Why Arctic Community Research Readiness and Priorities Matter

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Introduction

The Arctic Observing Summit 2018 focuses on the business case for a comprehensive pan-Arctic observing system that in part demonstrates the benefits for society at various levels, especially for those who call the Arctic their home(land). In this paper we bring our experiences in working with indigenous communities and community knowledge networks to highlight what we have identified are essential steps in ensuring that societal benefits of research and monitoring are accessed and embraced by Arctic communities, while developing a strong business case that promotes sustainability.

We emphasize that our experience primarily lies in direct collaborations with indigenous communities in Inuit Nunangat (Canada) and through network linkages to communities elsewhere in the circumpolar Inuit homeland. Our experience of engagement with community-based researchers has revealed a strong desire "to turn research inside out" by placing more focus and effort on research priorities that are important to communities and working with experts on addressing them (Bell 2016; Forbes et al. 2017). Such an approach, we argue below, would empower communities with tools and resources to determine their own research agendas and be capable (ready) to pursue research and monitoring collaborations for their own benefit. SmartICE, as a sea-ice monitoring and information service for communities by communities, is presented as an example of how a social enterprise business model may be both community directed and economically sustainable for pan-Arctic community-based observing systems.

We explicitly acknowledge Inuit aspirations for advancing self-determination and governance in research in Inuit Nunangat, as outlined in the recent Inuit Tapiriit Kanatami *National Inuit Strategy on Research* (ITK 2018). This strategy clearly articulates how research, done the right way, can produce knowledge that meets the needs and priorities of Inuit communities, while creating social and economic equity for Inuit in

Canada. This right way is spelled out in actions across five priority areas: 1) Advance Inuit governance in research; 2) Enhance the ethical conduct of research; 3) Align funding with Inuit research priorities; 4) Ensure Inuit access, ownership, and control over data and information; and 5) Build capacity in Inuit Nunangat research.

Addressing Community-Defined Knowledge Gaps

It is widely acknowledged that co-designed and co-produced knowledge in the hands of decision-makers at appropriate levels is the key to successful adaptation and resilient communities. There is an urgent need for locally applicable, decision-relevant, social-environmental knowledge from multiple sources in coastal communities, regional or territorial governments in the Canadian Arctic, and other circumpolar jurisdictions. Traditional research practices are inadequate to address complex sustainability challenges, or to identify and target community-defined knowledge gaps and research priorities. There is a growing recognition of the need for a transdisciplinary approach, led by or fully engaged with a broad range of rights- and knowledge-holder groups in an iterative mutual-learning process, to identify and follow pathways to better futures (Forbes et al. 2016; Future Earth Coasts 2018).

Despite a growing number of promising initiatives, capacity for research and knowledge mobilization in most northern communities remains limited There are substantial opportunities to expand capacity by knowledge sharing between northern communities, with the support of networks such as CACCON (Circum-Arctic Coastal Communities KnOwledge Network – “Catch-On”).

CACCON

As the Arctic regional engagement network of Future Earth Coasts, CACCON is collaborating with community knowledge hubs and promoting research empowerment and readiness as a key requirement to strengthen the resilience of coastal residents in a rapidly changing Arctic.

Through informal discussions with community members, other knowledge holders, research coordinators, and others over the past year, a former CACCON Coordinator Michelle Slaney prepared a draft framework on co-designing resilient Arctic coastal communities through research partnerships. This focused on co-design and co-production, identifying enablers and good practices. The intention is to use this as the basis for a co-produced document that extracts insights from success stories (“bright spots”) and develops guidance for strategies to formulate and open up pathways to more sustainable futures. This CACCON experience has informed and been informed by interaction with the global Coastal Futures initiative.

Coastal Futures initiative of Future Earth Coasts

Future Earth Coasts (a core project of Future Earth) has developed *Our Coastal Futures* as a globally coordinated but regionally or locally specific approach to:

- Enable regional stakeholders and institutions to develop a common understanding of their coasts and future prospects;
- Co-design robust strategies to chart desired coastal futures; and
- Co-produce innovative coastal sustainability initiatives and pathways to achieve those desired outcomes (Future Earth Coasts 2018).

The approach has a particular focus on local capacity building as the foundation for actionable strategies to advance the Sustainable Development Goals (United Nations 2017).

Our Coastal Futures seeks to foster new partnerships and opportunities for knowledge exchange in order to build shared understanding of the coastal social-ecological systems in which people live and of their trajectories, challenges, and opportunities. The aim is to enable governance bodies and stakeholders "to chart a course away from unsustainable practices toward desired [more] sustainable coastal futures, … to build the capability of the people and institutions that guide how we use coastal resources and sustain our coasts" (Future Earth Coasts 2018).

The need for new empowerment and capacity amongst stakeholder and governance communities is no less acute in the Arctic. Unparalleled warming trends, rapid loss of sea ice, and other environmental changes are assailing communities already challenged by a mix of social, economic, educational, and health constraints and tenuous transportation links. It is believed that a pan-Arctic engagement network such as CACCON can help lead to benefits for the safety and future security of indigenous and northern residents.

Research readiness and peer-to-peer capacity sharing

There is a wide divergence of capacity and research readiness in northern communities. Some major centres, such as Nuuk, Iqaluit, Cambridge Bay, Inuvik, or Barrow have research facilities (e.g. Nunavut Research Institute in Iqaluit, Aurora Research Institute in Inuvik) and institutional support and infrastructure for northern community-oriented research (e.g. Joint Secretariat, Inuvialuit Regional Corporation in Inuvik). Others are hard-pressed to find an office or a computer to support community knowledge management activities.

The CACCON vision is to prepare northern communities to embrace knowledge and research as a vehicle for economic development, while addressing important local priorities of sustainability and well-being. For many northern communities, the legacy of past research is largely one of exploitation, mistrust and fatigue. Northern indigenous residents are no longer interested in the old ways of doing research, which in many cases took advantage of their people, their knowledge, and their land to build academic reputations or satisfy government surveys (ITK 2018). Community members, from leaders to youth, want "to turn research inside out" by focusing knowledge acquisition (co-designed and co-produced research) on community priorities, collaborating with external experts as required to address their needs (e.g. ITK 2018).

In recent years, there has been a rapid expansion of interest and activity in community-based monitoring (CBM) in the Arctic. Residents, northern communities, researchers, and policy-makers have increasingly come to appreciate the strengths of CBM in local resolution and detail, potential for continuity, integration of traditional knowledge, capacity-building and relevance to community decision-making. The challenges, however, are to determine what knowledge is required to support local decision-making, where and how it can be sourced (including local traditional and purpose-developed knowledge), and how it can be made readily available when and as needed. It may be possible to overcome these challenges by enabling the community to select and pursue priorities for research and monitoring based on knowledge needs and gaps and to manage the information locally for ease of access by the community.

CACCON has proposed initiatives to develop and pilot a strategy to help communities become more research-ready. More specifically the aim is to promote, enable, and foster research as a driver of economic activity and a foundation for community well-being and sustainability. These principles are beginning to be recognized in Inuit-led research protocols (e.g. IRC, n.d.; ITK 2018). In a few places, staff resources are available at the regional level (e.g. Inuvialuit Settlement Region, Nunatsiavut) and locally, supported by research grants or other resources such as ELOKA (Exchange for Local Observations and Knowledge of the Arctic), in a few communities with a long tradition of community organization (e.g. Ittaq Heritage and Research Centre, Ilisaqsivik Sociey, in Clyde River, Nunavut, http://ittaq.ca/en; Jaypoody et al. 2017). CACCON inspired development of a northern-led community Facebook group addressing ice and breakup hazards, managed by the Joint Secretariat in Inuvik. Harnessing newly available social media in the Inuvialuit Settlement Region, with more than 550 members, this is empowering residents to share in the documentation and real-time hazard awareness of the breakup process in the Mackenzie Delta region (Whalen et al. 2017).

Critical components of research readiness in small Arctic community settings include:

- Community research space (a place to meet and work, with office resources);
- Employment and training of a full-time community research coordinator;
- Development and execution of a community research engagement strategy;
- An inventory of research support resources in the community;
- A database of local research projects and accessible data to support community decision-making;
- Establishment of community research priorities; and
- Convening a community-wide research group to pursue research priorities.

