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Heavy Metals in the Arctic

Proceedings

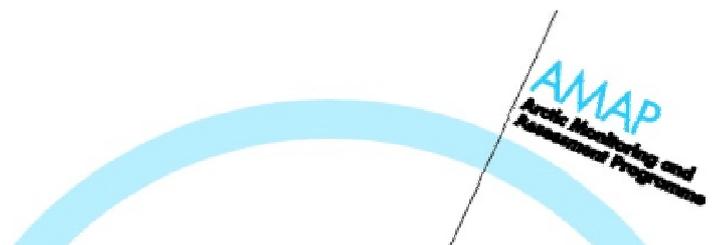
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Arctic Monitoring and Assessment Programme

Lead Country: United States
Sponsored by: U.S. Environmental Protection Agency
Chair: Dr. Suzanne K. M. Marcy



Acknowledgments

The *Heavy Metals in the Arctic* workshop was successful through the combined efforts of many. I want to thank each of the workshop participants for their high quality work and all of the participating Arctic nations for supporting their heavy metals experts in attending the workshop. This report is a reflection of their outstanding work.

I wish to thank Patricia Cochran, Executive Director, Alaska Native Science Commission, for facilitating our opening Talking Circle. I also thank Charles Brower, Director, North Slope Borough Department of Wildlife, for sponsoring the opening reception.

A special thanks to Jozef Pacyna (Norway) for serving as facilitator of the Exposure Group during the workshop and providing a follow-on summary of results. Special thanks also to Birgit Braune (Canada) and Jesse Ford (USA) who facilitated the two Effects Groups during the workshop and summarized results. In addition I thank Doug Dasher (USA) and Jesse Ford (USA) for their assistance as rapporteurs during the workshop and follow-on workshop summaries and editorial assistance, made possible through EPA contracts to the Alaska Department of Environmental Conservation, and Oregon State University. Finally thanks to all who provided comments during the writing of the workshop report.

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Suzanne K. M. Marcy
Editor and Workshop Chair

Executive Summary

In response to the United States commitment to serve as lead country for Heavy Metals under the Arctic Council, Arctic Monitoring and Assessment Program, during September, 1999, the U.S. Environmental Protection Agency sponsored the international workshop *Heavy Metals in the Arctic* in Anchorage, Alaska. The workshop served to bring together US and foreign experts in heavy metals in the areas of both exposure and effect and was convened to:

- Revise and finalize an existing draft of the Heavy Metals plan for AMAP Phase II.
- Introduce a risk assessment framework for ecosystem level assessments
- Build a heavy metals international work team to produce the AMAP Phase II reports.

The workshop was organized to facilitate group process, to provide a common base of understanding and background information on AMAP and risk assessment, and to produce revised research plans for AMAP Phase II on the exposure and effects of heavy metals. The workshop included combined plenary sessions and substantial time for small group discussions. Three break-out groups conducted the work, one on exposure, two on effects. By the end of the workshop, the two effects groups combined their work into one report. The following summarizes results.

Exposure

The “Exposure Group” discussed issues relevant to assessing the status and trends of heavy metal contamination in the Arctic air, water and terrestrial environments. The Group agreed that mercury would serve as the priority metal during AMAP Phase II with a focus on measuring total mercury in the Arctic and its physical and chemical speciation. On air emissions, they concluded that anthropogenic sources and fluxes of Hg and other heavy metals needs to be more accurately listed. Emphasis also needs to be placed on measuring emission rates from natural sources. A significant contributor to the total budget of heavy metals in Arctic air comes from long range transport. This needs to be measured, particularly from sources in Russia and China, two of the largest producers of Hg emissions to air. Changing world conditions will serve as principal drivers of increases in air emissions and should be considered in the future. The Group recommended that AMAP countries coordinate more closely to develop better dispersion modeling tools for assessing the contribution of heavy metals from outside sources.

The Group considered major river systems draining into the Arctic Ocean as sources of dissolved metals and contaminated sediments. To assess these inputs, principal data needs include measuring heavy metal loadings in water, suspended sediments and sediments in major

river drainages. The Group also recommended more accurate quantitative assessments of ocean transport of heavy metals using available information on the volume of water, patterns of ocean currents and heavy metals concentrations in Arctic waters. With ice serving as a medium for transport, a quantitative assessment of heavy metal dispersion with ice, and contamination of water and air was considered important to obtain a total budget of heavy metals in the Arctic. Finally, the Group recognized that animals can accumulate heavy metals in tissues and transport them across the Arctic environment.

To address quality assurance, the Group recommended that more sensitive and reliable methods for measuring concentrations of heavy metals be developed. More inter-comparison of sampling procedures and analytical methods need to be completed, particularly for atmospheric sampling.

