Environmental Science and Policy 83 (2018) 86–95

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Antarctic environmental protection: Strengthening the links between science and governance

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A R T I C L E I N F O

Keywords:
Policy
Science
Environment
Communication
Conservation
Human impact
Legislation
Antarctic Treaty area

A B S T R A C T

The Antarctic has significant environmental, scientific, historic, and intrinsic values, all of which are worth protecting into the future. Nevertheless, the area is subject to an increasing level and diversity of human activities that may impact these values within marine, terrestrial and cryosphere environments. Threats to the Antarctic environment, and to the aforementioned values, include climate change, pollution, habitat destruction, wildlife disturbance and non-native species introductions. Over time, a suite of legally binding international agreements, which form part of the Antarctic Treaty System (ATS), has been established to help safeguard the Antarctic environment and provide a framework for addressing the challenges arising from these threats. Foremost among these agreements are the Protocol on Environmental Protection to the Antarctic Treaty and the Convention on the Conservation of Antarctic Marine Living Resources. Many scientists working in Antarctica undertake research that is relevant to Antarctic environmental policy development. More effective two-way interaction between scientists and those responsible for policy development would further strengthen the governance framework, including by (a) better communication of policy makers' priorities and identification of related science requirements and (b) better provision by scientists of 'policy-ready' information on existing priorities, emerging issues and scientific/technological advances relevant to environmental protection. The Scientific Committee on Antarctic Research (SCAR) has a long and successful record of summarizing policy-relevant scientific knowledge to policy makers, such as through its Group of Specialists on Environmental Affairs and Conservation (GOSEAC) up to 2002, currently the SCAR Standing Committee on the Antarctic Treaty System (SCATS) and recently through its involvement in the Antarctic Environments Portal. Improvements to science-policy communication mechanisms, combined with purposeful consideration of funding opportunities for policy-relevant science, would greatly enhance international policy development and protection of the Antarctic environment.

1. Introduction

The fourth of October 2016 marked the 25th anniversary of the agreement of the Protocol on Environmental Protection to the Antarctic Treaty, which was signed in 1991 in Madrid and entered into force in 1998. The Protocol designates Antarctica as a natural reserve for peace and science (Article 2) and is the international agreement through which the Antarctic's environmental, scientific, historical and intrinsic (including wilderness and aesthetic) values are protected. In June 2016, at the 39th Antarctic Treaty Consultative Meeting (ATCM), Parties reaffirmed their strong and unwavering commitment to the Protocol as the international framework for comprehensively protecting the Antarctic environment, through the '*Declaration on the Twenty Fifth Anniversary of the signing of the Protocol on Environmental Protection to the Antarctic Treaty*' (Chile, 2016). Notably, the Declaration reaffirmed the importance of drawing upon the best available scientific advice for

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https://doi.org/10.1016/j.envsci.2018.02.006
Received 2 November 2017; Received in revised form 14 February 2018; Accepted 14 February 2018
Available online 27 February 2018

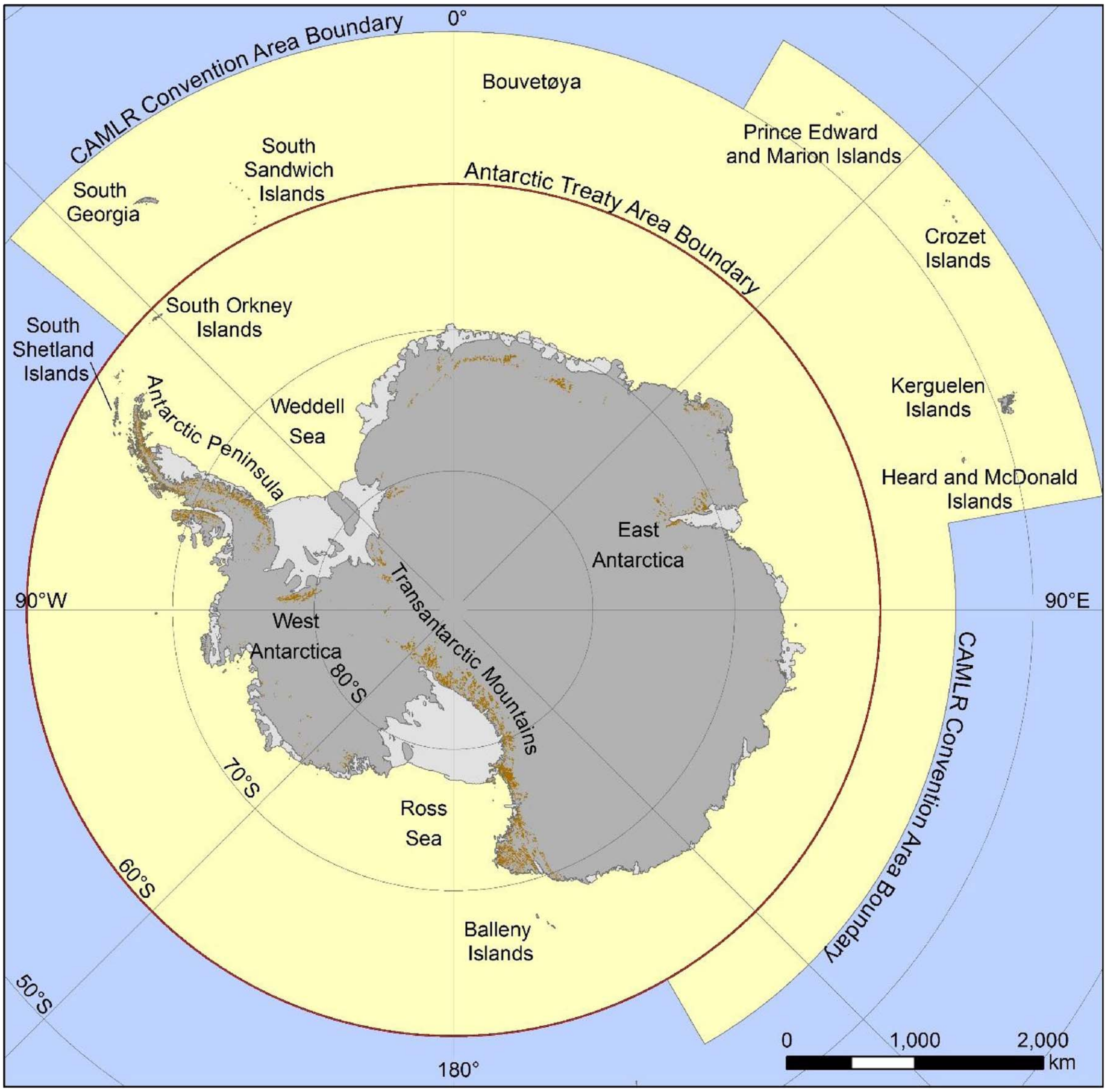

Fig. 1. Map of the Antarctic region, showing the Antarctic Treaty and CAMLR Convention areas.

