EU-PolarNet
White Paper No. 3

Managing human impacts, resource use and conservation of the Polar Regions

Research vessel in the Arctic Ocean *(Photo: Alfred Wegener Institute / Mario Hoppema)*

Humanity and the Polar Regions

As human activities exert intensifying pressures on the Polar Regions, concerns about their impacts are becoming increasingly acute. The changes wrought by these pressures carry with them the potential to alter the role the regions play in regulating global climate and other systems, and in providing other important ecosystem services. They may also change societies' relationships with one another. While it has become common knowledge that climate change is driving often dramatic changes in the Polar Regions - and at a much faster pace than elsewhere - human activities impact the poles through other channels as well. Various forms of pollution, transport, tourism, migration, infrastructure, and the pursuit of natural resources, combine to exert substantial impact.

The pressures driving change in the Arctic and Antarctic often originate far from the poles, through human activities such as the burning of fossil fuels or from use of chemicals and plastics. As the Polar Regions become more accessible and as the resources these regions possess become more accessible, the increasing human presence results in more direct impacts. Some changes are beneficial, as when new technologies and economic development improve living standards and increase the life opportunities for people in Arctic communities. However, there are detrimental impacts too, with increased waste, and disturbance of critical local or regional ecosystems undermining traditional livelihoods and causing other social disruption.

It is therefore imperative to strengthen scientific and policy understanding of the Polar Regions. In particular, it is urgent to improve understanding of how human interaction with polar environments can benefit people and societies, and how human activities can be pursued in ways that can at the same time protect and conserve the unique characteristics of these regions. In the Arctic, it is important to develop and optimize the sustainable use of resources for the benefit of local communities – and humanity in general although it should be considered that non-development of resources may be preferable in some cases. In the Antarctic, the imperative lies primarily in protection and conservation in accordance with the Antarctic Treaty System that supports peaceful use of the region, promotes science and other international cooperation and prohibits extraction of mineral resources.

In this context, **a strong EU research policy initiative should encompass these key elements:**

- A social-ecological systems perspective in which ecosystems and the human activities that impact those ecosystems, including resource use, are considered inseparable.
- A focus on critical thresholds beyond which return is unlikely in the near term. This directs attention to the feedbacks that influence such extreme shifts, especially those that can contribute to crossing thresholds.
- Attention to cumulative effects and extended causal relationships that play out over temporal and spatial scales, particularly interactions between people and nature.
- Development of metrics or indicators to monitor the status and resilience of social-ecological systems.
- Comprehensive analysis of governance and management systems for steering human activities in nature, their capacity to integrate and employ diverse knowledge to inform choices, and to make rapid adjustments as new knowledge is made available.

[1] See "definition of terms" at the end of this document

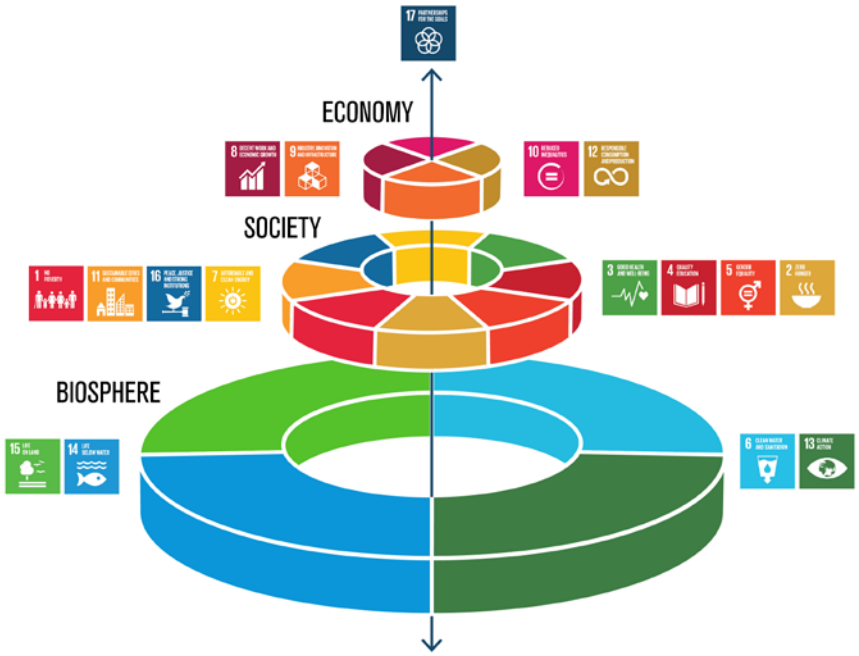

Fig. 1: UN 2015: 2030 Sustainable Development Goals *(Graphics by Jerker Lokrantz/Azote)*

The need for such integrative efforts is well-recognized. The UN Agenda 2030 Sustainable Development Goals are considered interdependent and indivisible. At the same time, Figure 1 illustrates how the achievement of economic and social goals is entirely dependent on meeting goals related to the biosphere. Deeper understanding of the interactions between these goals in the Polar Regions is crucial, particularly where dependency relationships between goals make attaining some goals contingent on attaining others.

The European Environment Agency's 2017 report on "Transitions to Sustainability" highlights the fact that while understanding of the systemic nature and multi-causality of environmental challenges is essential, research regarding how these challenges can be effectively navigated remains separate, and employs different disciplinary perspectives and methods. In order to respond effectively to the pace and breadth of change seen in the Polar Regions, far more effective integration of different types of knowledge - and to link knowledge with corresponding policy and with practice - is crucial. The level of sophistication regarding the organizational and institutional conditions required to break down the boundaries between the various disciplines has increased markedly over the past decade, as expectations have grown from multi-disciplinary projects to producing transdisciplinary insights. These efforts can and should be further developed and applied in the Polar Regions.

