-ICON engaging with the broader research community?

Ant-ICON has already engaged and will continue to engage with the research community through workshops associated with major SCAR conferences, virtual meetings, cross-representation on respective Steering Committees and other initiatives including practical training to facilitate capacity building. The Ant-ICON Steering Committee has proposed sessions to align with and showcase the research themes at SCAR Conferences, including, for example, the 10th SCAR Open Science Conference (2022). Ant-ICON has already held a series of programme initiation workshops with a range of stakeholders including representatives from the Ant-ICON Steering Committee, the Association of Polar Early Career Scientists (APECS), environmental experts from the CEP and scientists from SC-CAMLR. The Ant-ICON Steering Committee is developing workshop ideas, with topics considered so far including:

- The integration of science and associated outputs across geographical boundaries;
- The human dimensions of Antarctic conservation;
- Continent-wide data collection, including remote sensing and coordinated surveys;
- Principles and applications of data science, machine learning and deep learning;
- Ecosystem services in Antarctica;
- Formulating scientific research into applied, policy-relevant frameworks;
- Data visualization and outreach techniques; and
- Effective capacity building (in conjunction with APECS).

Challenges

Ant-ICON is different from most previous SCAR SRPs in that it has a greater focus on applied research that responds to the science needs of policymakers and that it aims to take a transdisciplinary approach to addressing a suite of timely research questions that are of interest not only to the scientific community but also to policymakers. Perhaps inevitably, this will lead to both anticipated and unforeseen challenges, but the process of identifying and addressing these challenges will, in itself, be valuable for the growth and development of the SCAR community. Challenges may include but are unlikely to be limited to:

- Difficulties in understanding the scientific needs of policymakers, and in turn delivering science outputs that fulfil policy needs and help inform policy development and agreement;
- Engagement of researchers in the delivery of more applied research to respond to policymakers' science needs;
- The provision of funding by national science funding agencies to deliver research that answers applied conservation or management questions rather than 'blue sky' research questions;
- Understanding the limitations of what research can be delivered with the available resources, given the breadth of conservation issues facing the Antarctic region;
- Effective communication and co-production of ideas between natural and social scientists as well as practitioners to ensure a truly transdisciplinary research approach;
- The development of clear boundaries between different groups within SCAR to reduce the likelihood of duplication of effort; and
- A mismatch between the pace of scientific advancement and that of policy development, making it challenging to facilitate a substantive impact in a relatively short time frame.

Ongoing, open and honest communication between relevant individuals, groups and organizations will be fundamental in helping to overcome these challenges (Evans & Cvitanovic 2018), and Ant-ICON strives to work continuously with its stakeholders towards improving engagement and collaboration in areas that are key to Antarctic conservation. The Ant-ICON Steering Committee plays a crucial role in this process, supported by its Advisory Group, and it is developing a close relationship with SC-ATS that will be essential to maximizing the conservation benefit of Ant-ICON research.

Conclusions

Faced with a suite of diverse threats, the Antarctic environment is in increasing need of environmental stewardship and policy decision-making that is in turn based on the best available science. The overall contributions of Ant-ICON will be:

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- Improved integration of the best available science outputs and policy needs;
- An increased level of high-quality research to support decision-making;
- A better understanding of threatened and vulnerable systems and species across the Antarctic region;
- Increased collaborations within, between and beyond academic disciplines;
- Improved integration of socio-ecological research; and
- Increased research capacity, particularly through the practical training and mentorship of EMCRs.

With the full participation of researchers across disciplines and strong engagement with policymakers and other stakeholders, Ant-ICON has started to contribute to the improved conservation and management of Antarctica, the Southern Ocean and the sub-Antarctic. Ant-ICON welcomes all new members who want to make a positive difference to the future of the Antarctic environment.

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Author contributions

KAH, MS and AT led the drafting of the manuscript with input and critical feedback from all authors.

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