Antarctica's management and protection.

Over several decades of environmental research, scientists have documented the sensitivity and vulnerability of the Antarctic and Southern Ocean to human impacts (Tin et al., 2009; Chown et al., 2012a,b) and to global environmental change (Constable et al., 2014; Turner et al., 2014). Scientists are increasingly willing to undertake policy-oriented research to help policy makers manage the region, but it may not be clear to the wider scientific community how best to achieve this.

To mark the Protocol's anniversary, a mini-symposium entitled '*Linking Antarctic Science with Environmental Protection: celebrating the 25th Anniversary of the Madrid Protocol*' was held on 23 August 2016 during the Scientific Committee on Antarctic Research (SCAR) Open Science Conference in Kuala Lumpur, Malaysia. The mini-symposium facilitated presentations and discussion on the role that Antarctic scientists and SCAR can have in informing policy development in support of the objectives and principles of the Protocol (Hughes et al., 2016a). This paper builds upon this theme and aims to communicate the opportunities and challenges for effective science-policy communication in the context of Antarctic environmental protection. In particular, this paper explores the links between Antarctic scientists and SCAR, and policy development by the ATCM and Committee for Environmental Protection (CEP) to advance the objectives of the Protocol, although many of the principles discussed are likely to be generally applicable. SCAR and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) also have a history of cooperation. Discussions are ongoing within CCAMLR about further opportunities for the Scientific Committee for the Conservation of Antarctic Marine Living Resources (SC-CAMLR) and CCAMLR to draw on policy-ready research outcomes made available via SCAR. To date much of SCAR advice has been provided via submissions to SC-CAMLR. Enhanced collaboration between the CEP and SC-CAMLR in recent years, including through two joint workshops (e.g., see Grant and Penhale, 2016), has identified several issues of mutual interest and a suite of shared science needs. Both the CEP and SC-CAMLR have recognised that closer engagement with SCAR will be helpful to further understand and address the implications of climate change for the protection and conservation of the Antarctic region (ATS, 2016; Constable, 2016; SC-CAMLR, 2016).

2. The need for environmental protection in Antarctica

Antarctica is a remote continent with an area of c. 14 million km^2, of which only c. 0.18% is ice-free (Burton-Johnson et al., 2016) (Fig. 1). The surrounding Southern Ocean contains a wide diversity and abundance of marine species (De Broyer et al., 2014), and the continent provides breeding areas for bird and marine mammal species and contains significant biodiversity, distributed across 16 recognised ice-free bioregions (Terauds et al., 2012; Chown et al., 2015; Terauds and Lee, 2016). Antarctica has an irrefutable intrinsic value as one of the Earth's least visited and least understood continents. Additionally, Antarctic environments have substantial scientific value, with a wealth of scientific information produced each year on aspects of Antarctica relevant to the life, earth and physical sciences (Kennicutt et al., 2015). Furthermore, Antarctica offers unique opportunities for scientific monitoring of and research on processes of global as well as regional importance, a tradition dating back to the International Geophysical Year (IGY) of 1957-58.

First discovered in c. 1820, for almost 200 years, the region has been through successive periods of sealing, whaling and fishing, with commercial exploitation of Southern Ocean fish stocks still on-going. During the early years, in particular, exploitation and exploration went hand in hand. In the years after the Second World War (1939–45), scientific interest in Antarctica increased substantially (Walton, 2013). This was demonstrated most obviously with the IGY (1957–58), which focused collaborative scientific effort on the continent to an unprecedented level, at a time that coincided with the Cold War years (Scully et al., 2011; Walton et al., 2011). Consequently, Antarctica was seen increasingly as a continent for science. Scientific activity continues today, with over 100 facilities including 40 year-round stations and 36 seasonal stations, supporting the research of the 30 countries that operate in the region (COMNAP, 2017). Tourism has also developed, with visitor numbers growing exponentially over the past 20 years. Now approximately 40,000 tourists visit Antarctica each year, with the majority landing at a small number of sites, located mostly on the Antarctic Peninsula and off-shore islands, and concentrated in the austral summer period November to March (IAATO, 2017; Liggett and Stewart, 2017). The duration of the summer tourism season is expanding slowly over time, which prolongs the pressure on visited environments (Bender et al., 2016). Infrastructure, including airstrips, research stations, and wharfs, continue to be developed or expanded to support scientific and tourism activities, with much of the activity on scarce ice-free ground (Hughes et al., 2011a; Pertierra et al., 2017).

Human activities have resulted in impacts upon the Antarctic terrestrial, freshwater, marine and ice environments including disturbance or displacement of wildlife, destruction of habitat, environmental pollution, introduction of non-native species, over-exploitation of marine mammal species and fish (including through illegal, unreported and unregulated (IUU) fishing which contributes substantially to the global catch of toothfish), incidental mortality of seabirds, by-catch and habitat damage associated with fishing activities (Bargagli, 2005; Frenot et al., 2005; Agnew et al., 2009; Tin et al., 2009, 2014; Aronson et al., 2011; Grant et al., 2012; Chown et al., 2012a; Coetzee and Chown, 2015; Hughes et al., 2015a). Given that human activity is likely to continue to increase and diversify in Antarctica, and pressures on the Antarctic environment arising from activities outside the region are also expected to intensify, further and more pressing conservation challenges are likely to result that will require timely development and implementation of effective environmental policy (Chown et al., 2012b, 2017; Hughes et al., 2016b).