Based on these discussions, the Exposure Group proposed a heavy metals research program that would be both sufficient and feasible for implementation with the anticipation that each country will prioritize the proposed program as appropriate for their national monitoring programs. In Sec. 2.5 in the document a full description of the program is provided with tables. A summary of recommendations and changes are as follows. To verify models estimating pollutant transport the Group recommended additions to the AMAP Air Sampling Network to include: Pt. Barrow (US), Alert (CA), Ny Alesund (Norwegian Arctic), Nord (Denmark), Pallas (Finland), Anderma and Ioni Lake (Russia) with additional recommended sites at Pevek and in the Norilsk region (Russia). In the atmospheric subprogram, the need for measuring different forms of mercury were targeted including elemental mercury, divalent mercury in gas phase, and total mercury on particles. Recommendations to the atmospheric media parameters include changing Hg to “essential” for all countries, and considering measures of Cd, Hg, Pb, As, and Se in snow pack as “essential sub-regional.” To assess inputs of heavy metals into the Arctic Ocean from rivers, assessments of Lena, Ob, Yenisey, Pechora, Kolima, Yukon, and rivers in Northern Canada should be included. For the marine abiotic media program, all metals, originally listed under “sediments” were moved to “sediment cores” to facilitate trend studies. Cd was moved to “essential sub-regional,” now consistent with other heavy metals. Under the marine biotic subprogram, changes were made for Beluga whales where Cd is now “essential sub-regional” with recommended measures in liver and kidney; and a further recommendation to add muscle tissue because of the importance of Beluga whales for subsistence. Under the freshwater program, sediment cores were targeted for all metals to facilitate trend analysis. Measures of Hg, Se and Annual Temporal Trends (ATT) are considered “essential sub-regional” for lake trout and pike. Hg in loon chick feathers are proposed as “essential sub-regional.” The terrestrial subprogram included both abiotic and biotic media and parameters. Measures of soil, peat cores, and ice cap cores are considered “essential sub-regional.” Media and parameters for biotic media were changed to include measures of Se in lichens as “essential,” Cd, Hg, and Se in mushrooms is “essential sub-regional,” and measures of Hg in rock ptarmigan liver is “essential” and kidney is “essential sub-regional.” The need to fully integrate the terrestrial program with the atmospheric and freshwater programs was emphasized.

Effects

The principal focus of the Effects Group was to address the assessment of cumulative impacts of Arctic contaminants on biological organisms, particularly sub-lethal effects. The Group discussed the current state of knowledge and data gaps for biological effects and related AMAP activities. Preliminary discussions focused on existing information on sub-lethal biological effects in Arctic organisms. Though information is recognized as limited, each participating expert reviewed available information ongoing in their country, laying the groundwork for producing recommendations for assessing effects and targeting areas of particular concerns. Summaries of these discussions for fish, birds, plants, mammals and others are provided in the proceedings.

One Effects Break-out Group focused on building AMAP Phase II based on ongoing and planned activities, the other Effects Group focused on a long range view for developing a monitoring and assessment strategy. Results from these two groups were then combined and include the following. Species characteristics appropriate for an effects program should include species that are important functional components of a community (e.g., keystone); species that are susceptible (both sensitive and likely to be exposed) to the heavy metal, and species that are logistically amenable to study. Methods considered to be sufficiently developed for determining biological effects included body condition, evidence of lesions, histopathology, and presence of metallothionein, or d-aminolevulinic acid dehydratase indicative of exposure to particular contaminants that result in known effects. Additional methods recognized as potentially powerful given further development include change in immune function, plasma protein profile changes, reproductive parameters, developmental effects and neurotoxicity. To be successful in understanding changes in animal and plant populations from heavy metals exposure, a linkage must be made between known exposures and observed effects. The Group strongly recommended that when a particular animal species is being studied, tissue concentrations should be coupled with previously observed biological effects recorded on the same animal. In addition, both tissue concentration studies and biological effects studies should routinely record age, size, sex, date of collection and reproductive condition to provide a standard set of descriptive information. To address quality assurance and quality control, the Group recommended that AMAP countries join existing inter-comparison studies.

The Group confirmed that the focus for assessing effects of heavy metals during Phase II should be on Hg, Cd, Pb, As, and Se. The Group emphasized that to measure biological effects, contaminant specific endpoints are needed to detect exposure to a specific heavy metal. General measures of effects at the individual, population and community levels of biological organization are also needed to identify cumulative impacts and the combined effects of multiple stressors. The Group recognized a clear need to develop more non-lethal sampling methods that would allow study of threatened and endangered species and fragile Arctic ecosystems.

Based on these results and the immediate needs of AMAP Phase II, the Effects Group generated a draft plan that is represented in Table 3.1 in Sec 3.5. The plan includes terrestrial, freshwater and marine components. Within the terrestrial component, media selected for the program include epiphytes, ground dwelling lichens or bryophytes for the plant community and rock ptarmigan, snow bunting and caribou in the animal community. Grouse were eliminated. In the freshwater environment, algae, stream and lake benthic invertebrates, resident Arctic char, and Pacific or Arctic tern are included. The marine environment media included under-ice algae, blue mussel, Arctic cod, sculpin species, black guillemot or thick billed murre, eider, ringed seal, walrus, beluga whale, pilot whale, and polar bear. The glaucous gull was dropped. For each of these media, specific endpoints are recommended and the rationale provided for selection. The media and endpoints were not given a priority status. General comments relating to this program re-emphasize the need for other important endpoints like behavior, immune function reproductive and developmental parameters, and endpoints at higher levels of biological organization. Traditional knowledge is a potential source of valuable information on observed effects and should be used.