Experience shows that the presence of other community initiatives, such as Ikaarvik and Ilisaqsivik, combined with local champions, has resulted in locally-driven enhancement of research readiness where these are present, but the challenge is to enable advancement in communities without such strengths and benefits.

Once a community has begun to develop research readiness, we anticipate that it will have the resources and capacity to pursue its own research agenda (through community-based monitoring or other approaches), while actively participating in Arctic science projects that are relevant to the region. Such opportunities would also ensure the integration of Inuit Knowledge and Values (*Inuit Qaujimajatuqangit*) in research design, implementation and interpretation.

Community-Based Knowledge Mobilization – the SmartICE example

SmartICE responds to a community priority for information on sea ice conditions for safe travel (Safer 2016; Kintisch 2017). It is co-designed with Inuit and involves Inuit in all its operations with the intention to integrate, not replace, Inuit Knowledge about sea-ice environments. Through generation and dissemination of near real-time ice information to communities, SmartICE directly supports public safety (by informing travel decisions about ice hazards), food security (by augmenting Inuit Knowledge of sea ice conditions for hunting and harvesting), and health and well-being (by informing safe access to land and ice, which supports community physical and mental health programs) at a time of unprecedented and unpredictable sea-ice changes.

SmartICE fills a knowledge gap identified by communities and enables them to manage its operations as best suits their needs and local ice conditions. In Nunavut communities, for example, a sea-ice user group created by SmartICE is made up of elders, youth, experienced and young hunters, local outfitters, and representatives from the Hunters and Trappers Organization, the Search and Rescue committee, the Canadian Rangers, Government of Nunavut Wildlife Division, and where applicable Parks Canada. The group directs SmartICE operators (local Inuit) when and where to survey and how the data should be disseminated to meet user needs. It has recommended the development of a SmartICE app to make available maps and data to tech-savvy younger generations who bring mobile devices with them on the ice, as well as the display of SmartICE information on a television screen in the local grocery store, where everyone comes to shop on a regular basis. The group also proposes new technology to develop and test and new/old data to be acquired/reclaimed – for example, Inuit knowledge of travel ice hazards – and made accessible to the community via the SmartICE data portal.

In response to increasing community demand for its services, SmartICE is expanding across the Arctic through the establishment of a northern social enterprise. Our choice of a social enterprise business model is consistent with Inuit societal values, such as caring for the environment (*Avatittinnik Kamatsiarniq*) and community (*Pijitsirniq*) and being innovative and resourceful (*Qanuqtuurniq*). It also commits to maximizing social impact and creating positive community change, while applying an entrepreneurial approach to the delivery of sea-ice information services. Currently, SmartICE is operational in eight communities from Nunatsiavut to Nunavut, with another dozen or so from across Arctic Canada exploring start-up opportunities.

A business approach to CBM recognizes the commercial value of local data, not only for community decision-making but also for business development and sustainability, especially in a changing Arctic. Although SmartICE primarily informs safe travel for communities, its data also enable and support economic activities for communities and industries alike. Mining, shipping, fisheries, emergency response, national defence, and environmental monitoring are all carried out to some degree on or through landfast ice. Therefore more specific information on sea-ice conditions, especially during freeze-up and break-up, reduces operational risk and improves performance for these commercial and government activities. Consequently, a key pillar of the SmartICE sustainability plan is to service clients in both commercial and public sectors, in order to support communities.

Community-based tourism, such as floe-edge and marine coastal tours, illustrates the opportunity for a sustainable sea-ice monitoring service for Arctic communities. Unpredictable ice break-up at the floe edge or ice break-through in areas that in the past were normally safe to travel on represent risks to the tourism industry, for which travel safety is paramount for market confidence and growth, and predictable ice conditions are essential for smooth operation and profitability. SmartICE is working closely with tourism operators to demonstrate that investment in SmartICE services makes sense for their industry in a changing Arctic climate, while at the same time keeping their communities safe.

Above and beyond the benefits of SmartICE for travel risk reduction, improved emergency management and climate change adaptation, we believe an important legacy of SmartICE will be to harness the vast potential of Inuit youth to engage in the knowledge economy through community-based ice monitoring, and inspire a new generation to embrace knowledge, technology, and research as a vehicle for economic development and well-being in their communities.

Recognizing Community Priorities in a Pan-Arctic Observing System

Although the primary beneficiaries of a research readiness agenda are communities themselves, we also recognize that pan-Arctic science initiatives and aspirations (e.g. a pan-Arctic observing system) will benefit from northern communities that are *research ready*. Inuit knowledge and perspectives, if not central to the subject matter, will certainly enrich the research process and perhaps expand the research scope. In many cases, community research priorities may share common themes with pan-Arctic observing systems (e.g. changing sea ice), but their rationale will be rooted in community well-being and sustainability. Accordingly, the community's research questions and sampling design will have a different emphasis, rooted in knowledge of the local environment and shaped by Inuit values and priorities.

Communities will benefit from knowing each others' knowledge gaps and needs, providing opportunities for shared expertise and training and networking of adaptation and sustainability solutions. As a northern network of community knowledge hubs, CACCON is well placed to facilitate this exchange of local experience and capacity. Territorial and national governments are also key stakeholders in a community *research readiness* strategy, because they may respond to shared priorities in a coordinated fashion, or design programs to better support common capacity needs.

Our vision is a *research readiness* strategy that empowers communities to develop the awareness, infrastructure, capacity and priorities for research, while actively pursuing collaborations that reflect Inuit values and share sustainability and well-being research goals. This will not only facilitate a meaningful pan-Arctic observing strategy, but also an Arctic-relevant pilot of the global coastal futures strategy of Future Earth Coasts. Guided by the global Sustainable Development Goals, the ultimate objective of this strategy is enhanced sustainability, health, safety, and well-being at regional, local, household, and individual scales. Enhanced research readiness is the platform on which broad collaboration to realize these goals can be founded.

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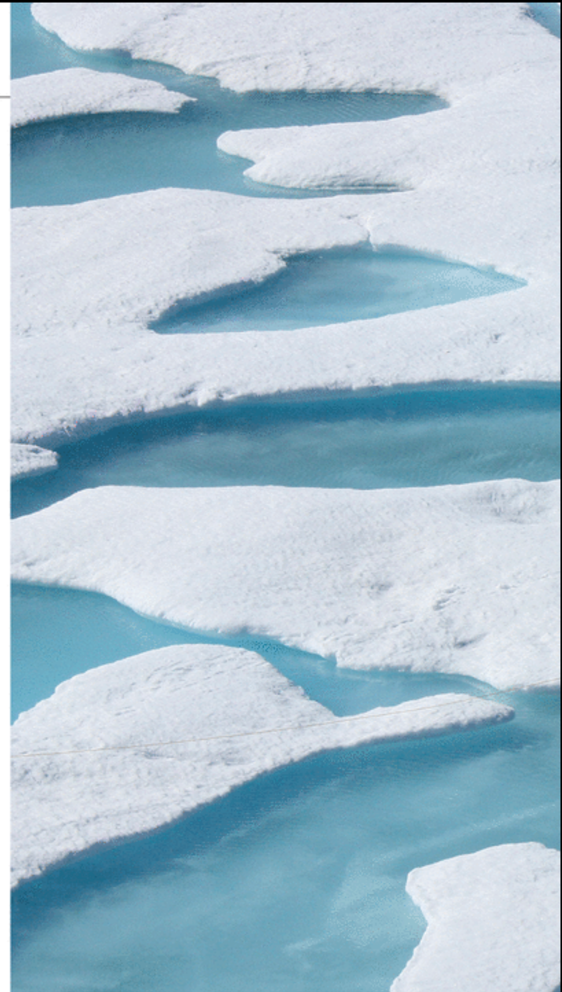

POLICY FORUM

SCIENCE DIPLOMACY

The Arctic Science Agreement propels science diplomacy

Amid geopolitical tension, science aligns common interests

By **Paul Arthur Berkman,[1] Lars Kullerud,[2] Allen Pope,[3] Alexander N. Vylegzhanin,[4] Oran R. Young[5]**