Similar, but with important differences

Although the Polar Regions share many similar characteristics, there are also fundamental differences. These include not least, the geopolitical differences pertaining to national sovereignty and international agreements that define shared goals and permitted activities. While the Arctic Ocean is itself an international area, the lands that define its shores are the territory of five Arctic countries which, together with Sweden, Finland and Iceland cooperate under the auspices of the Arctic Council (AC) and are home to indigenous populations who have lived there for thousands of years. The Antarctic is a continent under international governance through the Antarctic Treaty System (ATS). Parts of Antarctica have been visited for 200 years, but most permanent stations have been established since the Second World War, and many areas still remain unvisited.

In the Arctic, the overarching challenge is to combine improved human well-being and more resilient communities with environmental protection and sustainable management of resources - in a context of extraordinarily rapid change. In recent years' these efforts have often entailed increased participation by local communities, in particular indigenous communities, and efforts to integrate scientific and Indigenous Knowledge.[2]

Somewhat different challenges have emerged in the Antarctic, in particular, the need to manage the impacts of an increased human presence from science, fishing and tourism activities. Human interaction with the Antarctic is limited by an international treaty to peaceful purposes, including scientific discovery. Sustainable use or pursuing resource benefits excludes mineral extraction, while fishing the region is secondary to ecosystem conservation (as set out in the CCAMLR Convention).

In both instances, the fundamental imperative is to develop the knowledge needed to manage human activities in relationship

[2]There is an ongoing discussion about terminology that most suitably characterizes the knowledge held by indigenous peoples, including "Traditional Knowledge," "Traditional Ecological Knowledge," and Indigenous Knowledge. The term Indigenous Knowledge (IK) is used here to encompass all these types of knowledge.

to these sensitive and critical regions. This requires a far greater capacity to balance competing societal goals and increasing resource needs, with the need to exercise stewardship of the ecosystems that constitute our life support systems. Recognising these, this White Paper has three core themes:

1. The importance of conservation of the Polar Regions to preserve their intrinsic value, for humanity, including for future generations.
2. The need for sustainable resource utilisation in light of changing environments and expanding human needs.
3. With particular relevance to the Arctic, the importance of organizing resource and economic development in ways that benefit the people of the region including indigenous populations, and in particular those whose livelihoods have been disturbed and disrupted by human impacts from activities taking place or directed from far away.

Gaps in research and knowledge needs

In order to make wise decisions on issues of conservation and the use of resources provided by polar social-ecological systems, this White Paper addresses the most fundamental needs for societally-relevant research for the Polar Regions: 1) the need for deeper understanding of human impacts in complex, interlinked systems; 2) the need for more precise indicators and informational feedbacks to guide decision-making and management processes, as well as an improved capacity of those systems to incorporate and make use of relevant knowledge; and 3) a stronger understanding of the dynamics of knowledge integration, with a focus on strengthening methods for effectively bridging between scientific disciplines and the natural and social sciences, and also for incorporating the humanities and integrating Indigenous Knowledge. It is also important to extend such efforts to strengthening the links and interactions between science, policy and practice. These are described in greater detail under each sub-topic.

Subtopic 1: The direct and indirect impacts of human activities

This sub-topic addresses the need to better understand and quantify human impacts in complex, interlinked systems. Closer examination of human impacts where a long-term presence has left unwanted side-effects warrants particular attention. The cumulative effects of smaller impacts can also generate unwanted changes, and this is especially important where impacts themselves become drivers of further change through sequential or cascading effects.

A. Past presence – historical legacy of human activity

The legacy of decades of focused domestic, commercial and governmental activity in the Polar Regions, at a time when environmental standards were not always high, has resulted in major environmental damage at some locations. Pollution has led to impacts upon wildlife reproductive success and caused changes in biological community structure and function. In some instances, these changes have spilled over to impact human populations, for example, through contamination of traditional food sources. In Antarctica, the initiation of substantial human activity in the late 1950s produced contaminated soil and waste estimated to be of the order 1-10 million m^3. With a longer human presence and mineral resource extraction, transport and military base activities going back decades, the Arctic is much more widely impacted. Due to the cold and often dry conditions, natural remediation processes that work elsewhere are slow or ineffective in polar soils. **Research questions: What methods are available, including remote sensing techniques and community-based**

Port of Murmansk, Russia *(Photo: Peter Prokosch)*

Tourism in Antarctica *(Photo: Peter Prokosch)*

monitoring, to help determine the extent of contamination? How can we prevent mobilisation of contaminants and facilitate remediation of sites contaminated by fuel spills or other hazardous substances at a large scale and low cost?