3. Antarctic governance and associated policy bodies

The Antarctic Treaty System and its constituent governance bodies promote action to protect the values of Antarctica. However, the principal international agreement for governance of the Antarctic region (the Antarctic Treaty) does not itself include provisions focused on environmental protection. Rather, the Treaty, which came into force in 1961, established a unique system of international governance for the area south of 60 °S latitude, with the primary aims of ensuring the peaceful use of Antarctica, and promoting continued international cooperation in the conduct of scientific research. Under the Treaty, all territorial claims are held in abeyance, testing of nuclear weapons is prohibited and Parties are guaranteed freedom of access to the continent. Initially signed by 12 states, the number of Parties has grown to 53 (as of 2018), representing c. 65% of the world population (see Table 1).

Subsequently, further legal agreements and associated policy bodies were developed that, together with the Antarctic Treaty, constitute the Antarctic Treaty System (ATS) (Saul and Stephens, 2015). These agreements formally expanded the international objectives for the region to include the protection and conservation of the Antarctic environment. In relation to marine systems, the Convention for the Conservation of Antarctic Seals (CCAS, signed in 1972, entered into force 1978) was established originally to regulate commercial sealing activities, but with no commercial sealing activities in the Treaty area, and with additional protection given to all native seals under the Protocol on Environmental Protection to the Antarctic Treaty (also known as the Environmental Protocol or the Madrid Protocol), it now requires little active engagement from Parties. In contrast, significant international activity is undertaken under auspices of the Convention on the Conservation of Antarctic Marine Living Resources (CAMLR Convention, entering into force in 1982). The CAMLR Convention aims to conserve Antarctic marine ecosystems; harvesting can only be undertaken in a sustainable manner consistent with the Convention's overarching conservation objective. The Convention established a Scientific Committee (SC-CAMLR) which provides the best available scientific basis to inform and develop measures to conserve Antarctic marine living resources (e.g. by setting harvesting levels) and to address other management issues faced by the CAMLR Commission (CCAMLR).

The most recent major component of the ATS to be agreed was the Protocol on Environmental Protection to the Antarctic Treaty. The Protocol was developed after the Convention on the Regulation of Antarctic Mineral Resource Activities (Wellington Convention) failed to be ratified by all the Consultative Parties, and marked a stronger emphasis by the Treaty Parties on protection and conservation of the Antarctic environment. The Protocol was designed to address the particular environmental concerns and management challenges of the Antarctic region and sets out principles and standards for environmental protection. It designates Antarctica as a '*natural reserve, devoted to peace and science*' (Article 2), and requires that protection of the Antarctic environment and its value as an area for conducting scientific research shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area (Article 3). Another key provision within the Protocol, with direct benefits for the Antarctic environment, is the indefinite prohibition of any activity relating to mineral resource activities, other than scientific research, within the Treaty area (Article 7). In addition, the Protocol has six annexes that establish important requirements for the environmental management of activities conducted in Antarctica (see Table 2). They relate to (i) procedures and requirements for the prior environmental impact assessment of all proposed activities (ii) conservation of Antarctic fauna and flora, (iii) waste disposal and waste management, (iv) prevention of marine pollution, (v) area protection and management, and (vi) liability arising from environmental emergencies (the annex on liability was adopted in 2005, but has not yet entered into force).

The Protocol also established the CEP to provide advice and formulate recommendations to the Parties of the ATCM in connection with the implementation of the Protocol, including (but not limited to) advice on: (a) means of minimising or mitigating environmental impacts of activities in the Antarctic Treaty area, (b) the collection, archiving, exchange and evaluation of information related to environmental protection; (c) the state of the Antarctic environment, and (d) the need for scientific research, including environment monitoring, related to the implementation of the Protocol. There are currently 40 Parties to the Protocol (see Table 1), which are entitled to be members of the CEP. The Parties comprise all 29 Consultative Parties to the Antarctic Treaty (those Parties that have demonstrated their interest in Antarctica by

Table 1
Accession of countries to the main components of the Antarctic Treaty System and membership of the Scientific Committee on Antarctic Research (SCAR).

	Country	Antarctic Treaty		Environmental Protocol	CAMLR Convention[a]	Convention for the Conservation of Antarctic Seals	Scientific Committee on Antarctic Research	
		Consultative Party	Non-Consultative Party				Member	Associate Member
1	Argentina	●		●	●	●	●	
2	Australia	●		●	●	●	●	
3	Austria		●					●
4	Belarus		●	●				
5	Belgium	●		●	●	●	●	
6	Brazil	●		●	●	●	●	
7	Bulgaria	●		●	●		●	
8	Canada		●	●	●		●	
9	Chile	●		●	●	●	●	
10	China	●		●	●		●	
11	Colombia		●					●
12	Cook Islands				●			
13	Cuba		●					
14	Czech Republic	●		●				●
15	Denmark		●					●
16	Ecuador	●		●			●	
17	Estonia		●					
18	Finland	●		●	●		●	
19	France	●		●	●	●	●	
20	Germany	●		●	●	●	●	
21	Greece		●	●	●			
22	India	●		●	●		●	
23	Islamic Republic of Iran							●
24	Guatemala		●					
25	Hungary		●					
26	Iceland		●					
27	Italy	●		●	●	●	●	
28	Japan	●		●	●	●	●	
29	Kazakhstan		●					
30	Democratic People's Republic of Korea		●					
31	Republic of Korea	●		●	●		●	
32	Malaysia		●	●			●	
33	Mauritius				●			
34	Monaco		●	●				●
35	Mongolia		●					
36	Netherlands	●		●	●		●	
37	Namibia							
38	New Zealand	●		●	●		●	
39	Norway	●		●	●	●	●	
40	Pakistan		●	●	●			●
41	Republic of Panama				●			
42	Papua New Guinea		●					
43	Peru	●		●	●		●	
44	Poland	●		●	●	●	●	
45	Portugal		●	●				●
46	Romania		●	●				●
47	Russian Federation	●		●	●	●	●	
48	Slovak Republic		●					
49	South Africa	●		●	●	●	●	
50	Spain	●		●	●		●	
51	Sweden	●		●	●		●	
52	Switzerland		●	●			●	
53	Thailand							●
54	Turkey		●	●				●
55	Ukraine	●		●	●			●
56	United Kingdom	●		●	●	●	●	
57	United States	●		●	●	●	●	
58	Uruguay	●		●	●		●	
59	Vanuatu				●			
60	Venezuela		●	●				●