Global geopolitics are fueling the renewal of East-West tensions, with deteriorating U.S.-Russia relations in the wake of conflicts in Ukraine and Syria, issues involving cyber-security, and broader concerns about expanding militarization. Against this backdrop, the Agreement on Enhancing International Arctic Scientific Cooperation, signed on 11 May 2017 by foreign ministers of the eight Arctic States, including the U.S. and Russia, as well as Greenland and the Faroe Islands, is a milestone. This "Arctic Science Agreement" is a strong signal reaffirming the global relevance of science as a tool of diplomacy, reflecting a common interest to promote scientific cooperation even when diplomatic channels among nations are unstable (*1*–*3*). It provides a framework for enhancing the efforts of scientists working on cutting-edge issues, but translating the general language of the agreement into enhanced action requires further attention, collaboration, and effort among diplomats and scientists to ensure its successful implementation. With the International Arctic Science Committee (IASC) convening the International Science Initiative in the Russian Arctic (ISIRA) at the Russian Academy of Sciences in Moscow next week, we highlight steps to advance science, its contributions to informed decision-making, and its role in maintaining the Arctic as a zone of peace and cooperation.

STRENGTHENING ARCTIC SCIENCE

Negotiated under the auspices of the Arctic Council through a process co-led by Russia and the United States, the agreement recognizes first "the importance of maintaining peace, stability, and constructive cooperation in the Arctic." This legally binding agreement aims to enhance scientific cooperation by "removing obstacles" (*4*) and by providing a basic road map and commitment to facilitate consistent access for marine, terrestrial, and atmospheric research on a pan-Arctic scale.

The agreement aims to improve use of existing infrastructures that were previously unavailable; enable new movement of researchers, students, equipment, and materials; promote sharing of data and metadata in ways that were not previously possible; and encourage holders of traditional and local knowledge to participate in scientific activities across territories (see the map). The science community, working through the organizations representing it in the Arctic Council, including IASC, the University of the Arctic (UArctic), and the International Arctic Social Sciences Association (IASSA), as well as through separate meetings of science ministers, already has identified substantive priorities for the next phase of Arctic research (*5*).

Concrete examples of improvements needed to achieve success with the agreement would be to (i) establish procedures to expedite the granting of visas and permits for accessing field sites; (ii) digitize historic and other data from hard-copy formats and create shared platforms for searching data located in a variety of repositories, including coordination with the Arctic Data Committee and Sustaining Arctic Observing Networks; (iii) use organizations mentioned in the agreement to set up and monitor research partnerships across borders; (iv) increase support for field and summer schools and related means for training the next generation of Arctic scientists; (v) promote well-formulated comparative studies designed to examine common issues at multiple locations across the Arctic; (vi) maximize the use of icebreakers and other forms of infrastructure for scientific purposes; and (vii) create innovative venues that integrate natural and social sciences along with indigenous knowledge to address common concerns.

Some of these measures will require action on the part of officials in foreign ministries; others can be handled best through organizations representing the science community. Each of the signatories can and should designate an official point of contact with a mandate to assist with the implementation of the agreement, monitor progress regarding efforts to remove obstacles, and make recommendations for the adoption of additional measures as needed.

Although the Arctic States are the signatories, the agreement emphasizes that these States "may continue to enhance and facilitate cooperation with non-Parties with regard to Arctic science." This holistic (international, interdisciplinary, and inclusive) science cooperation broadens the scope of the agreement beyond its defined area (see the map).

PROPELLING SCIENCE DIPLOMACY

The Arctic Science Agreement is the third legally binding instrument to emerge from the efforts of the Arctic States, following the search-and-rescue (*6*) and marine oil pollution preparedness and response (*7*) agreements. All have benefited from Russian and U.S. leadership of the negotiations (along

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with Norway regarding marine oil pollution), but only the Arctic Science Agreement enhances the logistic capacity for cross-cutting knowledge discovery and application.

Historically, polar scientists have played important roles in building East-West cooperation as demonstrated at the height of the Cold War. The 1957–1958 International Geophysical Year stimulated cooperation leading to the 1959 Antarctic Treaty, with its membership based on "substantial research" to manage nearly 7% of Earth's area forever for "peaceful purposes only," becoming the first nuclear arms control agreement.

The Antarctic Treaty laid the groundwork for the 1967 treaty promoting the peaceful use of outer space. Derived from common interests of the United States and Russia, among other nations, these two international spaces (*8*) were used peacefully throughout the Cold War and remain insulated from global geopolitics as a result of science diplomacy [see the supplementary materials (SM)].

Drawing lessons from these regions and facing "burning security issues" involving nuclear weapons in the Arctic, Soviet President Mikhail Gorbachev observed in his 1987 Murmansk speech (*9*) that "scientific exploration of the Arctic is of immense importance for the whole of mankind." This speech triggered a stream of cooperative developments with science in the lead.

Recognizing the value of Antarctic Treaty linkages with the Scientific Committee on Antarctic Research, national academies of science moved quickly to establish IASC in 1990. Science-based public agencies took the lead in the 1991 formation of the Arctic Environmental Protection Strategy, which then became the first signed record of international governance among the eight Arctic States (see SM). This catalyzed the 1996 establishment of the Arctic Council (*10*) as a "high level forum" of the eight Arctic States and six indigenous peoples organizations with observers and six technical and science-based working groups, involving key Arctic stakeholders (see the map and SM). In parallel, the education community created the Circumpolar Universities Association in 1989. With the endorsement of the Arctic Council, the UArctic was born in 1998 (see the map).

Within and between nations, research and education together promote understanding of and resilience to external stresses and disturbances (*11*), applying methodologies of the natural and social sciences as well as indigenous knowledge to detect and interpret changes over time and space. For example, diminishing sea ice and increasing ship traffic in the Arctic Ocean highlight biophysical and socioeconomic changes that directly affect the security of Arctic residents facing risks today and

Supplies are retrieved by crew from the U.S. Coast Guard Cutter Healy while in the Chukchi Sea, 12 July 2011. The Arctic Science Agreement can improve researchers' access to marine and terrestrial regions.

across generations (*12*). Moreover, external stressors, which are planetary in scale, raise additional questions (see SM) about the future of the Arctic in our globally interconnected civilization (*5*).

Minimizing the risks of policy shifts, the agreement enhances the stability of research platforms across nations to interpret and disseminate previously inaccessible data, as well as generate continuous data to interpret marine, terrestrial, atmospheric, and human-centered changes on a pan-Arctic scale (see the map). Moreover, scientific investigation is being enhanced to facilitate research on land, extending from marine scientific research under the law of the sea, to which all Arctic States "remain committed" (*13*).

Resulting questions, information, and observations can be organized into data; analyzed to expose patterns, trends, and other insights; and become evidence that can underlie decisions (see SM) about built infrastructure and governance mechanisms. As an apex goal, informed decisions benefit from consideration of available options (without advocacy), which can be used or ignored by the decision-makers. In the

Arctic, this science-diplomacy process (see SM) is being enhanced by the agreement to address the "common Arctic issues," in particular, "sustainable development and environmental protection," established by the Arctic Council (*10*), balancing economic prosperity, environmental protection, and societal well-being. In this context, the Arctic Science Agreement emphasizes "the importance of using the best available knowledge for decision-making."