B. Cumulative and cascading impacts

The importance of combined or accumulated impacts of multiple stressors is a key consideration in establishing likely future scenarios. Approaches to management of potential and actual human impacts have shifted decisively from a focus on individual stressors or species towards ecosystem-based approaches. Along with this shift, a variety of conceptual, methodological and practical challenges have emerged for analysis of cumulative and cascading impacts. This shift to system approaches has increased the importance of clarifying and examining the wide range of operating assumptions used. Further systematizing of methods is important for considering not only stressors, but also their human-induced causes and the effects of subsequent environmental change on both Arctic and other communities. **Research questions: How can we improve understanding of the consequences of sequences of human-induced change on polar ecosystem services? What kinds of new methods are needed to effectively integrate both quantitative and qualitative data, fill critical data gaps, and analyse the likely effects of crossing thresholds that are likely to be irreversible in the near term? What tools and processes have proven effective in helping communities cope with these consequences and manage a resilient societal development in the region?**

In the context of complex systems, it is especially important to strengthen understanding of conditions in which impacts can themselves become stressors driving further change - either through reinforcing feedback effects, or through cascading impacts. For example, while anthropogenic climate change is the dominant driver of change in the Polar Regions, it is experienced most tangibly through cascades of impacts on changing snow and ice cover, on permafrost, on species migration, and on accessibility for human activities. The decline of snow and ice cover produces reinforcing climate feedbacks through reduction of albedo, yet it may also precipitate human responses that are less predictable, but potentially reinforcing. While an increasing systems orientation within the natural sciences makes examining feedbacks and cascading effects part of a natural progression, currently the role of societal responses to ecosystem changes in these broader causal cascades is seldom considered. **Research questions: How can we improve our understanding in sequences of impacts that spread, and that alternate between human activities and ecosystem change? How might crossing multiple thresholds interact to generate feedbacks that drive additional change that may be disruptive or dangerous?**

Subtopic 2: Choices about resource use, conservation and related impacts

This sub-topic addresses the need for more precise indicators and informational feedbacks to guide decision-making and management processes, as well as an improved capacity and interest of the people, organizations, and institutions involved to incorporate and make use of relevant new knowledge.

As environmental change in the Polar Regions makes these areas more accessible, opportunities to exploit their resources and space are increasing. In the Antarctic, science, tourism and, to a lesser extent, fisheries are expanding. In the Arctic, receding ice

and snow are opening new potential shipping routes, easing access for extraction of minerals and other resources and setting the stage for other kinds of commercial development. Species migration and changing ice conditions are opening for new or expanded fisheries. As a result, the tensions between competing imperatives are intensifying. Where and to what extent resource, transport, and other opportunities should be pursued - and where and to what extent should the resources, the intrinsic values, and the spaces be protected and conserved? Embedded in these questions is the way in which informational feedbacks are managed and utilized to guide decisions about conservation and resource use. Here the challenge is partly a lack of information. However, even more lacking is the availability of composite metrics characterizing human-ecosystems interactions that can be integrated into policy and management practices. Currently available indicators offer an inadequate representation of the complex interactions between people and polar ecosystems.

For example, educational levels or household income provide important information, yet they tell us little about people's interactions with nature or the ways that knowledge of ecosystems or traditional livelihoods interact with conventional systems to help provide for material and spiritual well-being. Therefore, there is an urgent need for research related to specific types of human activity that are rapidly expanding in one or both Polar Regions, and to management approaches and the kinds of indicators used to assess status and provide decision support.

A. Management/Governance of expanding human activities

Most human activities already generate impacts, and there is little doubt that further expansion on current trajectories could have consequences both for the Polar Regions and beyond. **With each of these trending activities, three of the central questions are: How can the activity be managed within ecosystem constraints? Can indicators be developed that more precisely describe interactions and feedbacks between human activity and ecosystems changes? How can further development be pursued in ways in which significant benefits accrue to local communities (Arctic)?**

Increasing Tourism: Across all the Arctic nations, tourism activity is estimated at over 10 million visitors per year and the numbers have increased in the past decade. Antarctic tourism is largely focused in the Antarctica Peninsula and nearby islands. Here, cruise tourism has increased 8-fold in the past 25 years with almost 350,000 passenger landings. Most of these landings are at a small number of visitor sites, and tourism continues to expand and diversify in more land-based activities. **Research questions: How can increasing tourism in the Polar Regions be effectively regulated to ensure its sustainability? What social and environmental risks do cruise ships and infrastructure development pose to these areas? What is the scope for consistent and dedicated monitoring of tourism impacts, particularly at highly visited sites? What are the social impacts of cruise ships on local communities and research facilities, including cultural changes and effects of increased local monetary wealth? How can ecotourism activities be anchored in and organized by local indigenous communities in ways that support and foster traditional livelihoods?**

Expanding transport links: Expanding opportunities for transport in the Polar Regions take many forms: establishment of rock, blue ice or snow airstrips to deliver better air-links, construction of road networks, and of wharf facilities in new areas that have been opened up to vessels due to sea-ice decline. Such developments make access to once remote locations easier, but

Cruise Ship Greenland *(Photo: Peter Prokosch)*

Antarctic Dumont-d'Urville-Station *(Photo: IPEV)*

may have both social and environmental impacts. Impacts upon indigenous communities may result from changing economic conditions and the influx of new people, traditions and ways of life. **Research questions: How can transport and other marine activities be developed that avoid disturbing current and future networks of marine protected areas? How can regular traffic be managed to benefit and not disrupt the livelihoods of local Arctic communities? How can fuels used in shipping best be transitioned to cleaner, more environmentally friendly alternatives?**

Environmental impacts of improved transport links include the introduction of alien species, which is a major driver of biodiversity loss globally, with the Polar Regions predicted to be especially vulnerable, particularly in light of regional climate change. **Equally applicable to both marine and terrestrial polar environments, research questions may include: which pathways for alien species introductions present the greatest risks and which locations are most vulnerable to invasion? What biosecurity techniques are most suitable to reduce introduction risk and what methods can be used or developed to respond to existing invasions? How can the risks of inadvertently transporting indigenous species between the different polar bioregions be reduced?**