To increase the potential for success in addressing biological effects, the Effects Group recommends moving away from stressor specific effects groups and to establish a cross-cutting group that would evaluate effects that may occur from any or all of the contaminants, including heavy metals. This is likely to be more effective because Arctic organisms are impacted by multiple stressors so observed effects are likely linked to exposure to more than heavy metals, few contaminant specific endpoints are available, and one team can integrate information across contaminants. The group should include marine, freshwater and terrestrial environments.

These recommendations are believed to be incomplete. The proposed plan is intended to inform future biological effects activities within AMAP. It is assumed that each nation will prioritize the proposed plan as appropriate for their national monitoring programs

Next Steps

The *Heavy Metals in the Arctic* international workshop was one event in a continuum of effort to plan, collect data and summarize results of research on exposure and effects of heavy metals in the Arctic. For successful implementation of AMAP Phase II for heavy metals it is important to establish an international Heavy Metals Team comprised of designated key experts from each Arctic nation in exposure and effects. Based on workshop results, follow-on work should include completing a nation by nation inventory of ongoing work relevant to the revised Heavy Metals Plan and identify what research is likely to be implemented over the next three years.

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Introduction

In September, 1998, the United States (US) formally committed to be the lead country for Heavy Metals under the Arctic Council, Arctic Monitoring and Assessment Programme (AMAP). In March, 1999, the U. S. Environmental Protection Agency (EPA) accepted this commitment on behalf of the US. On assuming this role, the immediate concern was to meet the request by the AMAP Secretariat to deliver, by November 1999, a final Heavy Metals Plan for AMAP Phase II. An existing draft plan, generated during the AMAP meeting in Girdwood, Alaska in May 1998, was available to use as the foundation for a final plan. There was no established Heavy Metals Team. EPA opted for an international workshop to bring together US and foreign experts in Heavy Metals, in the areas of both exposure and effects. Despite the short time interval available to organize and run the workshop, six Arctic nations (Canada, Denmark, Finland, Norway, Russian Federation, United States) were represented and 35 experts attended. The US is indebted to the flexibility and dedication of participants. These proceedings represent their work and the final heavy metals plan for AMAP Phase II which was presented to the Assessment Steering Committee and Assessment Working Group in Toronto, Canada in November, 1999 in preparation for the Arctic Council meetings in Washington D.C. the week following. These proceedings provide a fuller discussion on the rationale and process for meeting the needs for monitoring trends and assessing effects of heavy metals under the AMAP Phase II plan.

Workshop Objectives

The workshop “*Heavy Metals in the Arctic*” was convened to meet the following objectives:

- Revise and finalize the existing draft of the Heavy Metals plan that would establish a base Heavy Metals research agenda for Arctic Nations during AMAP Phase II.
- Introduce a risk assessment framework for ecosystem level assessments to improve long term research planning and integration of current work.
- Build a heavy metals international work team to produce the AMAP Phase II reports.

The workshop was organized to facilitate group process through the use of an opening “Talking Circle.” For a common base of understanding, background information on the Arctic Council and AMAP was provided, followed by reports on current research by key experts from each attending country. To introduce ecosystem level risk assessment, the US presented the process as developed for US watersheds. Finally, workshop participants offered views on how to best conduct the work. They elected to work in three break-out groups with separate topics: 1) exposure, 2) effects-current national activities, and 3) effects-long range planning. The Girdwood report was used as the starting framework. This workshop report provides national summaries of heavy metals work, discussions by the break-out groups, and a Heavy Metals Plan for both exposure and effects with recommendations for research.

How to use this document

The workshop proceedings are divided into specific sections to meet the individual interests of different readers. It contains four principal sections:

- **Section 1.0** includes background information, research updates by Arctic nations, and describes the workshop process. It is provided for those interested in reviewing background information and understanding how the work was accomplished.
- **Section 2.0** summarizes discussions by the Exposure group. Section 2.5 provides the updated Heavy Metals plan for AMAP Phase II: Exposure.
- **Section 3.0** summarizes discussions by the Effects groups. Section 3.5 provides the updated Heavy Metals Plan for AMAP Phase II: Effects
- **Section 4.0** includes recommendations and next steps.

Additional information is provided in several appendices including the revised agenda (Appendix A), the list of participants (Appendix B) and highlights from the workshop (Appendix C).

1.0. Workshop Process

The *Heavy Metals in the Arctic* International workshop was convened by Dr. Suzanne Marcy at 2:00 p.m. in the Anchorage Sheraton Hotel, Alaska, on Tuesday, 7 September 1999. Following a formal welcome to all participants and self introductions by each, participants reviewed the Agenda and workshop charge to address the questions: Why are we here, what do we know, what must we know, and how do we best fill the gaps.