LOOKING FORWARD

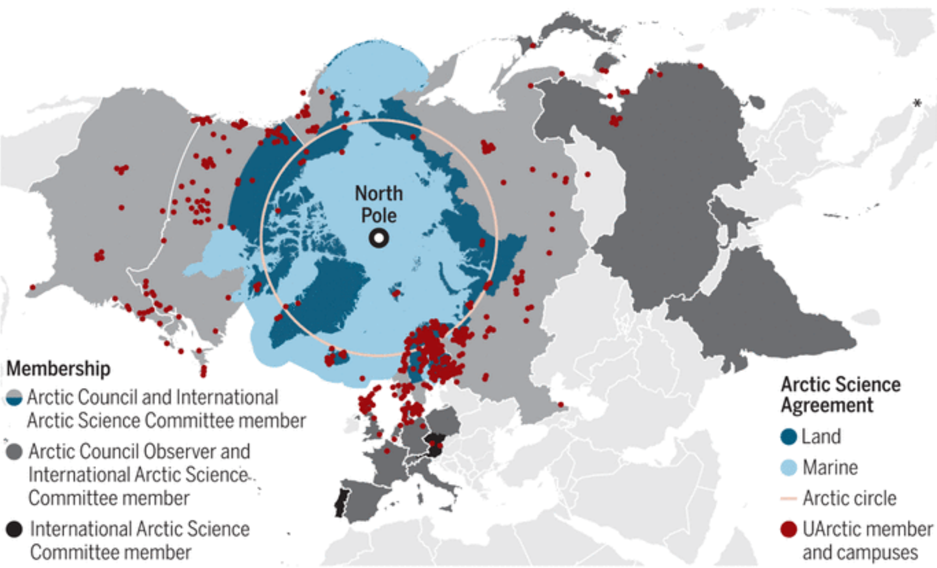
Science, whether for basic or applied objectives, can promote cooperation and prevent conflict by engaging diverse stakeholders in dialogue. With stakeholder inclusion (see the map and SM) enhanced by the Arctic

without planning across generations. Warming of the Arctic (*16*), thermohaline changes in the ocean from melting ice sheets, decreasing albedo as sea ice disappears, and increasing methane emissions from thawing permafrost all have climate footprints with societal, environmental, and economic implications on a planetary scale (*16*).

Effective implementation of the agreement will require its associated networks (including IASC, UArctic, IASSA, and partner organizations) to help strengthen research and education across borders (see the map). Considering the sovereign rights of Russia extending over nearly half the Arctic, research partnerships with Russian scientists are critical for Arctic science and diplomatic progress.

Land and ocean areas covered by the Arctic Science Agreement

The map draws on information from the following sources: Extent of the Identified Geographic Area in Annex 1 to the Arctic Science Agreement, U.S. Department of State (2017); H. Ahlenius/Nordpil; IASC; UArctic; thematicmapping.org. The map is a stereoscopic equal distance projection (north-south). See Supplementary Materials for high-resolution map with bathymetry and topography.



*Singapore is an Arctic Council Observer State.

GRAPHIC: ADAPTED BY J. YOU/*SCIENCE* FROM GRID-ARENDAL, K. L. FJÆRTOFT

Science Agreement, holistic evidence and options become increasingly feasible for informed decision-making (see SM) to achieve Arctic sustainability across the 21st century, recognizing that children born today will be alive in the 22nd century. As the upcoming ISIRA Workshop demonstrates, the agreement is already generating opportunities to enhance pan-Arctic research that will become increasingly vital, complementing implementation of the 17 Sustainable Development Goals on a planetary scale.

Discussions foreseeing $1 trillion USD of investment in the Arctic over the next few decades (*14*) reveal global commercial opportunities extending across the 21st century (*15*), but with local risks that will swell

Researchers can and should invoke the Arctic Science Agreement as a research-facilitation tool to build partnerships, conduct fieldwork, access data, and begin to answer previously unanswerable scientific questions, especially with pan-Arctic dimensions. The pathway for the researcher could involve the international research and education networks mentioned above to interface with the diplomats, for example, through periodic meetings jointly convened with foreign ministries.

Ultimately, the process of science diplomacy (see SM) builds common interests among allies and adversaries alike across a continuum of urgencies, spanning security to sustainability time scales with efficiencies

and synergies that transcend the geopolitics of today. These issues are being discussed among foreign ministries (*18*) and will be relevant to the continuing series of Arctic Science Ministerials (*19*). In the Arctic, as elsewhere, science diplomacy helps to balance national interests and common interests for the lasting benefit of all on Earth with hope and inspiration across generations. ■

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/358/6363/596/suppl/DC1

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Supplementary Materials for

The Arctic Science Agreement propels science diplomacy

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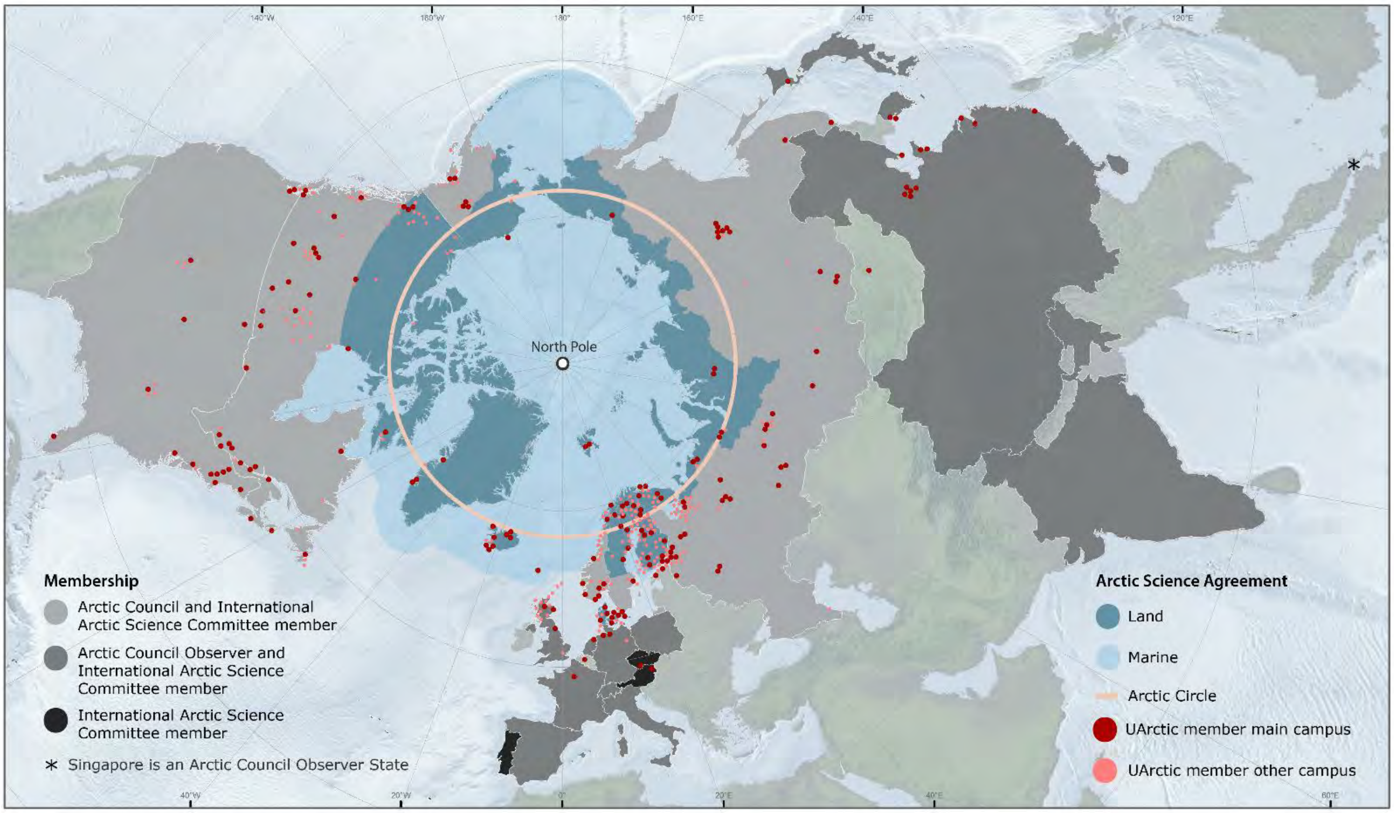
This PDF file includes:

Figs. S1 and S2

Land and ocean areas covered by the Arctic Science Agreement

The Agreement on Enhancing International Arctic Scientific Cooperation, signed in Fairbanks, Alaska, on May 11, 2017 applies to "Identified Geographic Areas" among the eight Arctic States on land and in the ocean. Signatories, affiliates and organizations named in the Arctic Science Agreement are shown with bathymetry and topography included in the map.