Land use: There is an urgent need for improving predictions of how the human footprint in the Polar Regions is likely to change, so that both social and ecological factors are given adequate consideration and management. For example, only 0.18% of the Antarctic continent is exposed rock. In parts of the Antarctic Peninsula, relatively flat, ice-free, coastal land suitable for station construction is a real non-renewable resource that is running out. In some areas, all sizeable ice-free promontories are either sites of research stations, visitor sites, or protected areas. This highlights the conflict between human activities and conservation of ground for penguin colonies, seal haul-out sites and vegetation - a conflict that will only become more severe as human presence increases. Evidence of past human presence is also important. Historical sealing sites provide vital material evidence of 19th century use of the areas yet are difficult for the untrained eye to comprehend and appreciate. In the Arctic, land use planning and land claims negotiations are often related to contemporary impacts from past transgressions and are part of reconciliation and tackling the socio-economic and cultural consequences of those actions. Constructive outcomes from negotiations facilitate cultural revival that can positively influence social well-being and health. Land use planning and extraction of renewable and non-renewable resources also raises questions of land use, infrastructure development and rights. Increased

coastal erosion is affecting both settlements and archaeological sites, especially in non-consolidated permafrost terrain. Co-design and stakeholder engagement processes – including meaningful consultation with affected indigenous communities – can mitigate negative consequences from such activities and help ensure local benefits. Knowledge of land use and conservation and sustainable modes of extraction needs also to consider power relations between the involved stakeholders. **Research questions: How can available knowledge be used to facilitate adaptive planning of future human activities to take into account conservation of existing wildlife and biodiversity and cultural heritage? How can co-design and consultative processes help ensure meaningful engagement, local benefits and proper attention to ecosystems impacts?**

Harvesting of renewable resources: Many renewable resources in the Polar Regions are subject to exploitation and this will change as global requirements for resources continue to increase. Fishing, use of space for renewable energy production (wind farms, etc.), biological prospecting, and even use of freshwater resources are all poorly understood potential impacts on polar ecosystems. Sustainable fishing, although closely regulated in the Southern Ocean by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), may be vulnerable to increasing variability in species populations, linked to climate change impacts. **Research question: how can our understanding of fish stock sustainability and resilience be improved by integrating data on oceanographic, climate, ecosystem and harvesting interactions?**

Extraction of non-renewable resources: The paradox of sustainability of a non-renewable resources requires particular attention. Extraction of non-renewable resources poses special challenges and initial assessment and ongoing monitoring of environmental, social and economic impacts from extraction of non-renewables is crucial. Systematic measures for the prevention of negative environmental and societal impacts must be developed, with integrated long-term monitoring systems as well as mechanisms for proper compensation when negative impacts do occur. Impact and Benefit Agreements for local populations are increasingly common in the Arctic, although the extent of use varies among countries. Social Impact Assessments (SIA) and Environmental Impact Assessments are valuable tools, yet also require further research in order to improve their integrated application as well as development of international benchmarks and standards. **Research questions: in what ways can research and policy effectively tackle the whole extraction cycle from exploration to the final stage of closure of operations and related remediation and reclamation activities? How can mining and even hydrocarbon extraction be pursued to ensure they are informed and guided by Agenda 2030 goals? What specific approaches to co-design for land-use planning, industrial development and assessment of social and socio-economic benefits have proven fruitful, and how might good practices be improved, expanded and scaled up? Where problems do occur, especially offshore, how can search and rescue operations be prepared for and organized more effectively?**

Research vessel in the Arctic Ocean *(Photo: Alfred Wegener Institute / Mario Hoppmann)*

B. Linking knowledge and decision making

A core theme of this White Paper is further developing and expanding the application of methods for linking knowledge and decision-making in ways that more closely reflect interactions between people and nature. This includes use of tools that already exist but are not yet sufficiently embedded in practice. Here we emphasize three key areas where research can play an important role in carrying this forward.

1. Indicators and effective management/governance processes

Sustainable Development Goals (SDGs) – Important work is already underway to identify Arctic-specific aspects of the SDGs, and it is important that further development with targets continues, as is being done elsewhere (with no native populations, the social-focused SDGs are likely to be less broadly applicable in the Antarctic). In addition, new research recently published by Weitz et al.[3] (2017) takes a system approach to examining the relationships between the SDGs and each of the target points to the importance of understanding how actions in pursuit of one goal can be expected to influence performance on others. The interaction matrix is currently being tested by the Swedish steel industry to increase the understanding of where actions taken to realize the SDGs can be most effective. The Finnish Arctic Council Chairmanship (2017-2019) is prioritizing developing ways to adapt the SDGs to the Arctic context. **Research question: How can further analysis and evaluation of these types of tools and processes be developed to support effective and strategic implementation of measures aimed at achieving Agenda 2030 in a Polar context?**

Indicators of social-ecological resilience – Indicators of social-ecological resilience encompass nature-human relationships, and inherently, the capacity of a community to effectively navigate an uncertain future. Approaches for developing Arctic-specific indicators have been proposed, yet these efforts to develop robust indicators of social-ecological resilience remain

[3]Weitz, N., Carlsen, H., Nilsson, M. and Skånberg, K. (2017). Towards systemic and contextual priority setting for implementing the 2030 Agenda. Sustainability Science. https://dx.doi.org/10.1007/s11625-017-0470-0