The opening day of the workshop focused on team building; learning about each of the participants and their interests in heavy metals in the Arctic. This was begun through the use of the traditional Talking Circle and follow-on reception. The second day focused on: 1) ensuring all participants had sufficient information about the Arctic Council and AMAP to understand the context within which the workshop was convened, and 2) reports of ongoing AMAP related research in different countries. From the afternoon of the second day through the end of the workshop, participants worked in small break-out groups to accomplish the work, coming together to share progress on a regular basis. Throughout, the workshop was designed to encourage open exchange and dialogue and the agenda remained fluid to meet the needs of participants. What follows is a description of each of these major elements of the workshop.

1.1. Traditional Talking Circle

In appreciation of the wisdom of Arctic Native peoples about group process, Patricia Cochran (Inupiat), Executive Director of the Alaska Native Science Commission and a trained facilitator, was invited to lead a traditional Talking Circle with participants on Tuesday afternoon

to open the workshop. Ms. Cochran began by explaining the three rules of Talking Circles (see Text Box 1.1). She then opened the circle with a prayer, formally introduced herself, and passed the talking stone to her left to continue the circle. Each member of the talking circle took the opportunity to make their comments. At the end, Ms. Cochran closed the circle with a prayer.

Members of the Talking Circle were asked to express why work on heavy metals in the Arctic was important to them. This was intended to encourage respect, understanding, early dialogue and a framework for the task ahead. Interests were as diverse as the backgrounds and focus of the participants. Common themes included a long history of appreciation of nature and personal interest in the Arctic. Approximately 30 scientists participated in the circle which lasted for three hours. Based on comments from participants, the process was very successful in introducing the experts to each other and facilitating follow-on work.

Box 1.1 Traditional Talking Circles

The Talking Circle has been used throughout history and has recently gained prominence as a teaching tool, a therapeutic tool and for group development and support. Traditional Talking Circles are conducted by healers, elders or trained facilitators.

They are introduced with the rules of the circle:

- 1. Respect for confidentiality*
- 2. Respect for each person in the circle*
- 3. Each person is given a chance to speak without interruption or comment.*

Individuals in the circle have the freedom to speak or not, and to say whatever they wish to share.

1.2. Overview: Arctic Council and AMAP Phase I

Workshop participants reconvened the morning of day 2 to focus on the context within which the workshop was designed. The Wednesday morning session opened with an overview by Dr. Suzanne Marcy (US) on the Arctic Council, including the Alta Declaration and roles of the five working groups: AMAP, Conservation of Arctic Flora and Fauna (CAFF), Protection of the Marine Environment (PAME), Emergency Prevention, Preparedness and Response (EPPR), and Sustainable Development and Use (SDU). The charge from AMAP was highlighted including the need to reflect new emphasis on assessing effects and measuring spatial and temporal trends, filling data gaps, and solving problems with methodology and quality assurance, quality control. Specifically, the AMAP Secretariat requested an updated Heavy Metals program that establishes

- Parameters to be observed, the media and specific animal tissue to measure and methods for air, sediments, and water;
- Data required for modeling of mercury
- Evaluation of effects, and
- Trend monitoring

The existing Heavy Metals Programme Plan, generated at Girdwood, was briefly summarized. The Plan made recommendations for circumpolar monitoring of heavy metal and trace element concentrations in:

- Atmosphere: air, precipitation, glacial cores
- Terrestrial: peat cores, reindeer
- Freshwater: land-locked Arctic char
- Marine: blue mussels, sculpin, Ringed Seal, Harbor Porpoise, Beluga Whale, Walrus, Polar Bear, Black Guillemot/Alcids, Kittiwake gull, Glaucous gull
- Human: human media.

Dr. Simon Wilson (AMAP Secretariat) followed with additional context information, outlining how heavy metals work fits with work groups addressing other issues (e.g., persistent organic pollutants, climate change, ultraviolet radiation, oil, human health). He emphasized that AMAP focuses on harmonization of existing activities by making small adjustments to national research programs that contribute to AMAP. Phase I of AMAP targeted circumpolar issues such as geographic patterns of contamination and identification of data gaps. During Phase II the focus is on temporal trends, environmental effects and further work on exposure issues. He charged participants to define the process for production of the next report on Heavy Metals due in 2002.

To provide insights on what has been accomplished to date, Dr. Jozef Pacyna (Norway) and Dr. Rune Dietz (Denmark), lead authors for the Heavy Metals chapter in AMAP Phase I, presented their views on data collected and published during Phase I, critical information gaps, and lessons learned from the previous process.

Dr. Jozef Pacyna began by emphasizing that global atmospheric emissions of Hg from anthropogenic sources in the early 1990's were about the same as from natural sources, approximately 1660 tons/year. Work is progressing to identify methods to clean up emissions and to establish policies to promote clean up. An important requirement for success is to establish financial mechanisms to implement emission reduction strategies. The benefit of emissions reductions have been well illustrated by the dramatic declines in lead deposition achieved (i.e., as measured through the moss monitoring network) through the reduced use of leaded gasoline.

