Transboundary pollution in a changing Arctic

White paper prepared for the Arctic Observing Summit, Vancouver, April 30-May 2, 2013

Jason Stow[1], Russel Shearer[1], Hayley Hung[2], Sandy Steffen[2], Tom Harner[2], Birgit Braune[3], Meredith Curren[4]

1. Aboriginal Affairs and Northern Development Canada, Northern Affairs Organization, Northern Contaminants Program
2. Environment Canada, Atmospheric Science and Technology, Air Quality Research Division
3. Environment Canada, Wildlife and Landscape Science, Ecotoxicology and Wildlife Health Division
4. Health Canada, Health Environments and Consumer Safety, Populations Monitoring Division

Introduction

Persistent organic pollutants (POPs), heavy metals and radionuclides released to the environment from industrialized parts of the world are transported to the Arctic through rivers, oceans and the atmosphere. Once in the Arctic, many pollutants accumulate in food webs where some biomagnify to levels at which adverse effects have been found in wildlife and humans. Arctic indigenous people are particularly vulnerable to the impacts of these pollutants to which they are exposed through their traditional diet including marine mammals and other aquatic species. Since the early 1990s, there has been an intensive circumpolar effort to study transboundary pollutants and their impact on ecosystem and human health in the Arctic. In 1991, Canada established the Northern Contaminants Program (NCP) specifically to take action on transboundary pollution impacts in Canada's North. The creation of the NCP coincided with the establishment of the Arctic Monitoring and Assessment Programme (AMAP), which coordinates monitoring and assessment activities for the circumpolar Arctic. AMAP is now one of the Working Groups under the Arctic Council addressing impacts from climate change, transboundary pollution and human health. The assessment reports and related documents produced by the NCP and AMAP form the scientific basis of this white paper and are listed as background documents at the end of the paper.

The Canadian NCP, in cooperation with AMAP and the other Arctic nations, effectively used scientific findings on pollutants in the Arctic to build a strong case for regional action on POPs and heavy metals under the pre-existing United Nations Economic Commission for Europe's Convention on Long-Range Transboundary Air Pollution. This was followed by a global agreement to take action on POPs under the United Nations Environment Program (UNEP) Stockholm Convention. Under this Convention, a Global Monitoring Plan (GMP) was implemented to assess regional and global levels, trends and transport of POPs and the effectiveness of the Convention (as described under its Article 16 – Effectiveness Evaluation). Arctic data sets on POPs for the two 'core' media of the GMP - air and human tissues (i.e. milk and blood) - were key contributions to the first GMP report in 2009 and will

continue to inform future GMP reports, to be delivered every 6 years. Starting with the next GMP report due in 2015, surface water has been added as a tier 2 core medium for evaluating perfluorooctane sulfonate (PFOS). Because it is an ionizable chemical, PFOS partitions strongly to water.
Recently, the results of NCP and AMAP monitoring and research on mercury in the Arctic contributed significantly to UNEP negotiations that concluded with a global mercury agreement on January 19, 2013 which is to be known as the Minimata Convention and will be open for signing in October 2013.

Each of these agreements has, and will have, articles that require Parties to assess how effective the agreements are at reducing the impacts of pollution. In large part they will be looking to the Arctic again as the global bellwether for decreasing levels of pollution. This puts pressure on the Arctic science community, and Arctic states in particular, to make the observations necessary to assess the effectiveness of global action on transboundary pollutants. These assessments will inform actions and amendments to international agreements that will enhance effectiveness, and in the case of POPs, expand the scope of the Stockholm Convention to include new POPs.

An Arctic observing system for transboundary pollutants should:

1. Monitor temporal and spatial trends of pollutants in the atmosphere, terrestrial, freshwater and marine ecosystems, and in humans.
2. Demonstrate the influence of global action on the observed trends in the context of other drivers that may be influencing the trends (e.g. climate change, resource development, socio-economic transition).
3. Assess ecosystem and human health risks arising from exposure to complex chemical pollutant mixtures in the context of cumulative stressors (e.g. climate change, resource development).
4. Assess emerging pollutant threats.

   In support of these activities:

5. Maintain a data management network that ensures long-term security and accessibility to pollutant related data.
6. Maintain a network of specimen archives that allow for retrospective analysis and research.
7. Engage residents of the Arctic to identify and define observing needs and to participate in community-based collection and interpretation of observational data.