Drilling and core sampling on the Arctic Coring Expedition on Lomonosov Ridge in the Arctic Ocean in summer 2004. *(Photo: IODP, H. Paelike)*

in their early stages. Meaningful efforts would examine the relationship between market and semi-subsistence economies, how indigenous and conventional knowledge interact and may complement one another, and between systems of legal rights and community capacity to organize and cooperate effectively (social capital). **Research questions: How can resilience indicators be developed through community-based participatory processes, while also being scalable to a pan-Arctic level? What types of indicators of social-ecological resilience might be applicable to the Antarctic?**

Capital Accounts – These accounts are a method of measuring and valuating resource stocks and flows where human activity draws on ecosystem services. While some of these accounts are available in the Nordic countries and could be available for Arctic-specific analysis, preliminary research suggests significant variation between countries. Significant differences remain in the degree to which such accounts are available, and in the extent to which they are used or able to be used in management and decision-making related to regulatory efforts such as the EU Water Framework Directive. **Research question: What are the practical and institutional obstacles to using such accounts for policy development and ecosystem-based management? What are the conditions under which regulators would be able to actively incorporate and apply such knowledge? How can the data and accounts be further developed and made more complete and more usable?**

2. Ecosystem-Based Management (EBM)

Ecosystem-based management has been embraced by the EU in areas such as the Water Framework Directive and others, while international Conventions such as the Ramsar Convention on Wetlands have shifted from their original bird species protection focus towards an ecosystem approach. Both of these agreements are highly applicable in the Arctic; however, there are numerous challenges to retooling former management practices to accommodate what amounts to a more complex approach to managing complex systems. One could argue that the conceptual or paradigm shift has taken place in these areas of management, but the systemic changes needed to fully implement that shift require much more work. **Research questions: What are the institutional, political and practical obstacles to adopting and implementing EBM on a larger scale? What lessons do successful implementation of EBM approaches offer for further development and implementation of the model?**

3. Participatory approaches to planning and management

Participation in decision and management processes by stakeholders and rights-holders is an important norm and expectation both within the EU context, and also in the work of the Arctic Council. It is also one of the conclusions of the Arctic Resilience Report (2016) that capacity for adaptation to climate and other environmental changes is greatest where communities have a strong ability to organize themselves to manage challenges and pursue shared goals. Effective participation in planning and management can be considered self-reinforcing, since it can both exercise and increase the ability to effectively contribute. One important type of process that is currently receiving well-deserved attention is participatory scenario development and analysis, where participants develop and work through contingencies in possible future scenarios. Prediction is often problematic where human choice and impacts are concerned. This means that exploration of multiple potential futures through scenario analysis is likely to be more valuable in practical terms. **Research questions: Which methods that employ co-design approaches in research, planning and management have proven fruitful? Further research that both uses participatory methods and tests possible variations could make an important contribution to developing and maintaining the capacity for effective management in rapidly changing Polar Regions.**

Subtopic 3: Strengthening integration

This sub-topic concerns the development of research to establish a stronger understanding of the dynamics of knowledge integration, with a focus on strengthening methods for effectively bridging between scientific disciplines, including between natural and social sciences and humanities, and for integrating

Indigenous Knowledge. Responding effectively to the pace and breadth of change also requires strengthening the links and interactions between science, policy and practice.

The Arctic Council has issued a number of statements in Ministerial Declarations and other directives emphasizing the importance of knowledge integration. One focus is to more effectively incorporate Indigenous Knowledge into the efforts of the Council's scientific Working Groups (WGs). The other regards strengthening of the WGs coordination and collaboration across their respective disciplinary and topical boundaries. Research funding calls at both national and European levels increasingly include an expectation of interdisciplinary collaboration and inclusion of relevant stakeholders as active partners. While such efforts speak to the importance of knowledge integration, they say less about how this can be effectively pursued and achieved. This points to knowledge integration itself as an important area for additional research, and for developing, testing and scaling up effective practice through scientific projects that incorporate, develop and test integrative methods. Where "interdisciplinary" points to real collaboration across disciplinary boundaries, "transdisciplinary" is indicative of such collaboration producing breakthroughs in knowledge, methods or fields of study.

"Silos" are not unique to scientific inquiry; policy institutions and communities of practice also construct specialized organizational structures in the form of ministries and specific types of NGOs. The focused knowledge development that defines disciplinary silos has been invaluable, as has the specialized knowledge held by Indigenous Peoples, by policymakers and by practitioners. This importance is captured in an alternative description of disciplinary silos as "cylinders of excellence", in recognition of the knowledge and expertise that has been developed. Nevertheless, many of the key insights needed to inform wise policy and management decisions and more effectively manage human activities ourselves in the context of global sustainability challenges lie in the spaces between these well-developed areas of specialization. Filling these key knowledge gaps can only be managed through effective transdisciplinary teamwork - in itself an area of knowledge.