Map by GRID-Arendal, K.L. Fjærtoft. Projection: Stereoscopic equal distance (north-south).
Sources: Extent of the Identified Geographic Area: Annex 1 to the Arctic Science Agreement and U.S. Department of State 2017; H. Ahlenius/Nordpil. IASC and UArctic; thematicmapping.org

FIGURE S1. High-resolution map with bathymetry and topography to elaborate national interests and common interests in the Arctic, accompanying *"The Arctic Science Agreement Propels Science Diplomacy"* (*Science* **358**, 596, 2017). This map accurately represents the "Identified Geographic Areas" on land and in the sea, as defined in the *Agreement on Enhancing International Arctic Scientific Cooperation,* which was signed in Fairbanks, Alaska, on 11 May 2017 by foreign ministers of the eight Arctic States (Canada, Denmark with Greenland and the Faroe Islands, Finland, Iceland, Norway, the Russian Federation, Sweden and the United States). Maritime zones defined by the 1982 *United Nations Convention on the Law of the Sea* extend from the territories of States into international spaces on the sea floor and in the superjacent waters – from national interests into common interests – especially with the Arctic High Seas fixed beyond sovereign jurisdictions surrounding the North Pole (Berkman, P.A. and Young, O.R. *Science* **324**, 339, 2009). The "Arctic Science Agreement" enhances the opportunity for informed decision-making (see Figure S2) to achieve Arctic sustainability across generations, delivering lessons for our globally interconnected civilization about the application of science diplomacy as an holistic (international, interdisciplinary and inclusive) process with evidence integration to balance national interests and common interests for the lasting benefit of all on Earth.

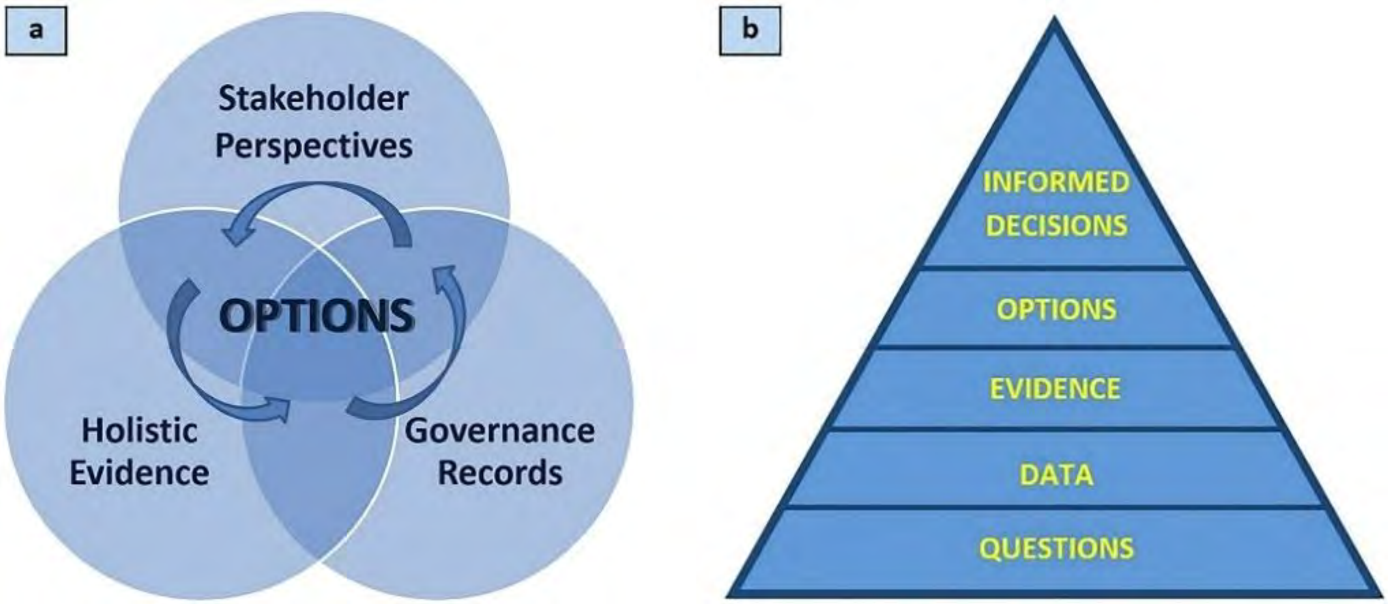


FIGURE S2. Decision-support process of science diplomacy (see Figure S1) illustrated by the *Agreement on Enhancing International Arctic Scientific Cooperation* (see Berkman, P.A., L. Kullerud, A. Pope, A.N. Vylegzhanin and O.R. Young. *Science* **358**, 596, 2017). (**a**) Holistic methodology to address issues, impacts and resources within, across and beyond jurisdictions independent of scale (from a family to our world). At the scale of our globally interconnected civilization, analytical results from science (defined inclusively as the study of change) contribute to holistic evidence for decisions about built infrastructure and governance mechanisms that are necessary to achieve progress with all seventeen United Nations Sustainable Development Goals. Context to introduce options for decision-making is revealed by the governance records (such as the "Arctic Science Agreement"), which represent authentic policies defined by officials with relevant decision-making capacities. Holistic evidence is further informed by diverse perspectives among stakeholders or major groups (https://sustainabledevelopment.un.org/majorgroups/about). This decision-support process starts with (**b**) questions that provide the foundation to build common interests among diverse groups inclusively. With questions, information and observations can be distilled into data (as anticipated by the "Arctic Science Agreement"), applying rigorous analytical methods from the natural sciences and social sciences as well as indigenous knowledge to reveal the dimensions, patterns and trends of issues, impacts and resources that require action by decision makers. The diplomacy comes from options (without advocacy), which can be used or ignored explicitly, leading simply to informed decision-making. The integration of options underscores the science diplomacy to achieve informed decisions across generations, which is central to sustainability in the Arctic and on Earth, recognizing that children born today will be alive in the 22nd century.

About LEO
The Local Environmental Observation Network
By Mike Brubaker and Mike Brook, Alaska Native Tribal Health Consortium

Alaskans live close to the land, and the health of communities is closely related to the conditions of the environment. Many Alaska Natives possess intimate knowledge of the weather, seasons, land, and natural resources; and this equates to superb skills in detecting subtle environmental changes and their impacts. The Local Environmental Observer (LEO) Network was originally designed as a tool to help collect and share the increasing number and wide range of unusual events witnessed by residents in rural Alaska communities. In recent years, these events have been captured in social media, like Facebook, which is very popular across Alaska. But Facebook focuses on immediate events rather than on ways to achieve long term learning and understanding. LEO Network focuses on creating a safe and respectful place for sharing knowledge, protection of privacy, archiving content for long term use, and providing technical assistance by connecting observers with topic experts.

LEO Network is part environmental observation field tool, part publishing platform, and part social network. It was developed by the Alaska Native Tribal Health Consortium in 2012, for the primary use of people in or working with rural Alaska communities. With the relaunch of the platform in 2015, enrollment was open to *anyone;* this has resulted in rapid growth in use and membership. To date there are 2,528 members in 588 communities and 50 countries around the world. The platform contains event-related local observations (1017) and news articles (1682) that are geo-coded, date-coded, tagged by topic, and linked to other content in the system. Examples include observations about unusual weather, seasonal change, wildlife, plants, infrastructure, invasive species and erosion.

LEO Network is not focused on being a quantitative monitoring system, but rather as a way for members to share qualitative, media-rich information about their changing environments. Where monitoring systems, citizen science projects, or research partners are available, LEO Network assists in connecting members with topic-relevant programs and participatory science opportunities.

Some of the guiding principles behind LEO Network include respect and engagement of different knowledge systems, including indigenous, local and scientific knowledge. LEO posts are permanently available to LEO members, and the original observer is attributed as lead author. Consultants, secondary observers, and other subject-matter experts are attributed as co-authors. All authors of an individual post are given the opportunity to review and provide final comment prior to publication. Recognition of participants in the system is emphasized with profiles and maps for every member and community, and the ability to apply the content in the system towards personal projects. Direct communication between members is encouraged and facilitated by the system, but in a way that protects the privacy of the members.