The long term sustainability of an Arctic observing system for transboundary pollutants will depend, in large part, on long term support from Arctic states. The monitoring and research programs that will form the observing system, along with the maintenance of essential data management and sample archiving infrastructure, should be considered core activities in the Arctic stewardship agendas of individual

Arctic states. Canada's Northern Contaminants Program (NCP) is an example of a long term monitoring and research program that helps to fulfil this mandate. This white paper describes how the NCP addresses the seven needs identified above and discusses areas for improvement. We also take a circumpolar view of how these needs are being met through AMAP.

Monitoring and Research

Systematic monitoring of pollutants in the Canadian Arctic environment is carried out under the NCP in the following generally defined compartments: atmosphere, terrestrial , freshwater and marine ecosystems, and humans. Research activities are designed to complement monitoring and expand knowledge on environmental trends, pathways, processes and effects. This approach is generally paralleled under AMAP.

Atmosphere

The atmosphere represents the primary transport pathway for pollutants from sources, i.e. point of emission, to the Arctic. It also allows for the exchange of pollutants between different environmental compartments (e.g. atmosphere – ocean exchange) and transportation within the Arctic. The atmosphere is also a sentinel for change because it responds relatively quickly to changes in emissions. These properties of the atmosphere contributed to its selection as a core monitoring medium under the Stockholm Convention's Global Monitoring Plan (GMP). The NCP currently monitors POPs and mercury on an ongoing basis at Alert, Nunavut, and mercury at Little Fox Lake, Yukon. Mercury is continually measured directly by a Tekran™ mercury vapour analyser, whereas POPs are analysed in air extracts collected weekly from glass fiber filters (particle-bound POPs) and polyurethane foam (PUF) or PUF-XAD traps (vapour-phase POPs). The monitoring program offers excellent temporal resolution; however, the distribution of sampling locations gives very poor spatial resolution. In an effort to expand the spatial resolution of the atmospheric monitoring program it has been recommended that the NCP deploy a network of passive air samplers across the Canadian Arctic. A more extensive and broadly distributed network of passive samplers should enable more detailed assessment of air mass - source relationships.. Such a network would also provide a spatially-resolved baseline for assessing future changes in Arctic contamination as a result of climate and human activity changes (e.g. resource development and increase in shipping emissions).

Ongoing air monitoring under AMAP includes continuous measurements of POPs at Ny-Ålesund, Norway; Stórhöfði, Iceland; and Pallas, Finland. Current long-term and continuous monitoring of mercury takes place at Ny-Ålesund and Amderma, Russia. Over the past twenty years periodic measurements have been made at other air monitoring sites in the Arctic, e.g. Barrow Alaska. While the potential for future air monitoring at these sites probably exists, there is currently no commitment for future monitoring. As a result, there are relatively few atmospheric monitoring stations currently operating in the circumpolar region. The spatial resolution of this monitoring network could be enhanced in an economical way by broader distribution of passive samplers. The current global atmospheric passive sampling network, known as GAPS, deploys passive samplers at ~50 global sites including 9 arctic/sub-arctic stations including: Alert, Nunavut; Coral Harbour, Nunavut; Barrow, Alaska; Dyea, Alaska; St. Lawrence Island, Alaska; Little Fox Lake, Yukon; Pallas, Finland; Stórhöfði, Iceland; and Ny-Ålesund, Norway. Co-location of passive samplers with traditional high-volume samplers enhances the interpretation of results obtained from passive samplers. An expansion of the GAPs network to include a greater number of Arctic sites could be one way of improving the spatial and, eventually, temporal resolution of atmospheric POPs monitoring. Development of a passive sampler for mercury would enable a similar expansion of the atmospheric monitoring network for mercury.

An important element of the atmospheric monitoring program for POPs under the NCP is the ongoing screening of air extracts for current use chemicals whose physicochemical properties suggest the potential for long-range transport to the Arctic or where there is evidence for Arctic contamination (e.g. the observation of certain flame retardants in wildlife). The presence of a chemical in Arctic air may be the first indication that a chemical poses a risk to the Arctic environment, and that it should be considered a POP for control under the Stockholm Convention. This activity requires collaboration with scientists that model atmospheric transport based on chemical structure and physicochemical properties. An ongoing challenge is the lack of cold temperature physicochemical property data for new chemicals, particularly those whose chemical structures suggest the potential for long range transport. Air extracts are also screened for chemicals that are first measured in arctic biota.