A. "Team Science" for the Polar Regions

As understanding of the importance of integrating different types of knowledge has grown, research on the factors that influence effective scientific collaboration itself has also increased and is sometimes described as "the science of team science." For example, researching breakthrough discoveries in the biomedical sciences, sociologist Rogers Hollingsworth identifies characteristics at both individual and institutional/organizational levels that contribute to integrative and path-breaking work. At the individual level, scientists whose experience and training bridge multiple disciplines contribute to both greater capacity to communicate across disciplinary boundaries and also in the kind of curiosity and interest that motivates such efforts. On the institutional/organizational level, conditions that entail longer-term, intense contact and interaction have proven extremely important. Hollingsworth's observations suggest two crucial elements that need to be developed. First, both the knowledge "silos" and the bridging of those silos are important in scientific discovery. Second, both individual characteristics and institutional/organizational conditions matter a great deal. For a variety of reasons much of the study of scientific collaboration has focused on either biomedical science or on teams that have produced other breakthrough discoveries. Yet, there are circumstances unique to the study of the Polar Regions, and to integrating biophysical sciences with the social sciences and humanities that may merit focused attention. **Research questions: How can the relevant insights of both "sustainability science" and the study of team science be operationalized in polar research? Communication and personal relationships that bridge disciplinary training have been found to be extremely important, but are there particular requirements for effectively bridging the wider differences between natural and social sciences? Do circumstances unique to Arctic or Antarctic social-ecological systems research create a need for particular kinds of skills, organizational structure or leadership? What are the time and effort requirements that come with learning to effectively communicate between biophysical and social sciences and humanities? How do these requirements differ for integrating scientific and indigenous knowledge, and what are the strengths and shortcomings of currently established inter/trans-disciplinary research methods?**

B. Bridging science to policy, policy to practice

It is also well-established, dating back to the German sociologist and economist Max Weber that the differing logics and values that guide science and policymaking represent important challenges, yet these differences are essential. The wide gaps between what is known and understood about resource conservation and use related to the Polar Regions, and how that knowledge is reflected in policy, suggest there may be circumstances specific to these regions that need to be accounted for. **Research questions: What methods have proven effective in communicating between science and policy, and how do these apply to circumstances unique to the Polar Regions? Since comparatively few countries have territory in the Arctic and the Antarctic is treaty governed, what communications and other tools that are polar-specific can be used to inform relevant policy in such countries? How can both localized livelihoods and the ecosystem functions of the Polar Regions be emphasized and balanced in a policy context with the sometimes more obvious opportunities presented by potential new transport routes, new tourism destinations, mineral and food resources?**

C. Achieving trans-disciplinarity with a social-ecological systems perspective

It has been noted previously that the research policy initiative urged by this White Paper seeks knowledge about how to more effectively and wisely manage human activities and resource use within the limits of the ecosystems upon which people depend - in a context that is rapidly changing due largely to anthropogenic forces. This, in turn, entails study of the causality of complex social-ecological systems, with cascades and cumulative effects, and with a particular focus on human activities

that especially impact the Polar Regions. Such research on complex systems interactions and feedbacks, with human activities playing a central role, requires effective integration of knowledge about the system in question, and also about the people and institutions conducting the research. It is neither necessary nor possible for research projects to tackle all of these kinds of bridging challenges simultaneously, yet it is essential that such bridging is part of an overall mix.

Historically, science has tackled the problem of complexity by isolating and studying the phenomena of interest to understand its properties. In contrast, this White Paper urges a systems approach that examines the phenomena of interest – management of human impacts, conservation and use of polar resources – in the system of which it is a part. Such an effort entails major challenges, especially with the inclusion of humans in the system definition. "Fractals" provide a useful metaphor to characterize the approach proposed in these pages. With fractals, smaller scale expressions of a phenomenon contain all the elements of the larger scale version of the phenomenon. Similarly, by focusing on the specific kinds of resource-related human activities that are identified in Sub-topic 2, human impacts and social responses in polar ecosystems remain in focus. Existing insights and new research questions regarding effective collaboration, trans-disciplinarity and other forms of knowledge bridging, also remain a key element of research and research practice. It is important to acknowledge that the kind of integrative efforts emphasized here are already being pursued in some specific projects and particular settings. These efforts can help point the way, and point to a final **research question: What new knowledge is needed to scale up these approaches, and to address the key gaps identified in research design to accelerate the development of effective responses to the changes seen in the Polar Regions?**

Relevant Cooperation Partners

It is important to include all stakeholders and rights-holders in the Arctic and Antarctic as participants in this research agenda. Effective engagement fundamentally requires knowledge of the diverse perspectives, motivations, values and insights to optimally balance choices regarding conservation and resource use - and managing the pursuit of resources within the constraints of polar ecosystems. An adequate and proper balance will be a moving target, requiring ongoing monitoring, recalibration and revision of earlier decisions. Monitoring and risk assessments therefore depend on input from a diversity of stakeholders, and research efforts should be truly collaborative and aiming at the co-production of knowledge and a sharing of responsibility.

Arctic stakeholders	Antarctic stakeholders
National, regional and local governments of Arctic territories and their collaborative fora. For example: • Arctic Council and its working groups: AMAP, CAFF, PAME, SDWG	Governments of claimant states and signatories to the Antarctic Treaty and its components. For example: • Antarctic Treaty Consultative Meeting (ATCM) • Commission for the Conservation of Antarctic Marine Living Resource (CCAMLR) • Committee for Environmental Protection (CEP)
International Arctic Science Committee (IASC)	The Scientific Committee on Antarctic Research (SCAR)
Arctic local and indigenous communities	National Antarctic Programmes and the Council of Managers of National Antarctic Programmes (COMNAP)
NGOs • National and international • Locally-organised campaign and pressure groups	NGOs • National and international
European and global public interest • News media • local cultural groups • Heritage / Museums	European and global public • News media • Cultural groups • Heritage / Museums
Business and Industry sectors: • Fisheries, shipping and logistics • tourism • renewable resources • non-renewable resources (oil and gas, and mining) • development of new technology • insurance solutions • biological materials (bioprospecting)	Business and Industry sectors, including: • Tourism • Fisheries • Infrastructure services

Enabling Capacities and Resources

One important goal with this White Paper is to identify potential actions that can contribute to strengthening collaboration across traditional scientific disciplines and established advisory groups to encompass a social-ecological systems perspective. A number of new and ongoing projects of the Working Groups (WGs) of the Arctic Council (AC) either have strong potential or are already exploring such collaboration. Yet, realizing this more extensive collaboration would require increased capacity for the Working Groups.