Dr. Pacyna then summarized key needs that included better data and modeling of global, local and riverine inputs, and consideration of effects. Although 1995 atmospheric emissions maps should be completed by the end of 1999, additional information is still needed from several critical regions, including Asia, South America, and Africa. Localized sources of atmospheric emissions within the Arctic must also be considered. Using modeled summer seasonal deposition, estimates of deposition can be determined (e.g., in the Kola/Karelia area most Cu and Ni is deposited within 800 km). Anthropogenic sources of heavy metals burdens in the Arctic include riverine inputs that is a major data gap. Significant freshwater sources to the Arctic Ocean

include the Lena, Ob, and Yenisey rivers in the Former Soviet Union, and the Mackenzie River in Canada. In addition to source and exposure information, Dr. Pacyna emphasized the importance of evaluating the risk posed by anthropogenic loads of heavy metals to the Arctic ecosystem, human health, economics and quality of life.

Dr. Rune Dietz went on to emphasize that the ultimate question is the nature and extent of impact of heavy metals on the condition of Arctic ecosystems. A critical step in determining this will be our understanding of spatial patterns. Spatial patterns exist for different heavy metals found within individual species and tissues (e.g., in willow ptarmigan liver and kidney, Cd is highest in western Canada, Hg is highest in central Canada, and Pb is highest in northern Fennoscandia). Spatial patterns differ among tissues within the same species as well (e.g., Cd is highest in polar bear livers in eastern Canada, and Hg is highest in polar bear hair and liver in western Canada). AMAP I provided this type of information (e.g., mercury levels in muscle, liver, and kidney of a different species with associated action levels). Global and local anthropogenic sources of heavy metals are important to consider when looking at spatial patterns of contaminants in target species and tissues. Time series data are also important. For example, information from sediment cores seems to be consistent in finding increases in Hg over the past 100 years. Shorter records from specific animal tissues (e.g., reindeer tissue in Sweden between 1983-1993) show greater variability.

1.3. Reports on Heavy Metals Research by Arctic Nations

Key experts from each of the participating Arctic nations were asked to provide an overview of ongoing research. The following are brief summaries of key points presented by each nation. Sweden and Iceland were unable to send representatives to the workshop and are not included below.

1.3.1. Canada

The Canadian Arctic Contaminants program is driven by human health concerns. The focus is on Hg, Cd, and to some extent Pb, with emerging interest in As and Se. There is reason for concern with respect to Hg. Canadian estimates of Hg fluxes to the Arctic based on lake sediments and snow are similar to those calculated by Pacyna based on emissions. A primary route of delivery may occur in association with excursions of ozone reduction following polar sunrise. Hg appears to be converted from gaseous to particulate form, possibly in association with bromine oxide in sea spray, and is deposited onto the snowpack. Concentrations in lake trout (but not whitefish) are above action levels and health advisories have been issued. Levels are also high in Arctic beluga, where the relationship with Se is strong in all tissues except blubber. The possibility of Hg storage as non-toxic Hg selenides is under investigation for whales. Beluga whales have levels of brain Hg that are lethal to some experimental animals, but only very little of the brain mercury in whales is methyl mercury. Of about 500 communities surveyed for blood Hg,

Arctic coastal communities were found to have higher proportions of people with levels in the “increasing risk” range (20 to 100 parts per billion) compared to people from other communities. Lake sediment core studies suggest that most of the Hg inputs to the Yukon and western Northwest Territories derives from natural sources, whereas in eastern Canada most is anthropogenic. Current cohort studies of children in Northern Quebec are underway, similar to studies being done in the Faroe Islands. Data from beluga whales, arctic-resident marine birds and lake sediment cores all suggest increasing levels of mercury in much of northern Canada.

1.3.2. Denmark

Greenland. Phase II AMAP studies focus on expanding the atmospheric monitoring station at Station Nord, spatial and temporal trend analysis, and human health, especially for central west and central east Greenland. Monitoring and modeling work has been expanded to cover Hg and Cd. Revised sediment core and time trend programs are being implemented for Phase II Essential terrestrial, freshwater, and marine biota. Contaminant screening is underway for various compartments of the Greenland diet, and blood samples are being analyzed for Essential metals in central East Greenland Inuit populations. Stable isotope techniques are being applied to pursue questions raised by differences in contaminant burdens of narwhale, as well as for temporal differences in contaminant burdens among ringed seals. Biological effects studies for Northwest Greenland focus on ringed seals, particularly for Cd. Bone density (jaw and vertebrae) and kidney histopathology studies are in progress. Several additional studies will be pursued if funding becomes available (e.g., Hg in dated Greenland peat bog, contaminant effects on Greenland Sea polar bear, Cd effects in West Greenland ringed seals). Denmark is the AMAP Co-lead (with Canada) for Human Health.

Faroe Islands. AMAP studies in the Faroe Islands began in 1995. Currently the emphasis is on identifying contaminant concentrations, particularly in organisms from the marine environment that are important sources of human food (e.g., pilot whales and fulmars). Primary interests are the effects of Hg and POPs on humans, and of heavy metals and POPs on marine animals. Current studies include investigations of contaminant burdens in pilot whales, fulmar chicks and adults, black guillemots, marine sculpin (*Myoxocephalus scorpius*), landlocked arctic char, hare, as well as sheep and cow milk. A recently completed cohort study of children in the Faroe Islands indicate subtle but significant effects of Hg on a neurological parameter for children exposed in utero and evaluated as toddlers and preschoolers (under 7 years of age).