Monitoring activities should be complemented by research that furthers our understanding of how atmospheric concentrations of pollutants are influenced by environmental processes, and how those processes are being affected by climate change. For example, it is expected that altered sea-ice dynamics, including longer ice-free seasons, will enhance the exchange of pollutants between the ocean and atmosphere, with consequences for interpreting atmospheric trends. This kind of research question is also important for modeling the transport and fate of pollutants. Incorporating the measurement of wet and dry contaminant deposition and evasion (i.e. fluxes) would be a valuable enhancement of existing monitoring programs.

Regularly updated models are important for describing and explaining pollutant distribution and trends, and relating these results to environmental processes and pollutant sources. The ability of models to predict how the environment will react to global emission controls is particularly important for setting emission reduction targets and creating realistic expectations for reducing contaminant levels in the environment. Ongoing support for regional and global pollutant models should be considered an important part of an Arctic observing system for pollutants. Models require data and information generated from other studies in order to accurately simulate contaminant behaviour and environmental processes. An assessment of current modelling data requirements reveals the following gaps:

1. Inadequate spatially-resolved observation data to verify model results;
2. Lack of physicochemical properties of new chemicals which drive transport and intercompartmental exchange;
3. Not enough process research studies (including contaminant interactions with particles, ice and snow, inter-media exchange, environmental transformation and degradation), particularly those related to Arctic conditions, for model parameterization and validation;
4. Lack of ocean and soil inventories for POPs and mercury (within the Arctic and globally) to assess the impact of secondary emissions;
5. Lack of primary emission inventory for most chemicals.

A key recommendation from the first GMP report of the Stockholm Convention on POPs was for an improved understanding of POPs long-range transport and environmental trends, particularly for air, through the use of models and awareness of climate change effects. An enhanced level of understanding is ultimately required to be able to link observations for POPs in air to the effectiveness of international regulation efforts. This same recommendation would also be quite pertinent to mercury.

Marine Ecosystems

The world's oceans, like the atmosphere, have the ability to transport pollutants from source regions to the Arctic via north flowing Pacific and Atlantic currents. The world's oceans also represent an enormous reservoir for persistent pollutants that will remain a secondary source of pollutants to the atmosphere long after global emissions have been eliminated. Ultimately ocean sediments may be the final sink for many of the more persistent pollutants and heavy metals such as mercury.

The Arctic Ocean and marginal seas are home to unique and productive food webs that are highly efficient at accumulating and biomagnifying pollutants. Fat-rich and long-lived species of seals, whales and seabirds, all contain levels of POPs and mercury that approach, and in some cases exceed, threshold levels for toxic effects. Among the most recognisable and most at risk species is the iconic polar bear. Polar bears and other Arctic wildlife are not only under threat from pollutants but are also at risk from the drastic changes occurring in their environment as a result of climate change, e.g. lengthening of ice-free season and loss of multi-year sea-ice.

Sporadic and infrequent measurements of pollutants in seawater have been documented over the past 20 years by both the NCP and AMAP, however, a systematic program to monitor pollutants in seawater is currently lacking. There is a need to establish baseline water column profiles for pollutants throughout the

Arctic Ocean and marginal seas including gateways of entry to the Arctic Ocean, i.e. inflowing Pacific and Atlantic waters. Once baseline conditions have been established, a monitoring programme should be developed that revisits sampling stations on a routine basis and enables the assessment of temporal trends. In addition to routine monitoring of pollutants, the collection of other important oceanographic and atmospheric data will also be essential. Where possible the collection of lower food web samples (phytoplankton and zooplankton) should be carried out at the same time/location. Research opportunities should also be maximized in an effort to improve our understanding of contaminant-related marine processes, including but not limited to: atmospheric exchange; sedimentation and temporal archives in sediment cores; chemical transformations in the water column, including those mediated by microbial communities. Understanding how these processes might be changing is an important overarching research priority.