Especially with issues of resource development and conservation in the Polar Regions, communication and research coordination are an essential function. This includes communication to effectively manage connections between diverse types of researchers, between Working Groups where projects are collaborative, also including representatives of the Arctic's Indigenous Peoples through the Permanent Participants. Given that many critical decisions will be made outside the Polar Regions, communications between researchers and decision makers at local, national and international levels are essential.

In the Antarctic, the Treaty Parties are becoming increasing aware of the need to develop more integrated reporting systems on environmental and human variables across the different regions of the continent and the Southern Ocean, to facilitate more effective governance of the Treaty area. For example, the Committee for Environmental Protection is developing mechanisms to identify and devise specific actions to prepare for, and build resilience to, the environmental impacts of climate change. However, opportunities for improved communication between different scientific disciplines, and between scientists and policy-makers within the Antarctic Treaty System, have been identified. EU Members comprise over 40% of the Consultative Parties that participate in decision-making at the annual Antarctic Treaty Consultative Meeting. The EU is exceptionally well-placed to drive forward research and communication, with over 20 Antarctic research stations and permanent field camps operated by EU nations, so that improved management outcomes can be delivered.

Funding and international cooperation

International collaboration is essential for this work, not merely because the Arctic extends beyond Europe and human engagement in the Antarctic involves numerous countries and stakeholders from around the world, but also because this work builds on existing research on Arctic and Antarctic issues. To make the most of existing expertise and capacity around the world, we need to reach out to the international community and we need to connect with all stakeholders and rights-holders. These will include: Arctic and Antarctic collaborators, IASC member states and SCAR participants, National Antarctic Programmes and Antarctic Treaty Consultative Parties, tertiary and research institutions and their networks, Indigenous Peoples, and European Institutions. For such cooperation to be adequately realized, funding will need to made available support the kind of time and effort required to build shared understandings, common language, and personal relationships that make it possible to effectively bring to bear the kind of diverse expertise needed to tackle the social-ecological challenges being experienced in the Polar Regions.

Way Forward and Key Action Areas

1. Engage iteratively with policy-makers to develop a focus on the existing and likely future threats to polar ecosystems and communities.
2. Identify available data sources for environmental and social variables required to assess systemic impacts upon Arctic and Antarctic environments.
3. Identify gaps in knowledge and initiate or enhance monitoring activities to strengthen future predictions of environmental impacts and trends in Polar Regions.
4. At policy-relevant spatial scales, integrate available environmental and societal knowledge to model future scenarios.
5. Use topical areas involving resource conservation and use (land use, tourism, transport, fishing, resource extraction) as focal areas for research on strengthening knowledge integration that can be incorporated into strengthened regulatory and management practices.

An Increasing Level of Urgency

Significant change has always been the reality of the Polar Regions. Yet a new urgency is brought by the unprecedented pace and breadth of that change, the potential disruptive impacts on both ecosystems and human populations, and the need to manage resource use and nature conservation in the Polar Regions with a wisdom and effectiveness never before as necessary. This translates to an urgent need for integrated knowledge on social-ecological systems that also incorporates aspects of resilience:

1. The breadth and pace of social and environmental change

With variation based on which Polar Region one is examining, changes in the Polar Regions include climate change, ocean acidification, ozone depletion, changing weather patterns, altered sea-ice extent, biological population range shifts, changing connectivity of biological populations (fragmentation and homogenisation), loss of livelihoods, and collapse of communities. There are of course important differences that depend on which Polar Region is being considered. Both are more sensitive to many global stressors than other regions, with impacts that are felt more acutely than anywhere else.

2. The unevenness of change and critical thresholds

While existing research attests to rapid change in the Polar Regions, it also points to some processes being non-linear, as some system feedbacks further accelerate the pace of change. This is

most obvious with the loss of snow and ice, the disappearance of which leaves darker sea or land surfaces that absorb far more heat, which in turn accelerates warming. There are, however, many other geophysical, biological and social systems processes prevalent in the Polar Regions that display amplifying feedbacks and self-reinforcing characteristics. This means that changes in social or ecological systems can frequently be cumulative, cascading and interactive. The presence of critical thresholds or "tipping points" means that beyond a certain point, systems are unlikely to recover to their previous state within decades or even centuries. The danger with such tipping points is that they are often difficult to identify except in retrospect, and some features, once lost, are forever lost and cannot be recovered. In 2016, the Arctic Council's Arctic Resilience Report identified 19 such potential systemic thresholds or tipping points that have been reported in the scientific literature. Many of these thresholds apply equally well to Antarctica, with, for example, predictions of dramatic melting of what was considered 'permanent' ice on the Antarctic Peninsula by the end of the century leading to changes in biodiversity and increased risk of invasive species.

3. Social and ecological systems are highly interconnected, both within the Polar Regions, between the poles and other regions, and across scales from local to global.