[a] Includes CAMLR Convention Members and Acceding States. The European Union has also acceded to the CAMLR Convention.

conducting substantial scientific research activity there, and which can participate in decision-making at the ATCM) and a further eleven non-Consultative Parties that have acceded to the Protocol. There are three standing Observers to the CEP (i.e. the Scientific Committee on Antarctic Research (SCAR), CCAMLR and the Council of Managers of National Antarctic Programs (COMNAP)), all of which can submit Working Papers to the Committee that may include specific recommendations. In addition, several bodies with relevant environmental, scientific or technical expertise are invited to contribute as experts, most notably the Antarctic and Southern Ocean Coalition

Table 2
Summary of the Annexes to the Protocol on Environmental Protection to the Antarctic Treaty.[a]

Annex No.	Title	Major role
I	Environmental Impact Assessment	The environmental impacts of any proposed activities in Antarctica shall, before their commencement, be assessed in order to identify any impacts on the environment, including cumulative impacts, and to identify alternative potentially less harmful approaches, as well as any monitoring required to verify the predicted impacts of the activity. The extent of the environmental impacts assessment required depends upon whether the predicted impacts are likely to cause less than, no more than, or more than minor or transitory impacts. Draft Comprehensive Environmental Evaluations (prepared for activities likely to have more than a minor or transitory impact) must be made publically available, circulated to all Parties for comment and be forwarded to the CEP for consideration before the activity commences.
II	Conservation of Antarctic Fauna and Flora	Annex II provides the rules and framework for protecting animals and plants in Antarctica. Permits are required to be issued for any harmful interactions with Antarctic native species. The introduction of non-native species is not allowed, except for limited purposes authorised under a permit. The Annex also provides for the designation of 'Specially Protected Species'. Annex II was revised and updated in 2009, including to consider the protection of invertebrate species.
III	Waste Disposal and Waste Management	Annex III establishes the principle that the amount of waste produced or disposed of in Antarctica should be minimised to protect the environment and other Antarctic values. It also establishes the framework for cleaning up waste sites on land generated prior to the Protocol; rules for the disposal of human waste and the use of incinerators; and a requirement to develop waste management plans. Some products, such as polychlorinated biphenyls (PCBs), polystyrene packaging beads and pesticides, are prohibited in the Antarctic.
IV	Prevention of Marine Pollution	Annex IV prohibits the discharge of noxious liquid substances, plastics and other garbage to sea from ships. Its framework is broadly consistent with the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL). The Annex also requires Antarctic Treaty Parties to prepare contingency plans for marine pollution emergencies in the Antarctic Treaty area. Annexes I to IV were adopted in 1991 together with the Protocol and entered into force in 1998.
V	Area Protection and Management	Annex V establishes two forms of protected area (Antarctic Specially Protected Areas (ASPAs) and Antarctic Specially Managed Areas (ASMAs). Both ASPAs and ASMAs require management plans to be prepared, which must be reviewed at least every five years. ASPAs are designed to manage and 'protect outstanding environmental, scientific, historic, aesthetic or wilderness values' and scientific research. Permits are required to enter and conduct activities in ASPAs. ASMAs are designated to '…assist in the planning and co-ordination of activities, avoid possible conflicts, improve co-operation between Parties or minimise environmental impacts'. Annex V also provides for the de'signation of Historic Sites and Monument to protect and conserve sites of recognised historic value. Annex V was adopted in 1991 and entered into force in 2002.
VI	Liability Arising from Environmental Emergencies	This Annex outlines arrangements to prevent and respond to environmental emergencies in the Antarctic Treaty area arising from scientific research programmes, tourism and other governmental and non-governmental activities. It establishes the rules governing liability for the environmental emergencies and provides that compensation may be claimed from the polluter if that party has not taken prompt and effective response action. Annex VI was adopted in 2005 and will enter into force once approved by all Consultative Parties.

[a] Amended from CEP (2016).

(ASOC) and the International Association of Antarctica Tour Operators (IAATO), but also the International Hydrographic Organization (IHO), the Intergovernmental Panel on Climate Change (IPCC), the International Union for Conservation of Nature (IUCN), the United Nations Environment Programme (UN Environment) and the World Meteorological Organization (WMO). Parties to the CAMLR Convention that have not acceded to the Treaty are also obliged to observe measures established by the ATCM to protect Antarctica, including the Protocol, thereby binding the work of the ATCM and CCAMLR in protection of the Antarctic region (see Articles III and V of the Convention).

The CEP has been meeting for 19 years and has discussed a wide range of issues relevant to environmental protection. Since 2007, the CEP has maintained a prioritised rolling five-year work plan to guide and focus the Members' individual and collective efforts. The Committee's top priorities currently include:

- understanding and responding to the environmental consequences of climate change in the Antarctic region;
- addressing the risks to biodiversity associated with the introduction to Antarctica of non-native species, including the transfer of native species between bioregions within Antarctica, which are likely to increase with increasing human activity in Antarctica and with climate change;
- appropriately managing the environmental impacts of tourism and non-governmental activities; and
- improving the effectiveness of protected area management, and further developing the Antarctic protected area system, including in the marine environment.