The LEO Network is designed with an emphasis on ease-of-use, availability everywhere, and language that is accessible to all. Translation of the platform into Arctic languages has encouraged growth and the potential of a broader dialog between members. A mobile application is available for Apple and Android for posting observations in the field, and the LEO Network website provides features both for posting observations as well as exploring the observations and individuals that make up the Network.

The value of the LEO Network is based on the quality and usefulness of the information for its members. As such, an important principal of LEO is to be highly responsive to the questions and information shared by the observers. LEO Network has a specific workflow design that supports timely editorial and consultative services to support the contributions of the members.

LEO Network has been successful in Alaska, and as a platform is experiencing circumpolar and global expansion. Through this platform, sharing between knowledge systems has increased, as has community involvement, and awareness among service providers and researchers about current events that are shaping activities and lives at the community level.

SUCCESSES AND CHALLENGES OF INTERDISCIPLINARY OCEAN ACIDIFICATION RESEARCH IN ALASKA

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SUCCESSES AND CHALLENGES OF INTERDISCIPLINARY OCEAN ACIDIFICATION RESEARCH IN ALASKA

EXECUTIVE SUMMARY

Arctic regions are a bellwether for ocean acidification impacts, experiencing rapid and extensive onset of anthropogenically acidified conditions. Ocean acidification is already occurring in important commercial and subsistence fishery habitats and could have cascading economic consequences. In response to this risk, the Alaska Fisheries Science Center and the Pacific Marine Environmental Laboratory formed a novel partnership, the Alaska OA "Enterprise," to produce forecasting models of ocean acidification effects on fisheries and coastal communities from ocean observations, climate model predictions, and species response studies. This interdisciplinary scaled approach has been extremely successful in calculating and communicating potential economic risks and community vulnerabilities to decision makers. We highlight these successes to demonstrate the potential of this interdisciplinary framework to develop community research and monitoring priorities and build support for a sustainable long-term research program. Maturing Enterprise research along with extensive stakeholder feedback have co-identified future research objectives, including additional monitoring of spatiotemporal variability and experiments that assess long-term population acclimation potential and the roles of co-stressors for a wider portfolio of locally important species and populations. However, these emerging complexities represent a key challenge for future work: current resources cannot cover all observational scales and species of interest. To meet these needs, we emphasize that biogeochemical models, new observing technologies, and expanded partnerships may lead to new insights and meet the demand for actionable information on OA issues.

KEY WORDS

Ocean acidification; Alaska; Arctic; monitoring; modeling; forecasting; species-response; economic impacts; technology development; interdisciplinary collaboration

STATEMENT TO THE 2018 ARCTIC OBSERVING SUMMIT

During the last decade, research has propelled ocean acidification (OA) to the forefront of the marine resources conversation in Alaska (e.g., Frisch et al., 2015). The progression of OA in this region has been faster than in many other ocean basins (Mathis et al., 2011a), and research shows that OA is already leading to some geochemical impacts in Alaska (Cross et al., 2013; Mathis et al., 2014). Of particular concern is that this anthropogenic perturbation could cause ecosystem-level shifts that diminish the overall economic value of commercial fisheries and reduce food security for communities that rely on subsistence harvests. Alaskan fisheries accounted for more than 60% of the catch by weight in U.S. fisheries with a first-wholesale value of approximately $4.2 billion USD in 2016 (Fissel et al., 2017), which created an estimated 99,000 full-time jobs and $12.8 billion in total output for the U.S. economy (McDowell Group, 2017). At this level, even a relatively small decline in one or more Alaskan fisheries could have cascading economic impacts for local communities, Alaska, and the U.S. as well as for trade with other nations.

Based on the potential risk to Alaskan fisheries and communities, the NOAA Alaska Fisheries Science Center, the NOAA Pacific Marine Environmental Laboratory, and regional universities proactively responded with baseline support from the NOAA Ocean Acidification Program (Sigler et al., 2008) to formalize a research initiative as the Alaska OA “Enterprise.” Understanding that the ultimate goal is to build resilience for local communities and the statewide economy to OA related changes, the Enterprise efficiently collects data and conducts experiments that directly support bioeconomic modeling of OA impacts, creating OA risk information that can be rapidly used by decision makers including local, state, and federal natural resource managers.

This novel partnership has produced a number of early achievements that support the business case for ocean observing in this region, the topic of this year's Arctic Observing Summit. For example, the Enterprise collaboratively produced a multi-faceted OA risk index for Alaskan communities (Mathis et al., 2015). Since publication, this information has been presented to a range of constituencies from school and community groups to the Alaska Governor's Office and the Alaska State Legislature. Larger communities with strong, diverse economies were predicted to be most resilient to OA, while smaller communities more dependent on marine resources for income and food security were predicted to be more vulnerable. This assessment sparked important and continuing conversations between stakeholders, decision makers, and researchers about how to build resilience against these risks.

Another key achievement was a targeted research initiative to assess the effects of OA on the economically critical red king crab fishery. Ocean biogeochemical observations (Mathis et al., 2011a, b; Cross et al., 2013; Evans et al., 2014) informed laboratory experiments that demonstrated altered embryo development and larval survival (Long et al., 2013b) and decreased juvenile growth and survival (Long et al., 2013a) under near-future OA scenarios. These results parameterized a population dynamics model to predict potential effects on fishery yield (Punt et al., 2014), which subsequently allowed quantification of the potential economic impacts in Alaska (Seung et al., 2015). By scaling the research up to the bioeconomic level, Seung et al. (2015) highlighted proactive fishery management adaptations which could minimize the economic impacts of OA. Specific actionable items included the need for ocean monitoring and more accurate spatially and temporally appropriate species-specific response data to support OA-related management decisions. This integrated research initiative was brought before the Alaska

Governor's Office Climate Leadership Task Force as critical evidence supporting investment in marine OA observing efforts.

Ongoing interactions among researchers and with stakeholder groups remain essential for the sustainability of the Enterprise. In 2016, a parallel effort by the U.S. Integrated Ocean Observing System led to the development of the Alaska Ocean Acidification Network (AOAN) specifically to connect scientists to community members, fishermen, and tribal leaders in Alaskan communities to share questions, needs, and concerns. By participating in AOAN, Enterprise members receive critical local knowledge and history as well as feedback from these communities that help inform research priorities and identify educational needs regarding the public understanding of environmental changes occurring in Alaska.

From the onset, it was recognized that the complexity and scope of Enterprise research would increase and expand over time. Species-specific sensitivity analyses continue to be critical for identifying the range of OA impacts (e.g., Hurst et al., 2013), but are recognizable oversimplifications of real world situations. With community and stakeholder support, current and planned research projects are exploring the interactions between OA and co-occurring stressors such as warming (Swiney et al., 2017), food web alterations (Hurst et al., 2017), and deoxygenation (Sigler et al., 2017). More complex response variables are being measured to consider cellular and molecular responses that lead to responses in macro-scale life history parameters studied previously (Meseck et al. 2016; Coffey et al. 2017; Sigler et al. 2017). Longer-duration experiments are being conducted to explore long-term sensitivity of vulnerable species and potential acclimation or adaptation capacity, a resilience that could substantially delay OA effects (Long et al., 2017).

However, critical gaps still remain. As an example, species need to be prioritized for response studies to include species that are important for local communities and keystone species that are bioindicators of ecosystem-level responses to OA. Researcher and stakeholder consensus has identified the need to understand the response of salmonids to OA because of their importance to local communities and ecosystems. This Alaska fishery sector is of critical importance to the food security of many small communities: annually, salmon represents 33% of the first wholesale value of commercial fisheries in Alaska, providing an estimated 32,900 jobs and over $5.9 billion to the U.S. economy (McDowell Group, 2017). To date, salmonid research has not been a focus of the Enterprise research portfolio. Expanding the Enterprise portfolio to include salmonid and other important species will depend on developing and leveraging new partnerships. Recently, the NOAA Ocean Acidification Program and the Department of Fisheries and Oceans Canada developed a collaborative framework on shared high-latitude OA objectives, which includes coordination of efforts between DFO and NOAA on monitoring, experimental research, modelling, and information sharing. Preliminary results from a knowledge gap analysis conducted by NOAA and DFO also pointed to the gap in salmonid research, further building researcher and stakeholder consensus around this new research priority that could drive new projects.