To date, the establishment of a seawater monitoring program in the Canadian Arctic has been hampered by numerous challenges. The logistics of sampling large amounts of seawater under the ultra-clean conditions required to measure trace levels of pollutants are very difficult and require specialized equipment. Sampling and extraction are usually carried out on board a research ship of which there are few that operate regularly in Arctic waters, and for which operational time is very expensive. To date, scientists that have successfully made measurements of POPs and mercury in seawater have mostly been able to do so on “ships of opportunity”, whereby they generally collaborate on a multidisciplinary program such as ArcticNet and OASIS. This is likely the most practical way in which seawater monitoring could take place, however, it will require very close collaboration with large scale, ship mounted, oceanographic programs in order to ensure that the necessary monitoring data is collected. Another approach may be to mount smaller scale sampling expeditions based out of Arctic communities on small research vessels or on sea-ice. This simpler approach for water sampling may, for example, be feasible for monitoring PFOS in surface waters in accordance with its addition as a tier 2 medium (for PFOS) under the Stockholm Convention’s GMP. Relatively low water sample volumes are required for the detection of PFOS which greatly simplifies sample collection. A community based approach to sea-water monitoring may also have the benefit of being able to re-visit the same sampling locations year after year, which would be difficult to achieve aboard research vessels serving a multitude of scientific interests.

The NCP has a well established program for the annual monitoring of pollutants in marine wildlife, including arctic charr, ringed seals, beluga whales, polar bears, and seabirds. The sampling program, involving the collection of at least 10 individuals of each species from several broadly distributed locations annually, is designed to achieve a statistical objective: detection of a 5% change over a 10-15 year sampling period with a power of 80% and confidence level of 95%. The establishment of monitoring objectives rooted in statistical power is important for assessing the effectiveness of the monitoring program. Similar monitoring programs have been established under AMAP for some marine mammals, fishes and invertebrates. In a recent analysis of temporal datasets carried out for the 2011 AMAP Mercury Assessment, 61 marine time series (15 blue mussels, 12 fishes, 8 polar bear, 6 seabirds, 10 cetaceans (whales), and 10 pinipeds (seals)) were identified that had a minimum of 6 years data with data both before and after 2000. It is unknown at this time how many of these collections have been discontinued. Of the 61 time series analyzed for trends, none were from the Russian Arctic, which represents a substantial spatial gap in circumpolar coverage. The distribution of sample stations for lower trophic level species is limited in both AMAP and the NCP. The incorporation of regular whole food web studies that capture planktons and marine fishes in addition to the more regularly monitored predatory species could help fill this gap.

A large number of factors, or drivers, can influence the temporal trends being measured in biota. These factors may range from changes in the physical environment, e.g. change in sea-ice dynamics, to changes in food web structure and feeding habits of the target species. When it comes to interpreting trend data it is important to understand the processes that contribute to the accumulation of a particular contaminant in the target species and how those processes may have shifted over time and to what effect. For this reason, it is important that research on contaminant-related environmental processes and how they may be changing be carried out in concert with monitoring. Some examples of important ongoing research topics include pollutant transport pathways and processes, chemical degradation and transformation by both physicochemical and biological processes (e.g. mercury methylation/demethylation processes), food web structure and dynamics and biomagnification, atmosphere-ocean exchange and the role of sea-ice, biological effects of pollutants on highly exposed species, and particularly those which may be already stressed due to adverse environmental conditions brought on by climate change, and the toxic implications of exposure to complex contaminant mixtures.

Freshwater Ecosystems

Lake and river systems represent important environmental receptors for airborne long-range pollutants. Atmospherically deposited pollutants accumulate within the lakes and rivers of a given watershed where they are then taken up by the aquatic food web. Predatory fish species, often preferred for human consumption, and fish-eating wildlife regularly contain levels of mercury that are of concern to health authorities and may present a risk to the fish themselves and wildlife that consume them. The river systems that drain large Arctic and sub-Arctic watersheds are also responsible for transporting a substantial amount of pollutants to the Arctic Ocean and marginal seas. While estimates vary, rivers are thought to be responsible for a significant proportion (>10%) of mercury entering the Arctic marine environment.

The NCP currently supports regular (annual) monitoring of landlocked charr, lake trout and burbot from three distinct regions of the Canadian Arctic: Resolute and area, the Mackenzie River valley, and southern Yukon. The statistical goal for this monitoring is the same as described for marine biota, i.e. detection of a 5% change over a 10-15 year period with a power of 80% and confidence level of 95%. Periodic monitoring of other species, including whitefish, northern pike and walleye, has also been carried out. Within the AMAP region similar monitoring programs in Sweden, Greenland and the Faroe Islands, build on long historic datasets for certain species of freshwater fish, including pike and landlocked charr. A recent analysis of temporal datasets carried out by AMAP for the 2011 Mercury assessment, only found 16 time series that met the selection criteria of having at least 6 years worth of data both before and after the year 2000. Of those, 12 were from Canada (NCP). No time series that met the selection criteria were submitted from Alaska or Russia which represents a significant geographic gap in the circumpolar distribution of data. It has been demonstrated that lake ecosystems are very sensitive to airborne pollutants, particularly mercury, which is reflected in fish tissue concentrations. It is therefore important that the few monitoring programs for freshwater fish be continued as well as others which perhaps did not meet the AMAP assessment criteria.