4. The importance of scientific evidence in environmental policy development

Antarctica is a continent where science and supporting logistics are the dominant human activities, with over 30 states undertaking regular science programmes in the region. Much of the resulting research evidence may be of relevance to policy makers (Kennicutt et al., 2015). In their decision-making processes policy makers have to draw on the information available (including scientific information), to identify and implement an agreed course of action to address a problem or opportunity. Policy makers inevitably have to balance competing stakeholder interests when making decisions (Rose, 2014). They may take into consideration the precautionary principle and previous experience, but a greater emphasis is now being placed on building environmental policies based upon the best available scientific evidence taking account of the uncertainties in that evidence (see Constable, 2011; Cook et al., 2013; Pullin et al., 2016). In the Antarctic context, the CEP seeks to draw on the best available relevant scientific evidence when providing advice and formulating advice and recommendations to the ATCM in connection with the implementation of the Protocol. This highlights the need for effective communication between Antarctic scientists and policy makers. Indeed, the Protocol clearly acknowledges the important role played by the scientific community in general, and SCAR in particular, to contribute to the further shaping of Antarctic environmental policies (Article 12 (2)).

As is the case globally (e.g. Pereira et al., 2013), the provision of robust environmental information to policy makers as the basis for the best possible protection of the Antarctic environment is made challenging by several factors:

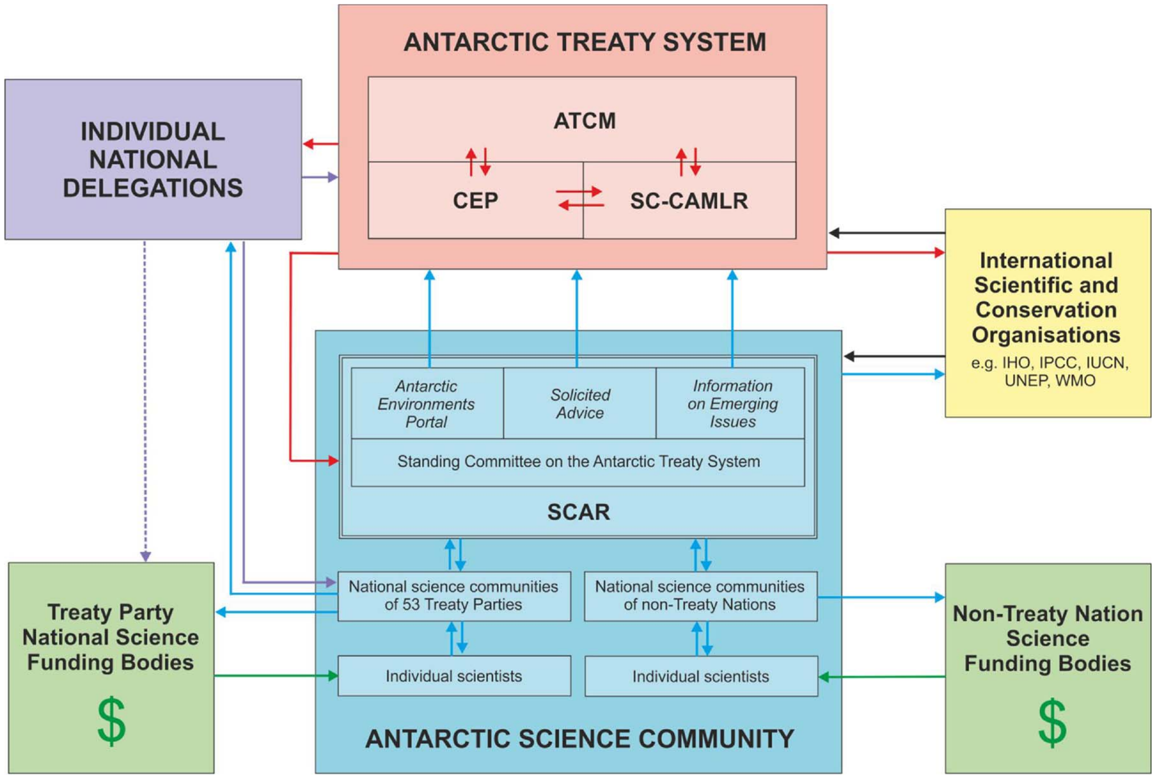

Fig. 2. Antarctic science-policy communication pathways. Arrow colours reflect the source of the communicated information. The dotted arrow highlights a particular opportunity for further improvements in communication between some individual national delegations to the ATCM and their respective national science funding bodies to consider more targeted funding of environmental science relevant to Antarctic policy needs.

1 Knowledge of the Antarctic environment and broader scientific understanding is incomplete (for examples of changing circumstances see, e.g., Ainley et al., 2013; Hughes et al., 2015a,b and Parker et al., 2016), and it can be challenging to communicate knowledge gaps and uncertainties, and the implications of these, to policy makers, who wish to make decisions based on the best available evidence.
2 In contrast, the rapid rate of developments in many scientific fields means that it is sometimes challenging for policy makers to remain up-to-date on policy-relevant scientific information.
3 Integrating evidence from different academic fields (for example, to determine the impacts of climate change) and presenting this in a form relevant to policy makers is often difficult.
4 No single country is likely to have access to expert scientific opinion on all Antarctic environmental topics within its own research community, making consultation between international experts essential if the best available advice is to be made accessible to individual policy makers, the CEP and ATCM. However, cultural barriers in science production and communication can make this process difficult and time-consuming, particularly when many countries are involved as is increasingly the case.
5 Language barriers and limited access to some research journals containing relevant information may make it difficult to access and understand all the available research evidence (Elzinga, 2017).

Ultimately, efforts to enhance Antarctic environmental protection would be further strengthened by developing greater synergies between the governance bodies on the one hand and the science community on the other hand. Fortunately, there are mechanisms already in place linking scientific evidence to governance, with SCAR playing a key role.

5. Effective science dialogue – the role of SCAR

Scientists undertaking policy-relevant research usually want to ensure their work has maximum policy impact and makes a positive difference to Antarctic environmental management. Two main routes are available for scientists to contribute to ATS deliberations: either through the ATCM and CEP National Delegations (see: http://www.ats.aq/devAS/cep_authorities.aspx) or through SCAR (Fig. 2).