An additional gap identified by the Enterprise is the need to expand oceanographic monitoring to describe the dynamics of OA on the multiple spatial and temporal scales that drive biological systems. This is an enormous challenge in the vast, remote territory of Alaska: the Alaskan coastline is longer than the U.S. coastline along the East Coast, West Coast, Gulf of Mexico, and Great Lakes combined. Currently, our long-term monitoring assets are limited to two biogeochemical moorings and one quadrennial ship-based survey in the Gulf of Alaska.

While new technologies are expanding capacity for cost-effective OA observations in surface waters during the open water (ice-free) season, OA events are often most severe and sustained in sub-surface waters where many fishery species live.

To supplement this observing portfolio, the Enterprise is partnering with researchers in the Alaska Climate Integrated Modeling (A-CLIM) Project. Biogeochemical observations and species-specific sensitivities based on Enterprise and AOAN research are being used to validate a regional Bering Sea model that includes OA variables and simulations. This will create a powerful new tool that scales up Enterprise observations to predict OA conditions over a much broader territory, including at the sub-surface, and connects OA biogeochemistry to potential impacts across the Alaskan food web. The Enterprise is also exploring opportunities to partner with the National Marine Fisheries Service during their groundfish and crab population surveys in the Bering Sea. This would co-locate chemical measurements with a current, multi-decade time series of fisheries data. Such a collaboration could identify relationships between OA and fishery populations.

In summary, the early experience of the Enterprise includes several key lessons that may be of interest to the Arctic Observing community. The early successes of the Enterprise were predicated on a few critical components. Establishing and maintaining a focus on robust, peer-reviewed science provided confidence in the observations. Second, both biological and chemical observations were rapidly incorporated into tangible assessments that were accessible to the public fostering interest and collaboration across the state. The stable, multi-year funding mechanisms through NOAA’s OAP allowed the research to develop into the multi-layered biological and oceanographic observations used in these widely disseminated forecasting products. As OA science continues to mature, we look forward to building upon the established foundation to improve the assessment of ongoing OA in high latitudes. This will include developing sensitivity profiles for a wider suite of ecologically and economically critical species and generating forecasting products that meet local, state and federal policy-making needs. This will require continued engagement with multiple stakeholder groups to respond to emerging concerns within specific communities and industries. Addressing this increasing breadth of foci will only be possible with even greater partnerships that integrate efforts at the local, statewide, national, and international levels.

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A Century of Marine Monitoring in Scotland: A Small Nation at one of the Gateways to the Arctic

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Abstract: *Scotland has sustained marine monitoring in support of government, society and marine industries for over 130 years. Over this period we have also been involved in marine monitoring which has failed in different ways. This paper discusses lessons learnt in a small country situated at one of the gateways to the Arctic and historically linked to other Arctic nations.*

Scotland is a nation of about 5 million people situated at one of the gateways to the Arctic. The people of Scotland have historical links with the peoples of Scandinavia, Faroe and Iceland. Scotland has a mixture of a few large cities, some larger towns plus many remote rural communities, including on our islands; Shetland, Orkney and our smaller isles. Our coastal communities have relied on fishing for many centuries for employment and economy. In Scotland, fishing is still very much focussed around family boat ownership rather than large companies. Today the industry is split between inshore fisheries, predominantly small day boats crewed by one or two people which target shellfish and are based on the west coast, and offshore fisheries consisting of larger vessels from our major fishing ports (Peterhead, Fraserburgh and Lerwick), and targeting demersal and pelagic fish species, as well as scallops and prawns..

Since the 1970s new industries such as aquaculture (mainly on the west coast for salmon, but some shellfish as well), and oil and gas (mainly in the North Sea) have come along to add to our maritime industries. In the very recent past marine renewables have been added to the mix. Other marine industries, including ship building and whaling, were important in the past, but have now declined or ceased.

Marine monitoring started in Scotland in the late 1800's following the birth of marine science in large programmes such as the Challenger Expedition. The Marine Laboratory Aberdeen started in 1893 as a fish hatchery, but rapidly developed into a science base which provides advice to the Scottish administration. Since its foundation, the Marine Laboratory has been involved in many different forms of marine monitoring ranging from small projects based on citizen science, up to major internationally coordinated programmes. Programmes include oceanographic, contaminant and fish stock health monitoring.

Many lessons have been learnt, been forgotten, and then re-learnt along the way. We currently operate monitoring programmes which have been sustained for over 130 years in one case, over many decades for much of our monitoring, to some programmes of just a few years duration. Monitoring sustainability has often relied on the fact that we have owned our own vessels. Hence we have been able to decide what monitoring we sustain based on our own knowledge of Scotland, its people and environments, and it's concerns without having to convince funding committees or remote panels of "experts".

Our longest time series, across the Faroe Shetland Channel and which monitors both the warm water flow of Atlantic water towards the Arctic, as well as one of the few deep water cold, dense outflows from the Arctic, was initiated by an international project trying to understand changes in the “great fisheries”, i.e. North Sea herring. When the project ended, we maintained the time-series as being a key one to provide the context to changes in Scottish waters.

Over the intervening century, Scotland has experienced great changes in its fisheries and fish stocks, such as the collapse of the herring fisheries in the 1970s, and the decline and subsequent recovery of cod in the 2000’s. For our larger, offshore fishing industry, the results of our monitoring is often viewed based on its outcomes. For fishermen, monitoring and assessments which result in more catching opportunities is “good” science, whereas monitoring which results in advice for reduced catching opportunities is “bad” science. Marine scientists must maintain objectivity as their goal, and be prepared to deliver bad news as well as good. However, they also need to manage expectations.

While the need to provide advice to manage the fisheries is still a key driver of our monitoring, in the last decade the need to assess the health of the ecosystem in general has risen up as a priority, driven by global marine sustainable development policies such as the Stockholm Declaration (1972), the Rio Declaration (1992) and Agenda 21 (1992).

For many years, in Scotland at least, we struggled to understand what the practical implementation of the “ecosystem approach” meant. This confusion was greatly helped in 2002 with the publication of the UK Governments “vision” for our seas, as “clean, safe, healthy, productive and biologically diverse oceans and seas”, to which the Scottish Government added “managed to meet the long term needs of nature and people”. This phrase had a fundamental effect on what we monitored and how we organised our monitoring. A set of simple words were extremely powerful in conveying to the public and to scientists the purpose of our monitoring. The phrase is now built into the European implementation of the ecosystem approach; the European Marine Strategy Framework Directive (MSFD). The MSFD requires member states to assess the health of its marine ecosystems under 11 Descriptors; Biological diversity; Non-indigenous species; Commercial fish and shellfish; Food webs; Eutrophication; Sea-floor integrity; Hydrographical conditions; Contaminants; Contaminants in seafood; Marine litter; Underwater noise. This has driven us to establish new monitoring programmes for aspects of the environment we previously largely ignored, such as introduced sound and marine litter.

Finally, when trying to coordinate our national marine monitoring within international efforts, we have learnt that an overriding need is good, clear, transparent governance. Governance needs three levels; “Leadership” which includes the politicians and administrators who control funding and policy, and add legitimacy and clear purpose to monitoring; “Management” which includes resource managers and Directors of institutes who can redirect people and ships, and implement a strategic approach; and “Operational” which includes the people that actually implement the monitoring “on the ground”. Transparency is needed so the public can see what the governance is doing, and trying to do, and understand why. Without good governance we have seen monitoring programmes stagnate and not be able to meet current challenges, struggle to obtain cohesive data quality and delivery, and cease owing to a failure to link monitoring, driven by a specific technology, to societal need.