1.3.3. Finland

AMAP studies in Finland complement existing contributions to numerous regional and national programs, including the ICP-Forest program, Boreal Environment Research Integrated Monitoring Program, the Geochemical Atlas of Finland, and NIVAs Heavy Metal Survey of Northern Lakes. Current projects include a cooperative investigation with the Russian Federation

on the ecogeochemistry of the Barents region, and ongoing operation of several atmospheric monitoring stations. The atmospheric monitoring station at Pallas was established specifically for AMAP. Modeling studies focus on atmospheric Hg, as well as Pb deposition. There is a north-south transect of five lakes in which the biogeochemistry of heavy metals, including Hg, is under investigation. With respect to human health, studies of Cd, Pb, Hg, Se, and Ni in maternal blood are done on a five year schedule; high levels are not seen. Supporting programs determine contaminant burdens in moose and reindeer (liver and muscle). Studies of biological effects focus on wood ants and the common shrew.

1.3.4. Norway

Hg speciation is being studied at Ny Alesund. Depletion of gaseous Hg following polar sunrise is also seen in the Norwegian arctic. There is ongoing work on the survey of global emissions, and on contaminant cycling processes in the Barents and Kara Seas. Current biological studies focus on moving beyond issues of contaminant accumulation to identify species sensitivities and biological effects. Studies in three categories are of interest:

- community/population responses (e.g., benthic communities, fish diseases),
- bioassays (in vivo and/or in vitro), and
- biomarkers (e.g., cytochrome p-450, DNA adducts).

The goal is to be able to understand linkages between accumulation of specific metals, and growth or other health/ecosystem effects in relevant species. To this end, Norway participates in several international programs (e.g., ICES OSPARCOM, ICES WGBEC, BEQUALM) to identify and standardize techniques and associated quality assurance protocols for indicators of biological effects. Techniques for metallothionein induction (MT) and d-aminolevulinic acid dehydratase (ALA-D) are adequate for fish and are being used in Norway to look at effects of discharges from mining and smelting. Other techniques, such as oxidative stress indicators, lysosomal stability (membrane integrity) in fish and mussels, and scope for growth (mussels) are also under investigation. A primary concern is to identify techniques for studying effects, especially higher order effects (neurotoxicology, immunosuppression) of methyl Hg.

1.3.5. Russian Federation

Although there is no formal AMAP program currently in place in the Russian Federation, AMAP is working to identify key regions in the Russian arctic, and is working with RAPON/ICC to put forward a proposal under UNEP Global Environment related to food security for indigenous peoples. AMAP is also working to raise matching fund for UNEP support for long-range transport studies in the Russian arctic. The European Union has recently decided to support a heavy metals emissions inventory for Russia, and work is expected to begin in October 1999.

1.3.6. United States

The U.S. does not have a formal Arctic program, but there are several studies in place that can contribute to AMAP National Implementation Plans. Assessment of atmospheric mercury transport and deposition has begun with implementation of Hg monitoring at Barrow. This program is intended to examine Hg speciation in relation to polar sunrise and ozone depletion. Back trajectory modeling to identify potential Hg source regions is also anticipated. Sediment cores are being analyzed from the Beaufort and Chukchi Seas, the Bering coast, and Cook Inlet to determine long-term trends in heavy metal deposition. Marine mammal studies include analysis of 25 heavy metal/trace elements in fur seals, ringed seals, and beluga, concentrations and biological significance of Ag, Se, and Hg in seals, levels and physiological significance of Cd in walrus kidney and liver, Se effects on hatchability and deformation of seabirds, and food chain transfer of Pb, Hg, Cd, and Se. A study of cord blood has been initiated. A recent competition sponsored by the National Science Foundation has additionally resulted in the funding of more than a dozen Arctic contaminants projects.

1.4. Assessing Risk in the Arctic

The outline for the *Heavy Metals Assessment Report AMAP Phase II* presented to the AMAP working group in March, 1999 was organized to reflect the elements of a heavy metals risk assessment in the Arctic with an emphasis on mercury. It included sources and fate and transport of heavy metals, characterization of system stressors, biological effects (including combined effects issues) and determination of appropriate assessment endpoints to estimate risk. As much as possible, the AMAP Phase II Heavy Metals report will be organized to conceptually link:

- activities and sources to stressors
- stressors to exposure (fate, transport, contact, co-occurrence)
- exposure to adverse effects
- effects to values of concern.

These linkages are possible insofar as research is designed and data collected to address them.

To illustrate the power and challenges of this application at the ecosystem level, Dr. Marcy (US) provided a watershed ecosystem case history and lessons learned summary taken from work conducted in the US in five watersheds across the nation. The principal messages included:

- conceptual models integrate available knowledge into a format that conceptually links activities to effects on human and environmental values, easily understood by diverse audiences;
- the process identifies potential areas of investigation, new scientific questions, data gaps, and in particular, provides a framework for addressing the combined effects of multiple stressors;

- science can be conceptually linked to management concerns and environmental results, making better use of scientific information for decision-making.