Continued research on pollutants in freshwater ecosystems, including pathways and processes of transport, chemical transformations e.g. mercury methylation, and food web dynamics is needed to help better understand and model how freshwater ecosystems will react to changing global pollutant emissions and climate. Longer ice-free seasons, increased biological activity and shifting hydrological cycles are already influencing lake ecosystems. In some watersheds, the degradation of permafrost and associated landform instability is having a significant impact on downstream water bodies. For the most part the influence that these environmental changes may have on contaminant dynamics in freshwater ecosystems is unknown and needs to be investigated.

Terrestrial Ecosystems

Terrestrial ecosystems receive direct deposition of pollutants from long-range atmospheric transport which sorbs to soils and vegetation from where they can enter into terrestrial food webs. Soil and vegetation can act as efficient repositories for pollutants and can release them back to the atmosphere as a secondary source. However, terrestrial foodwebs are not nearly as efficient at accumulating and biomagnifying pollutants as aquatic foodwebs, and therefore ecosystem and human health risks associated with terrestrial ecosystems are not of great concern.

A wide variety of terrestrial plants and animals were surveyed for POPs, heavy metals and mercury in the 1990s, however, for the most part long term monitoring has not been established. Presently annual monitoring of caribou from two Canadian barren ground caribou herds is carried out under the NCP. Caribou are sampled annually and analyzed for a suite of inorganic elements, including mercury. Persistent organic pollutants are not measured routinely in caribou, though periodic measurements have been made, most recently for current use chemicals such as fluorinated organic compounds. Within the AMAP region the only other regular sampling program for terrestrial wildlife is for reindeer in Sweden. Scandinavian countries also participate in a Europe-wide moss monitoring program under the International Cooperative Program on Effects of Air Pollution on Natural Vegetation and Crops (ICP – Vegetation). This program includes an extensive and geographically complete survey of heavy metals, including mercury, in mosses every five years.

While there may be little concern for ecosystem and human health risks associated with pollutants in terrestrial ecosystems, there may be other reasons why monitoring and research of pollutants are important in these systems. In remote regions, such as the Arctic, terrestrial soils and plants are exposed to long-range pollutants exclusively through atmospheric deposition. Monitoring of various components of terrestrial ecosystems might represent an opportunity for measuring temporal trends in contaminant deposition that is currently under-used.

Arctic soils and plants may also play an important role in global contaminant budgets. Terrestrial ecosystems contain large amounts of organic carbon, to which many pollutants such as POPs are readily sorbed, and which may represent a large reservoir of these pollutants. It has even been suggested that boreal forests could intercept atmospherically transported pollutants on their way to the Arctic. Evasion of these stored pollutants to the atmosphere could act as secondary sources long into the future. Forest fires have also been shown to release pollutants from soils and vegetation. Changes in snow cover, air temperature, and the frequency of forest fires could influence all of these processes in the future. It was recently recommended to the NCP that research into Arctic terrestrial surfaces, including soils, lichens and peat, and the role they play in regional and global mercury cycles, including physical-chemical processes with a focus on fluxes to and from the atmosphere under a variety of climatic conditions represented an important knowledge gap for terrestrial ecosystems.

Human Health

Concern over potential human health risks among northern indigenous peoples (i.e., Inuit and First Nations peoples) due to dietary exposure to persistent organic pollutants and heavy metals such as mercury from the consumption of traditional/country foods was the primary impetus for the creation of the Northern Contaminants Program. Human Health concerns have also been major factors in the creation of international and global agreements on POPs, including the Stockholm Convention, and were also influential in UNEP Negotiations that recently led to the development of a global agreement on mercury. In Canada's North, aboriginal populations and particularly Inuit are exposed to levels of POPs and mercury that