We have already noted how the increase in human activities in the Polar Regions generates local impacts. In the Arctic, these come from increased economic activities, including tourism, transport and efforts to secure both finite and renewable natural resources, much of which is driven by interests outside of the region. In the Antarctic, these impacts are generated from an increased human presence through expanding tourism and establishment of research stations and provision of infrastructure. Yet, many of the most powerful drivers are generated by human activities taking place far from the Polar Regions. One critical effect is that the causal links between many human activities and their harmful societal and ecological consequences are blurred both by time, and by geographical distance. Coastal erosion caused by intensified storms and a lack of dampening landfast sea ice, infrastructure collapse due to permafrost thaw, ecosystem effects of accumulating chemicals and plastics, are difficult to connect directly to the activities that produce these changes. This distance between cause and effect adds to the challenges of understanding causal relationships and sequences; it also complicates the process of curbing, managing or modifying the human activities that are ultimately the source.

4. Effective management under changing conditions

The pace and scope of change is generating increasing scrutiny of the Polar Regions not only from researchers, but also from both new and established stakeholders interested in pursuing opportunities for securing and/or utilizing polar resources. The Polar Regions are opening up with increasing speed. In the Arctic, this is contributing to more localized developments such as demographic change and relocation and migration, contributing further to conditions of rapid change. The Antarctic is also seeing intensified pressure on the 0.18% of the continent that is ice-free ground. The tourism industry has increased dramatically in the past two decades, with current numbers close to

Tourists visiting Antarctic Glaciers *(Photo: P. Prokosch)*

50,000 individual tourists landing each year, at numerous locations mostly situated on the Antarctic Peninsula. The region is also seeing an increasing number of research stations being constructed, predominantly on scarce coastal, ice-free ground. As a consequence, existing management and planning mechanisms may not be keeping up effectively. It is essential that modes of management and planning for the use of polar resources are strengthened, with better integration of newly emerging knowledge and more effective use of that knowledge for setting priorities and managing dynamically and adaptively. Because of the differences between the Arctic and Antarctic in activities and international agreements, questions of effective planning and management will necessarily differ. In the Arctic, the need is to understand how to successfully balance conservation and exploitation, and to ensure social and economic development for the people of the region. In the Antarctic, guided by the Antarctic Treaty System, further knowledge on which to base decision-making is crucial.

5. Urgent need, yet important opportunity

The need for knowledge integration to inform the balancing of conservation and use, planning and management, has arguably never been more urgent. However, as the challenges are now broadly understood, we may be better prepared to act now than at any time previously. Communication between research communities, policymakers, practitioners and local communities is often difficult. However, awareness of the need for bridging knowledge systems, and for bridging science, policy and practice, has explicitly been on the agenda for at least a decade. Expectations of inter-disciplinarity in research projects have increased to go well beyond simply including both social and natural scientists and humanities in research projects, or requesting consultation with stakeholders and rights-holders. A growing body of research has identified the characteristics and conditions that provide opportunities for breakthrough thinking and integrative thinking through "team science" and other forms of collaboration. Similarly, calls for integrating conventional science with different knowledge systems (for example, Indigenous Knowledge and local knowledge) are being taken seriously. Equally important are calls for not merely handing over the finished products of scientific research to policymakers and stakeholders, but also including local peoples' interests and insights when designing and conducting research (co-design).

Definition of terms

Resources. We use the word 'resources' in a broad manner to cover both harvestable and non-harvestable, renewable and non-renewable resources. In addition to direct economic/societal benefits, the less tangible benefits of undisturbed nature and cultural heritage in both a localized and broad sense are also important. Ecosystem resources include food (fish/shellfish, plants, livestock, terrestrial and marine wildlife), freshwater, raw material (minerals, wood) and energy (fossil and renewable energy resources), although in the Antarctic, only fish and krill are allowed to be taken. Cultural resources include aesthetic and intangible values (wilderness or spiritual), cultural heritage and landscapes. Clearly, many polar resources are finite and non-renewable. Without suitable and adaptive management and planning, resources may be lost, or used in a sub-optimal manner, depriving future generations of opportunities. Furthermore, polar resources may yet be undiscovered or not considered as resources according to present thinking.

Use: Resource 'use' includes not only resource utilisation (e.g. mineral resource extraction, use of space to develop transportation infrastructure), but also resource conservation/preservation (e.g. protection of habitats, landscapes and heritage, and stewardship of resources for use by future generations).

Stressors and change drivers: Many of the dominant stressors impacting the Arctic and Antarctic originate from outside the Polar Regions (long-range transported pollutants, climate change, ocean acidification, demand for energy and raw materials, demographic change). Yet, a growing human presence in both regions is also producing stresses. Interactions between stressors - with some stressors causing or exacerbating others - are often poorly understood, but potentially powerful. Increasing pressure is largely due to activities undertaken on an industrial scale.

Human activities: Housing/urban development, transport activities (roads, rivers, ocean routes, airfields), mining/drilling (extraction), energy generation (wind/solar farm, power stations), fishing, hunting, harvesting (crops and livestock), research (including bioprospecting), tourism, and indigenous dwelling, spiritual and subsistence activities.

Impacts: Impacts on ecosystems: pollution, species invasion, habitat loss, extinction, wildlife disturbance, water availability, energy input, etc. Impacts on people: heritage loss, wealth generation, changing societal values, etc.

Ecosystem services: Ecosystem services are the direct and indirect contributions ecosystems make to human well-being. These "services" support human survival and quality of life either directly or indirectly.

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