1.5. Setting the Course for Break-out Groups

Equipped with available background information, participants prepared for the break out groups on Wednesday afternoon by expressing individual goals for workshop outcomes.

Although input was diverse, central themes were to:

- Build on and refine the current draft Heavy Metals plan generated in Girdwood that many countries are already implementing.
- Refine designs, sites, measures, sampling frequency for data collection for exposure, including that needed for trend analysis and modeling
- Define work on effects including what should be measured, where and which tools
- Address quality assurance and quality control issues.

Based on the expertise available among participants, there was strong interest to break up into topic groups on exposure and effects. Three break-out groups were established that worked independently for the remainder of the workshop, coming together several times to share progress and receive comments from the entire group. The three groups included: 1) Exposure and sources (facilitated by Dr. Jozef Pacyna-Norway); 2) Effects-AMAP Phase II framework (facilitated by Dr. Birgit Braune-Canada) and 3) Effects-long range planning (facilitated by Dr. Jesse Ford-USA). The results of these discussions are provided in Sections 2.0 and 3.0.

1.6. Workshop Closure

Reports by each of the break-out groups occurred on Friday morning and again in the afternoon. During the Friday morning plenary, the newly assigned US Consul General to the Russian Federation, the Honorable Lisbeth Rikken, joined the workshop. Participants took the opportunity to engage Ms. Rikken in an informal discussion about heavy metals research in the Russian Federation. In the afternoon session, results were consolidated into two reports, one for exposure and one for effects. Final assignments were made to summarize results with thanks to Jozef Pacyna for exposure and Jesse Ford for effects.

In closing remarks the Chair expressed a hope that members of the workshop would consider themselves as part of a Heavy Metals Team under AMAP and work in partnership with the US in ensuring that work during AMAP Phase II is successfully reported. With thanks and appreciation for the excellent work completed by workshop participants, the Chair adjourned the meeting at 5:00 p.m. on Friday, September 10, 1999.

2.0. Exposure

The “Exposure Group” (see text box 2.1) discussed issues relevant to assessing the status and trends of heavy metal contamination in the Arctic environment. Based on those discussions, the Group recommended changes to the existing draft AMAP Monitoring and Effects Programme 1998-2003, and produced the Phase II Heavy Metals Plan for Exposure. The Group’s discussion is summarized below and includes their rationale for recommended changes. The specific plan and tables are provided in Section 2.5.

Text Box 2.1. Exposure Group

Steve Brooks (USA)
Maria Dam (Faroe Islands/Denmark)
Doug Dasher (USA)
Sirkka Juntto (Finland)
Steve Lindberg (USA)
Lyle Lockhart (Canada)
Keith Mueller (USA)
Jozef Pacyna (Norway) facilitator
Barbara Reilly (USA)
Andrew Robertson (USA)
Sergey Vlasov (Russian Federation)

2.1. Discussion Focus

The Exposure Group agreed early in the meeting that mercury would serve as the priority metal during AMAP Phase II with a focus on measuring total mercury in the Arctic and its physical and chemical speciation. In light of this decision, the main focus of the Exposure Group during the workshop was to:

- review available information on the sources and pathways of heavy metals based on information generated during AMAP Phase I,
- compare this information with the needs defined at the AMAP Workshop: *Modeling and Sources: Techniques and Associated Uncertainties in Quantifying the Origin and Long Range Transport of Contaminants* held in Bergen, Norway in June, 1999 and
- determine data needs for AMAP Phase II to meet the requirements for mercury, as well as other metals of concern particularly Cd, Se, Pb, and As.

Key topics for discussion included current understanding of the sources and emissions of heavy metals into the air and aquatic environments, and pathways of heavy metals into the Arctic via air masses, water currents and sediments trapped in ice. Additional discussion focused on measurements needed to verify models estimating fate and transport. Quality assurance and data reporting were addressed in relation to these topics. The following provides details and recommendations made by the group.

2.2. Heavy Metals in Air

Heavy metals are released into the atmosphere by both natural and anthropogenic sources. Major anthropogenic sources of atmospheric heavy metals within and outside the Arctic are fairly well recognized. However more must be done to update emission rates, volumes and to generate better estimates of contaminant loads. The group discussed what was needed to assess emissions within and outside the Arctic, and to improve transport modeling and data acquisition.

2.2.1. Air Emissions within the Arctic

Within the Arctic, anthropogenic emission sources and fluxes of Hg and other heavy metals to the air need to be more accurately listed (see Text Box 2.2).

Emissions should be measured as volumes of exhaust gases and heavy metal concentrations within exhaust gases from these sources. More information is needed on emission estimates from local authorities in non-Arctic nations.

At this time anthropogenic sources and fluxes are better understood than natural sources and fluxes, particularly for Hg. More emphasis needs to be placed on measuring emission rates of heavy metals from natural sources such as volcanic eruptions and venting, sea-salt emissions (mostly Se), and re-emissions from aquatic and terrestrial surfaces. Measurements of heavy metals, principally Hg, that re-volatilize from aquatic and terrestrial surfaces in the Arctic, have been started by US, Canadian, and Norwegian scientists.