SCAR is an interdisciplinary body of the International Council for Science (ICSU), and its dual role is to initiate, promote and coordinate scientific research in, from and about Antarctica and the Southern Ocean and to provide independent scientific advice to the Antarctic Treaty System and other bodies. SCAR is currently comprised of 43 member countries (Table 1) and nine ICSU Unions. The first meeting of SCAR was held in February 1958, before the Antarctic Treaty was drafted. SCAR was, in fact, integral in shaping the Antarctic Treaty itself and later in providing a framework for scientific activity within the Treaty area and further north (Walton et al., 2011; Elzinga, 2017). Since that time, an enduring strength of SCAR has been its ability to integrate research effort by scientists from many countries and disciplines and operating across the whole of the Antarctic continent and Southern Ocean to address science and policy questions that are challenging for a single country to deliver. This contribution has been regularly acknowledged since the first ATCM (Recommendation I-IV), including in the body of the Protocol itself (Article 12(2)). Although it participates in the ATCM and CEP as an Observer, and so does not participate in decision-making, the Rules of Procedure of the CEP give SCAR the capacity to submit Working Papers, and thereby make recommendations for these bodies to consider. SCAR has a long-standing reputation as a source of reliable, independent and objective scientific advice to the ATS, not least as a result of many submissions that have informed and improved policy and/or management actions to conserve and protect the Antarctic environment and its biota (Walton and Clarkson, 2011).

The Standing Committee on the Antarctic Treaty System (SCATS; see http://www.scar.org/antarctic-treaty-system/scats) is the current SCAR body tasked with co-ordinating SCAR's scientific advice to the ATS. For any given topic, SCATS will consult with relevant experts (within the SCAR community, or beyond if required), collate the best available evidence (based on research in the Antarctic and Southern Ocean itself, but also beyond when relevant), and present it in a way that can be readily understood by policy makers. SCAR is one of the most productive CEP participants, having submitted over 165 papers to the ATCM/CEP since the Protocol entered into force and the first meeting of the CEP took place in 1998 (Dudeney and Walton, 2012).

SCAR's contribution to the ATCM and CEP occurs in two main ways: (1) by responding to direct requests that arise during the annual meetings (i.e. solicited advice) or (2) by identifying and bringing important emerging issues to the attention of the ATS. In recent years, the ATCM and CEP have solicited and subsequently received advice from SCAR on topics including wildlife disturbance (SCAR, 2008), persistent organic pollutants (POPs) (Fuoco et al., 2009), bioprospecting (SCAR, 2010), and the use of Remotely Piloted Aircraft Systems (RPAS) near wildlife (SCAR, 2017). SCAR has also had considerable input into the development and review of a wide range of relevant Codes of Conduct (see http://www.scar.org/codes-of-conduct). Proactively, SCAR has also provided information and advice to the CEP on topics such as specially protected species (SCAR, 2002), non-native species (SCAR, 2012) and bioregionalisation (i.e. the Antarctic Conservation Biogeographic Regions; Australia et al., 2012, 2017).

The production and release of the 2009 Antarctic Climate Change and Environment (ACCE) Report is an illustrative example as to how SCAR's work can influence the discussions and decisions in the CEP and ATCM over time. The 2009 ACCE report presented a comprehensive review of scientific understanding of how the Antarctic climate is changing, how it is likely to change in the future, and what the associated environmental impacts might be (SCAR, 2009; https://www.scar.org/policy/acce-updates/). The report was produced with international contribution from more than 200 scientists from the physical, earth and life sciences and was more than 500 pages in length with over 1800 academic references. The ACCE report directly informed policy when it was used as the basis for discussions at an Antarctic Treaty Meeting of Experts (ATME) on Climate Change held in 2010. The meeting generated 30 recommendations, which are subject to continuing consideration by the ATCM and CEP, and resulted in the development of the CEP Climate Change Response Work Programme (CCRWP). In 2017, the CEP established the Subsidiary Group on Climate Change Response (SGCCR) to help the Committee in its considerations of how to address the implications of climate change for protection of the Antarctic environment, including recommendations arising from the 2010 ATME. The value of the ACCE work by SCAR is further reflected by the ATCM's request to receive annual updates.

Since 2003, SCAR has also communicated policy-relevant science through an annual lecture presented during the Treaty meeting and dedicated to a scientific topic of interest for the Treaty meeting Delegates. The aim is to provide accessible information about relevant scientific topics, increase the presence of science in the Antarctic Treaty and CEP meetings, and provide an opportunity for debate and discussion. Recognising the value of the annual SCAR lecture to their discussions, at the 2017 ATCM the Parties decided that future lectures should be scheduled for early in the meeting. The complete list and content of all the SCAR Lectures to the ATCM can be seen and their content downloaded from: https://www.scar.org/antarctic-treaty/atcm-presentations/.

6. Communicating science to policy makers through SCAR: what researchers need to know

It is important to ensure that all scientific information used as input in policy-shaping discussions and environmental management decisions adheres to the fundamental principles of scientific rigour and impartiality. Scientific information that is relevant to communicate to policy makers can include (a) new and emerging environmental issues, (b) reviews of the state of knowledge on policy-relevant issues or (c) scientific/technical advances in methods for environmental protection developed specifically for Antarctica, or developed elsewhere but applicable to Antarctic environmental situations. Irrespective of the route by which science is communicated to ATS policy makers, the evidence-base for the findings and any associated recommendations must be clear. Ideally, policy makers like to take decisions on the basis of strong scientific evidence, but it is also important for them to know (and still be able to act, as appropriate) if the scientific evidence base is weak. In some cases, the response might include, for example, to recommend actions to support or undertake more research to improve the evidence base, but to take precautionary steps for the time being. Indeed, SCAR's Rules of Procedure for Subsidiary Bodies require that evidence presented by SCAR to external bodies to inform policy or management decision-making is peer-reviewed and reviewed through SCATS. Research addressing priority topics listed in the CEP Five-Year Work Plan and the recently developed CCRWP will, at least initially, attract most attention from policy makers (see: http://www.ats.aq/e/cep.htm). The involvement of scientists from multiple countries, and/or multinational support for research evidence that is presented, can help with building broad support within the ATS, particularly in light of Article 3 of the Antarctic Treaty that promotes international cooperation in scientific investigation in Antarctica. This is particularly important to enable countries to be involved at an early stage in the development of policies that may directly affect them. The greater engagement of early-career scientists, including through the Association of Polar Early Career Scientists (APECS), may provide an additional opportunity for enhancing the interface between science and policy (e.g. through the support of the SCAR-COMNAP Fellowships Scheme).