Tracking Harmful Algal Blooms in the Pacific Arctic

The Aleutian Pribilof Islands Association (APIA) has been working for over a decade to understand the risks from paralytic shellfish poisoning (PSP), both to people and the ecosystem. Our work at APIA on harmful algal blooms began in 2005 with 20 monitoring stations from Ketchikan all along the Gulf of Alaska coast, all of it, all the way to Russian where we also trained technicians on the Commander Islands to collect monthly samples and test for PSP. The initial monthly sampling effort lasted just over a year and established a necessary PSP baseline for future PSP work in Alaska.

Species Tested:
We monitor mostly blue mussels because they are more available and easy to collect in most location, but in King Cove, Sanak Island and Sand Point we collect butter clams for testing. The various species of bivalves (clams, mussels, oysters, scallops) react differently to the PSP toxins; mussels become toxic very fast and loss (depredate) the toxins quickly, in as little as a week. Littleneck clams tend to not become as toxic as butter clams, but razor clams, butter clams, scallops and cockles can become very toxic. Butter clams tend to maintain their toxic levels longer than other bivalves. We also test other species as required and needed. We have also tested Dungeness crab, different species of sea birds and sand lance (a forage fish eaten by may predators.

What We Have Learned:
Over the years we have learned that PSP is found all along the Gulf of Alaska coast and into the Bering Sea and the Arctic Ocean. The APIA PSP research effort resulted in uncovering the risk of eating the hepatopancreas (guts) from crab and shrimp from our research in Haines, Alaska (Tiayasanka Harbor, Lutak Inlet, Dungeness crab PSP results at 1,055 µg/100g when the FDA limit for PSP in bivalves is 80 µg/100g). We also secured the unfortunate honor of recording the highest PSP level ever measured in Alaska, blue mussels from Viking Cove, Haines had PSP at 21,600 µg/100g. The data sets for some of our monitoring stations reveal an obvious shift in persistence of PSP and especially in the Aleutian Islands and Pribilof Islands.

Akutan Forecast Station?
We have seen that high levels of PSP in Akutan seem to forecast region-wide (Aleutian Islands) PSP events. In July 2010 the Akutan PSP levels were 390 µg/100g and in 2015 the levels reached 221 µg/100g, both were years of region-wide PSP events. These region-wide PSP events occur during years we measured high ocean temperatures (collected at Akutan, King Cove and Unalaska). Usually Adak, Alaska (further out the Aleutian Islands' chain) has low PSP levels, but the PSP levels reached 94.3 µg/100g on 6/18/15, the highest level ever recorded for Adak. Also in 2015, Pauloff Harbor, Sanak Island butter clam collected 5/16/15 had a PSP level of 336 µg/100g and Unalaska mussels on 6/12/15 had PSP levels of 784 µg/100g. The 2017 Akutan PSP levels were low, only reaching 40.5 µg/100g in August.

Northern Shift of PSP Events
The northern shift of high PSP levels is of great concern. The monitoring station of St. George in the Pribilof Islands of the Bering Sea indicated PSP was below 80 µg/100g until 2014 when the levels in September 2014 were at 240 µg/100g, then in July 2016 jumped to 1,590 µg/100g. The levels measured in August 2017 were 575 µg/100g.

Fall, Winter, Spring PSP Events and Food Safety Concerns:

King Cove, Alaska is very important for its valuable subsistence butter clam resource in the Lagoon, but PSP events beginning in 2008 have increased the risk of subsistence harvests. In July 2008 the PSP levels in butter clams was 1084 µg/100g, in July 2010 it was 641 µg/100g, June 2016 it was 481 µg/100g, but some of the PSP events also occurred during the colder months, the months with an 'r' in them.

King Cove PSP events during fall, winter and spring

Date	PSP level
3/27/09	152 µg/100g
4/30/10	106 µg/100g
12/28/10	138 µg/100g
12/9/11	99 µg/100g
10/22/13	108 µg/100g
4/6/14	98.1 µg/100g
4/16/15	89 µg/100g
11/16/16	88.9 µg/100g
2/1/17	93.6 µg/100g
10/16/17	99.2 µg/100g

PSP and the Ecosystem:
Reports of dead and dying seabirds, sand lance (a forage fish) and large fish have led us to focus on the ecological effects of PSP. Windrows of tons of dead sand lance across from Sand Point on Unga Island, and near False Pass, and the sick and dying birds (gulls and eagles were noted) feeding on the sand lance resulted in our asking fishers, elders and others in the Aleutian Island and other Bering Sea communities about these events and about their thoughts. The survey reveals a link with the dead sand lance and sick or dead birds. A dead gull recovered from False Pass in July 2015 had elevated PSP levels (13.4 µg/100g), but without controlled experimenting and testing we cannot determine if the PSP was the cause of death. The False Pass technician who collected the gull described that during the 2015 event many gulls and eagles lacked coordination, had difficulties in flying and some died.

The Hypotheses:
The Steller sea lion population is depressed in much of the Aleutian Islands, and as low as 95% below historic levels. Judging from the data we have gathered over more than a decade in the Aleutian and Pribilof Islands and the local knowledge shared with us, we see a strong link to PSP events and the 95% decline in the endangered sea lion population and seabird die offs in the Gulf of Alaska and the Bering Sea.

Some species are at risk from direct poisoning from PSP by consuming the organism that makes the PSTs (paralytic shellfish toxins), from *Alexandrium sp.*, or feeding on the toxic organisms further up the food web. For example, copepods and euphausiids feed on *Alexandrium sp.,* become toxic with the PSTs and pass these toxins up the food web to other forage species such as the common forage fish in the region, sand lance. The toxins can incapacitate the forage species at which time they are easy prey for top predators such as sea lions. We have measured PSP from samples collected from dead sea lions' andf sea otter's stomachs in the Aleutian Islands.

A delayed response occurs after the forage species (copepods, euphausiids, sand lance) die and are thus removed from the food web, leaving other marine predators without food. Accordingly, this can explain why, after several months, we see starving marine life, especially sea birds washing up on beaches, most starved to death. The birds didn't die from PSP toxicity, they died because the PSTs disrupted the ecosystem. Months after the massive 2015 harmful algal bloom in the Gulf of Alaska (GOA), thousands of murres, starving or starved to death, washed up on GOA beaches. And, months after the record 2016 PSP levels in the Pribilof Islands (St. George PSP levels 1,590 µg/100g), starving and starved puffins washed up on the islands' beaches. The PST didn't kill the puffins, they died from starvation because the PST disrupted the ecosystem.

We recorded high levels of PSP in sand lance collected near Homer, Cook Inlet, Alaska. Live sand lance collected in Taiysanka Harbor, Haines, Alaska in July 2014 had whole body PSP level of 34.8 µg/100g (composite sample). A composite sample of 5 sand lance from Katmai Bay collected 7/28/16 had a PSP level of 11.2 µg/100g. Dead sand lance with the highest PSP levels we measured were from our most northerly monitoring site near Deering, Norton Sound, Alaska. The Deering sand lance had PSP levels of 758 µg/100g (whole body). Samples of sand lance recovered from a 2017 Deering, Alaska king salmon's stomach are in the ADEC-EHL queue with HPLC results expected soon.

Other species at risk in the Gulf of Alaska and Bering Sea include Yukon Rivers king salmon, walrus, fur seals and sea otters; they all could feed on PSP-contaminated prey. Hundreds of sea otters tested for PSP had detectable levels of the toxin. A dead sea otter collected in southeast Alaska on 8/7/14 had a PSP level of 541 µg/100g in pleural fluid (around the lungs) and another had domoic acid (another harmful algal bloom toxin found in Alaska) of 595 PPM in its urine (FDA legal limit for domoic acid is 20 PPM).

During the 2015 Gulf of Alaska harmful algal bloom (HAB) event, several monitoring stations, reported from plankton tows, had high concentrations of the dinoflagellate *Alexandrium sp*. (responsible for PSP) and *Pseudo-nitzschia*, the marine planktonic diatom genus containing some species capable of producing the neurotoxin domoic acid. We did not detect any domoic acid in the biological samples sent to the ADEC-EHL.

APIA will continue its harmful algal bloom studies, and continue to work to understand risks of PSTs to people and the marine ecosystem.

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