are sometimes of concern to health authorities, although human concentrations of certain contaminants (e.g., legacy POPs) have been decreasing in northern Canada over the past two decades. A prospective longitudinal study on child development carried out among Inuit from Nunavik, Northern Québec, has found that prenatal exposure to pollutants, including mercury and PCBs, were having an adverse effect on immune function and neurodevelopment, while postnatal PCB and lead exposures may cause other neurodevelopment effects. Recent results from Nunavik indicated that prenatal mercury exposure was associated with poorer intellectual function, and poorer attention in the classroom according to the child's teacher. This suggests that prenatal mercury exposure is a risk factor for attention deficit in childhood. Further, heavy metal exposure during the gestational period can impair the development of visual processing.
Research on the human health effects of pollutants and the interactions between complex contaminant mixtures and nutrients in traditional/country foods continues to provide essential information for conducting human health risk assessments. For example, contaminant risk factors may be offset by key nutrients in traditional foods that can protect against adverse effects of environmental exposures, such as marine mammal fats. Other studies have indicated that beneficial nutrients associated with the consumption of traditional country foods (compared with some market foods), are necessary for the maintenance of good overall nutrition and health. The results of on-going risk assessments, along with monitoring, are essential to the development of public health advice for northerners to make informed decisions surrounding exposure to contaminants through a traditional diet, especially when the risk of exposure is high to the individual or the fetus. The risk communication associated with these results, and the partnerships with regional health authorities responsible for health communication, are important aspect of the NCP and should be considered essential elements of any pollutant observation system that has human health implications. The NCP provides critical information to northerners and health authorities related specifically to food safety and food security.

The ultimate goal of global emission reduction strategies is to reduce pollutant exposure among human populations. An observation system designed to monitor human exposure to long-range pollutants that also assesses the dietary and environmental sources of exposure is needed to assess the effectiveness of global action. Under the NCP, Arctic communities, and particularly those where certain contaminant exposures have previously been high (i.e. approaching guideline levels of concern), participate in exposure assessment and human biomonitoring studies roughly every five years. Surveillance carried out during these studies involves the collection of human tissue, such as maternal blood, which is analyzed for a suite of contaminants including POPs and heavy metals, as well as other general health parameters. Dietary and lifestyle questionnaires are also administered coincident with collection of biomonitoring samples to evaluate dietary exposure. Similar studies have been conducted among circumpolar Inuit through cooperative and coordinated studies conducted under AMAP. It is important that these monitoring studies continue on a regular basis. Ongoing monitoring is needed to assess potential human exposure to new chemicals and to assess temporal trends in exposure to pollutants that are already covered by global agreements. Human monitoring remains a core monitoring component of the Stockholm Convention's GMP and will likely become a key component of a future GMP under the new global mercury agreement.

Research and monitoring on human exposure and health risks associated with transboundary pollutants should be linked to related ecosystem-based studies. The relationship between environmental pathways and processes and human dietary exposure is critical for assessing the effectiveness of global agreements such as the GMP of the Stockholm Convention on POPs and the new global agreement for mercury.

Community Engagement in pollutant observing systems: Community Based Monitoring

Arctic communities have a very large stake in the quality of their environment and must be engaged at all levels of any observing system, from design to implementation. The NCP is overseen by a multijurisdictional Management Committee that includes representation from Northern aboriginal organizations on an equal footing with federal, provincial and territorial governments. Through their representation on the Management Committee, Aboriginal organizations are able to influence NCP decisions regarding the design and implementation of the program. Regional Contaminants Committees, established in each of the five northern regions (Yukon, NWT, Nunavut, Nunavik, and Nunatsiavut), bring together regional and community representatives to review and revise regional monitoring and research priorities, review of proposals, and provide advice related to communications capacity building and outreach. Community based reasearchers and organizations are encouraged to lead projects through a specific community-based monitoring and knowledge integration sub-program that promotes the use of traditional knowledge along with western science. Community-based leadership and participation is not limited to this specific subprogram but encouraged in all research and monitoring activities carried out by the NCP. At the most basic level, community-based hunters and fishers provide an essential service to NCP researchers by guiding them safely during field campaigns and through collection of specimens. Increasingly, these community-based experts are being engaged in the interpretation of results, particularly with respect to fish, wildlife and ecosystem processes. Community-based leaders, often in cooperation with regional governments, are also starting to engage the scientific community, including NCP researchers, to address issues of importance to the communities, including those related to transboundary pollution and climate change.