Scientific advice will have greater uptake when provided in a form that is both 'policy-ready' and relevant to the needs of policy makers. It is important to note that the process of changing or developing Antarctic policy may take several years, including because all decisions are taken by consensus and multiple factors may need to be taken into consideration. While the pace may seem slow, by the standards of international organisations generally, the ATS can move quickly in some cases. An example is the publication in 2012 of the Antarctic Conservation Biogeographic Regions (Terauds et al., 2012) and their adoption that same year by a Resolution at the ATCM as a way of informing the further development of the Antarctic protected areas system (ATCM Resolution 6 (2015), Hobart 2012; updated through ATCM Resolution 3 (2017) Beijing, China; see http://www.ats.aq/devAS/ats_meetings.aspx?lang=e). Irrespective, the opportunity to contribute to and improve policy and management of the region is profound, making even complex and lengthy processes worth the effort for individual scientists or science research consortia.

7. The Antarctic Environments Portal

Knowledge disseminated through thematic syntheses and status reports may quickly become outdated due to a rapidly changing knowledge base. The recent advances in developing 'on-line' platforms and mechanisms for dynamically disseminating and updating knowledge, in a manner that gives the audience confidence the information is accurate and current, are particularly important for improving the delivery of science into policy. The recently developed Antarctic Environments Portal (www.environments.aq) takes advantage of these approaches and presents an additional mechanism for communicating research to policy makers. The Portal was launched in 2015 and was developed by New Zealand, SCAR and a consortium of other countries that are active in the ATCM and CEP. It is an online resource that provides the scientific community with a ready-to-use, efficient and scientifically sound mechanism for presenting scientific evidence for use in Antarctic policy-making. The Portal aims to make relevant scientific knowledge readily available for policy-making in the Antarctic context, and thus provide a better foundation for effective Antarctic governance and management. It consists of short articles on a variety of topics relevant to the work of the CEP, including, for example, non-native species, wildlife disturbance, climate change impacts on Southern Ocean biota and area protection. The articles contain no recommendations and reflect the current state of knowledge on a topic, based upon the available peer-reviewed literature. The Portal has been recognized by the Treaty Parties as an important mechanism for making high-quality, accurate, non-political and up-to-date scientific advice available (ATCM Resolution 3 (2015), Sofia, Bulgaria). As the use of the Portal by science contributors and policy makers expands, it has the potential to have an increasing impact on the way that Antarctic Treaty Parties discuss and shape Antarctic environmental policies. Nevertheless, establishing such information sources is not without its challenges, and the Portal's editorial process seeks to ensure scientific robustness of all content, as well as regular reviews to ensure that the content is kept up-to-date.

8. Science-policy communication: fulfilling the potential

To support progress on Antarctic environmental protection and conservation, policy makers need to clearly communicate their priorities and related science requirements, and scientists need to effectively communicate the policy implications of their research. Consequently, communication between policy makers and scientists needs to be established and nurtured, with an emphasis on transparency increasing the likelihood of progress (Sutherland et al., 2011; Turnhout et al., 2014, 2016). Antarctic policy priorities need to be understood by both national and SCAR representatives participating in ATS meetings. Such priorities are outlined in the meeting reports of the ATCM, CEP and CCAMLR, and are made available on the Antarctic Treaty Secretariat and CCAMLR websites, but may not be well known within the wider Antarctic scientific community. A further science-policy communication issue may be the generic way in which policy makers specify their science needs, and may not provide an adequately specific question for a scientist to answer.

Better communication of policy priorities and related science needs will help raise awareness among scientists, and is likely to result in increased delivery of science highly relevant to policy. In this regard, at its meeting in 2017 the CEP agreed to develop a list of its priority science needs, as a practical approach to enhancing communication with SCAR, national Antarctic science funding bodies and the Antarctic science community in general (ATS, 2017). Other relevant initiatives include the dedicated sessions held during the last two biennial SCAR Open Science Conferences (held in Auckland, 2014 and Kuala Lumpur, 2016), which highlighted and reinforced the importance of policy-relevant science to a broad and multidisciplinary Antarctic scientific community. Such sessions may be an 'eye-opener' for scientists, particularly those who do not regularly interact with policy-makers and who may benefit from hearing about the utility of their research in a policy context.

SCAR is well-placed to respond to scientific requests from policy makers based on existing published data. Under some circumstances, the proactive development of bespoke scientific projects responding to CEP and ATCM policy priorities may be a helpful further means to enhance environmental policy delivery, particularly when undertaken in collaboration with one or more ATS National Delegations (see Fig. 2). Some Parties (e.g., the countries of the co-authors of this paper) routinely incorporate scientists in their National Delegations to ATCMs, to provide expertise and represent national positions on scientific topics, and to gain a direct understanding of the issues under discussion and related science needs. The broader inclusion of scientists on national delegations could be encouraged. Further, many government policy makers directly engage with Antarctic researchers when preparing for ATCMs, to seek advice or input into meeting papers and national positions, which is setting a positive example for other delegations to follow. Alternatively, science could respond to existing or emerging conservation priorities to inform policy makers and to enable the development of appropriate policy instruments.