There exists a wealth of opportunity in Arctic communities to carry out enhanced community-based monitoring and research throughout the year. Building capacity in communities to conduct monitoring and research has the potential to expand and enhance Arctic observing systems well beyond what can be achieved by southern based researchers. The establishment of the Canadian High Arctic Research Station (CHARS) in the community of Cambridge Bay, Nunavut, will contribute greatly to establishing a year-round presence for Arctic science and technology in the Arctic. The presence of the station in Cambridge Bay and the implementation of monitoring and research activities through the science and technology program will help to increase the capacity of northern communities to participate in and lead in these activities.

Data Management

The ability of an observing system to influence the development of policies for the protection of the Arctic environment is dependent on how effectively results can be communicated to a diverse audience. The results of monitoring and research must be translated into policy relevant communications materials in a timely manner and tailored specifically for the information needs of a given policy development activity. This requires timely and complete access to monitoring data for the generation of data products, such as up-to-date figures on temporal trends. The experts generating these data products should be able to access the necessary data through a single source, such as a data portal with links to a network of interoperable databases. This network could consist of databases that are managed by a variety of entities, such as governments, international science organizations, or academic institutions according to international standards that ensure interoperability and security of data. Ensuring interoperability between databases is essential and will help to reduce instances of duplication, i.e. the same data stored in multiple databases, and the discrepancies that can arise over time between duplicate datasets. The establishment, coordination, and maintenance of an effective data management system for any Arctic observing network will require a long-term commitment of human and financial resources by participating countries.

The current data management framework for the NCP is being completely overhauled in order to achieve the objectives expressed above. Currently data is archived and managed within the institutions of the main project leads. This has created problems when NCP and AMAP assessment leaders have attempted to compile monitoring data for the purpose of regional and circumpolar trend analysis and assessments. At best, the compilation of data is time consuming, and the format of the data is inconsistent. At worst, data could be withheld or delayed in their delivery as a result of undue control being exercised by individuals reluctant to participate in the assessment process. The management of atmospheric data is an exception, whereby data has been regularly submitted to AMAP's atmospheric thematic data centre at the Norwegian Institute for Air Research (NILU).

AMAP has designated a series of thematic data centres designed to capture monitoring data as part of its open access data policy. These data centres include the AMAP/UNECE-EMEP/OSPAR "ebase" data repository for atmospheric contaminants data, managed by NILU, the USA-UFA Syncon database at the University of Alaska, Fairbanks (UAF) for freshwater and terrestrial ecosystem data, the marine thematic data centre at the International Council for the Exploration of the Sea (ICES), in Copenhagen, Denmark, and the radiation data centre at the Norwegian Radiation Protection Authority (NRPA), Oslo, Norway.

The atmospheric data centre at NILU has been successful at capturing data from air monitoring stations throughout the circumpolar region. This has facilitated the circumpolar analysis of atmospheric monitoring data for assessment purposes. Some data on marine fishes, mostly from the North Atlantic and Bering Sea, has been captured by the marine thematic data centre at ICES, which was used for the generation of trend data in mussels and marine fishes. Much of the monitoring data, however, for marine fishes, mammals and seabirds, as well as freshwater and terrestrial ecosystems, is not being captured in thematic data centres. These data had to be obtained from individual scientists during the most recent circumpolar mercury assessment.

The NCP is currently capturing project metadata on the Polar Data Catalogue (PDC) which is operated out of the Canadian Cryospheric Information Network at the University of Waterloo. A plan is currently being developed to use the PDC for long-term data archiving across many multi-disciplinary programs. So far this has included NCP, Canadian International Polar Year data, ArcticNet, Circumpolar Biodiversity Monitoring Program (CBMP), Beaufort Region Environmental Assessment (BREA), the Nunavut General Monitoring Plan (NGMP) and the NWT Cumulative Impact Monitoring Program (CIMP). The use of the PDC will continue to be expanded.

Sample archiving

A great amount of effort and expense is often invested in the collection of monitoring samples from remote regions of the Arctic. It is therefore particularly important that the use of these samples be optimized in order to extract the greatest amount of information possible. This may include future use of left-over sample material for purposes that are not yet foreseen and possibly by methods that have yet to be developed. In order to use previously collected samples they must have been archived in an appropriate manner that preserves the integrity of the sample as well as the information (data) regarding the samples' heritage.

Archived samples have been used very effectively to assess temporal trends of new chemical pollutants in Arctic biota. Using state of the art analytical methods, NCP and AMAP scientists were able to recreate temporal trends of fluorinated surfactants and brominated flame retardants using exclusively archived samples. These results were instrumental in making the case to have these chemicals added to Stockholm Convention on POPs. Archived samples would also allow for the screening of yet unknown chemicals of concern. The potential uses for archived specimens are not limited to chemical analysis but may include measurement of other biomarkers and genetic material that could reveal important information regarding the health status of the animal from which the sample was collected.

Most of the samples collected during NCP monitoring activities are currently archived by the institutions who host the lead researcher. While this system has worked well to date, there is concern over the long-term sustainability of these archives, particularly as institutional mandates evolve over time (e.g. the closure of Canada's ice core archives). Archiving facilities that house NCP samples do not currently adhere to a uniform standard of practice for specimen banking, which may also limit the usefulness of samples for future measurements of parameters that might be subject to degradation. One exception is the National Wildlife Specimen Bank that is maintained by Environment Canada at the National Wildlife Research Centre in Ottawa, which is a model facility for specimen banking. Specimen banking requires a significant investment in infrastructure and a commitment to future maintenance and management, with strict guidelines and procedures for use of archived materials.

An Arctic observing system for pollutants should establish a network of standardized specimen banks for the preservation of monitoring samples, including existing, new and/or enhanced facilities.

Conclusions

The NCP and AMAP remain as relevant today as they were over 20 years ago when they were first established. They represent two of the very few Arctic science programs in the world with long-term datasets that continue to contribute to the overall knowledge of the Arctic environment and human health. They are also prime examples of how science-based programs with clearly defined objectives can influence and inform policies and decision-making at the community, regional, national and global levels. The Arctic region remains a bellwether for global effects from transboundary pollution and climate change. The continued operation of these programs therefore remains critical to assessing impacts to the Arctic region from global sources of pollution and to evaluating the effectiveness of global pollution agreements.

Background Documents

AMAP, 2003. AMAP Assessment 2002: The influence of global change on contaminant pathways to, within and from the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xi+65 pp

AMAP, 2009. AMAP Assessment 2009: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xiv+256 pp

AMAP, 2009. AMAP Assessment 2009: POPs in the Arctic. Science of the Total Environment 2010, 480, 2851 – 3051

AMAP 2011. AMAP Assessment 2011: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xiv + 193 pp.

Kallenborn R, Reiersen L, Olseng CD. Long-term monitoring of persistent organic pollutants (POPs) in the Arctic: a versatile tool for regulators and environmental studies. Atmospheric Pollution Research. 3 (2012) 485-493.

Donaldson SG, Van Oostdam J, Tikhonov C, Feeley M, Armstrong B, Ayotte P, et al. Environmental contaminants and human health in the Canadian Arctic. Sci Total Environ. 2010;408(22):5165-234.

Van Oostdam J, Donaldson SG, Feeley M, Arnold D, Ayotte P, Bondy G, et al. Human health implications of environmental contaminants in Arctic Canada: A review. Sci Total Environ. 2005;351-352:165-246.

Boucher O, Bastien CH, Saint-Amour D, Dewailly É, Ayotte P, Jacobson JL, et al. Prenatal exposure to methylmercury and PCBs affects distinct stages of information processing: An event-related potential study with Inuit children. Neurotoxicology. 2010;31(4):373-84.

Boucher O, Burden MJ, Muckle G, Saint-Amour D, Ayotte P, Dewailly É, et al. Response inhibition and error monitoring during a visual go/no-go task in Inuit children exposed to lead, polychlorinated biphenyls, and methylmercury. Environ Health Perspect. 2012a;120(4):608-15.

Boucher O, Jacobson SW, Plusquellec P, Dewailly É, Ayotte P, Forget-Dubois N, et al. Prenatal methylmercury, postnatal lead exposure, and evidence of attention deficit/hyperactivity disorder among Inuit children in Arctic Québec. Environ Health Perspect. 2012b;120(10):1456-61

Ethier A-, Muckle G, Bastien C, Dewailly É, Ayotte P, Arfken C, et al. Effects of environmental contaminant exposure on visual brain development: A prospective electrophysiological study in school-aged children. Neurotoxicology. 2012;33(5):1075-85.

Turunen AW, Jula A, Suominen AL, Männistö S, Marniemi J, Kiviranta H, et al. Fish consumption, omega-3 fatty acids, and environmental contaminants in relation to low-grade inflammation and early atherosclerosis. Environ Res. 2013;120:43-54.