The lack of scientific certainty is sometimes used as a reason to defer decisions in political settings. This raises the interesting question of how much scientific certainty is enough, which will vary depending on the issue in question and the risk appetite or requirements of the decision maker(s). The role of science is to reduce, and where possible quantify, uncertainty so decision-making can take place in light of the best available evidence. There are many examples of the effective transfer of scientific knowledge into Antarctic policy. One of the best examples relates to the issue of non-native species in Antarctica. The CEP has been aware of the issue of non-native species for many years and initiated further work on the topic, including through the Non-native Species Workshop in Christchurch, New Zealand, in 2006 (Rogan-Finnemore, 2008) following the publication of a comprehensive review of the issue by Frenot et al. (2005) and the delivery of the SCAR lecture on the topic to the ATCM by Prof. Steven Chown in 2005. As a result of SCAR and COMNAP initiatives and international programmes conducted during the International Polar Year 2007–2008 (e.g. the 'Aliens in Antarctica' project; Hughes et al., 2010, 2011b; Chown et al., 2012b; Huiskes et al., 2014), the threat to the Antarctic terrestrial and marine environment due to the introduction of non-native species in a context of climate change, was more clearly defined (SCAR, 2012). This issue is of the highest priority for the CEP and, with further substantial input from SCAR, the Committee has agreed guidelines included within the Non-native Species Manual (see: http://www.ats.aq/e/ep_faflo.htm) to help stakeholders, such as national Antarctic programmes, scientists, logisticians and the tourism industry, to minimise the risk of non-native species introductions. Moreover, a collaboration with COMNAP led to the publication of the COMNAP/SCAR Non-native species voluntary checklists for supply chain managers (https://www.comnap.aq/SitePages/checklists.aspx).

A critical reality is that those responsible for policy making often do not fund the science needed for decision-making. There are some examples of national Antarctic science funding and policy-making responsibilities co-existing within a single organisation, or at least having clear formal links, but this is far from a universal arrangement. As long as this disconnect remains, the application of science to policy will remain ad hoc yielding sub-optimal outcomes. The need for enhanced funding for the kind of applied work referred to above, including for example long-term monitoring, and for the research underpinning it (Fig. 2) is substantial but not always available (Kennicutt et al., 2014; Constable et al., 2016; Xavier et al., 2016). The Parties to the ATS agreements, and the institutions of the ATS, could usefully work towards developing mechanisms to promote financial support for research to address policy priorities. Current examples include studies to inform wildlife approach distances, or forecasting population and ecosystem responses to changing impacts and climates.

Communication by ATS National Delegations to their domestic research funding bodies of the need for resources for policy-relevant Antarctic environmental research would, in this regard, also deliver a multitude of tangible benefits. Moreover, national funding calls targeting specific environmental issues would directly contribute to policy progress, and raise the profile of these research areas within science communities. As the focus on the impact of research grows (e.g. van Noorden, 2015), individual scientists, and those who influence funding policy, will find it more straightforward to justify the use of their own time and national resources on research that focuses on agreed priorities, while not losing sight of the scientific integrity that remains the focus of all research endeavours.

9. Conclusions

Effective communication between scientists and policy makers is clearly essential for the development of informed policy and of relevant and directed research efforts that effectively protect Antarctica and the Southern Ocean from current and emerging environmental threats. Despite existing and more recently developed initiatives to enhance communication, further opportunities exist to connect the work of scientists and policy makers. The situation could be improved by increasing scientists' awareness of the opportunities to inform environmental policymaking within the ATS. The ATCM and CEP could communicate more clearly the specific knowledge gaps that must be filled to progress Antarctic environmental protection. SCAR could further assist by strengthening its already substantial communication to its members about the areas of research that are needed by the ATCM and CEP (as has recently be done with the CEP's Climate Change Response Work Programme; see http://www.ats.aq/e/cep.htm) and by continuing to inform the science community though meetings, such as the one that led to this paper, about routes through which policy-relevant science can be communicated to policy makers (i.e. through ATS National Delegations or SCAR, or the Antarctic Environments Portal; see Fig. 2). Effective communication between National Delegations to the ATS and their domestic science funding bodies is required to establish a clear mechanism to commission and ensure adequate resourcing of applied research that fulfils specific policy needs. Without a clear link between policy needs and national funding, the delivery of targeted policy-relevant science is unlikely to be forthcoming.

While it is without question that improved communication between scientists and policy makers and a more considered and proactive integration of scientific knowledge into policy-making would be ideal, the reality is, as so often, very complex, and it would be naïve to assume that the obstacles we are currently facing could be easily overcome. In this paper, we have tried to bring together a host of general suggestions as well as examples of good practice that show how the situation might be improved. Our suggestions point towards thoughtful incremental improvements designed to have maximum impact rather than a radical overhaul of the existing system, which is not necessarily required or even feasible.

With Antarctic environments facing mounting threats from local and global human impacts, policy makers have never been in greater need of timely, high quality and relevant scientific evidence on which to develop appropriate policy and management responses. Conservation best practice developed in the rest of the world may be usefully tailored for the specific circumstances of the Antarctic. However, encouraging the scientific community to undertake policy-relevant research is critical for Antarctic policy to keep pace with current and emerging conservation and environmental management challenges and requires the development of open channels of communication as well as targeted funding at national and international levels.

Acknowledgements

This work originated out of presentations and discussion that occurred during a mini-symposium held on 23 August 2016 at the SCAR Open Science Conference, Kuala Lumpur, Malaysia entitled 'Linking Antarctic Science with Environmental Protection: celebrating the 25th Anniversary of the Madrid Protocol' and we thank the organisers of this meeting. Steven Chown is acknowledged for his substantial contribution to this project. Laura Gerrish is thanked for map preparation and Malgorzata Smieszek is thanked for providing comments on a late draft of the manuscript. We are particularly indebted to two anonymous reviewers for their insightful comments. KH is supported by UK Natural Environment Research Council (NERC) core-funding to the British Antarctic Survey (BAS). JCX is supported by the Investigator FCT program (IF/00616/2013) and had the support of 'Fundação para a Ciência e Tecnologia' (FCT), through the strategic project UID/MAR/04292/2013 granted to MARE. AW is a Research Associate of the Belgian Funds for Scientific Research – FNRS and acknowledges the support of the Belgian Science Policy Office for the CCAMBIO and MICROBIAN projects and her participation to the Belgian delegation in CEP.

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