Text Box 2.2. Key Sources of Emissions

- *Combustion of fuels to produce heat and electricity;*
- *Industrial processes, including exploitation of mineral resources and smelting of ores;*
- *Mobile sources, including urban traffic, sea-going transport, ice breakers, fishing boats, and aircraft;*
- *Sources relating to tourism development, and*
- *Waste disposal, including waste incineration.*

2.2.2. Air Emissions Outside the Arctic

A significant contributor to the total budget of heavy metals in the Arctic region comes from long-range air transport. An accurate estimate of heavy metal emissions from outside sources is key to assessing the relative contribution of long range transport to total loadings.

To help meet this need, the IGBP Global Emission Inventories Activity (GEIA) program and the Norwegian Institute for Air Research (NILU) is working to determine the spatial distribution of heavy metals emissions and generate maps using data on non-Arctic anthropogenic sources from 1995 for Hg. Hg emission inventories will be prepared for elemental Hg and

bivalent Hg in gaseous phase and elemental Hg on particles. Emission maps for other heavy metals, particularly Pb and Cd, will also be updated for 1995. These efforts are expected to be completed by the end of 1999.

Two of the largest producers of Hg emissions to air, however, include China and Russia where data are limited. To estimate outside contributions of heavy metals to the Arctic environment, AMAP should support emission inventories in these two countries.

Another issue discussed was the importance of changing world conditions that could serve as principal drivers of change in air emissions, altering emissions substantially over time. This should perhaps be a focal issue under AMAP in the future (see text box 2.3)

Text Box 2.3. Potential Drivers of Air Emission:

- *Climate change (particularly for Hg)*
- *Changes in industrial and pollution control technologies*
- *Exploitation of Arctic resources*
- *Economic development world wide*

2.2.3. Modeling Atmospheric Transport

Both “dispersion” and “receptor” models have been developed as a way to estimate the extent to which emissions from distant sources contribute to contamination in the Arctic environment. Dispersion models have been principally used to date by Canada, Norway, Sweden, Russia (via the UN ECE European Monitoring and Evaluation Programme-EMEP) and the United States.

The group recommended that AMAP countries coordinate more closely to develop better dispersion modeling tools for assessing the contribution of heavy metals from outside sources. To do this better data are needed to meet the needs of modelers (see text box 2.4)

Receptor modeling may prove useful for determining source apportionment in Arctic air. However, it was felt that a large number of metals would have to be measured to obtain reliable results for model verification.

Text Box 2.4. To Improve Modeling

Data improvements are needed to:

- *generate more accurate emission data and maps*
- *ensure that meteorological data are available to AMAP modelers*
- *allow verification of model results through measures of concentration of metals in air and precipitation and in the use of meteorological parameters.*

2.2.4. Measurements of Heavy Metals in Arctic Air

To verify models estimating pollutant transport from emission sources from within and outside of the Arctic, data from a complement of key locations is needed. The group identified a set of locations that should be part of the AMAP air sampling network (see text box 2.5)

At these sites Hg should be measured in air and precipitation. Specific details on other metals to be sampled, sampling procedures, analytical methods and Hg chemical forms are provided in Section 2.5. AMAP countries are encouraged to take comparable measures at other stations on a voluntary basis.

2.3. Heavy Metals in Water

Very limited information was collected during AMAP Phase I on discharge and transport of heavy metals in water. However, heavy metals can be transported to, and around, the Arctic by several aquatic mechanisms including rivers, ocean currents, ice, and through biological transport. The Group discussed sources, discharges and transport of heavy metals to the Arctic and made recommendations as summarized below.

2.3.1. River Transport of Heavy Metals

The Group recognized the importance of major river systems draining into the Arctic Ocean that may carry dissolved metals and suspended solids contaminated by heavy metals.

The principal need given current knowledge is to gather data on heavy metal loadings in both water, suspended sediments, and sediments in major river drainages as shown in Text Box 2.6. In this work, efforts should be made to distinguish between anthropogenic and natural sources. In addition, assessments are needed that evaluate local impacts of heavy metal loadings in estuaries receiving waters from these rivers.

Text Box 2.5. Additions to the AMAP Air Sampling Network

Planned sites:

- Point Barrow, Alaska
- Alert, Canada
- Ny Alesund, Norwegian Arctic
- Nord, Denmark
- Pallas, Finland
- Anderma, Russia
- Ioni Lake, Russia (Chukotka)

Recommended sites:

- Pevek, Russia (potential)
- Norilsk region (potential)

Text Box 2.6. Major Rivers to Assess for Heavy Metals

- Lena
- Ob
- Yenisey
- Pechora
- Kolima
- Rivers in Northern Canada
- Yukon River System

2.3.2. Ocean Transport of Heavy Metals

Available information on the volume of water, patterns of ocean currents and heavy metal concentrations found in Arctic waters will be useful in evaluating more fully the importance of ocean transport of heavy metals. The Group offered a number of suggestions for improving the data on, and understanding of, this transport mechanism. They recommend:

- more accurate quantitative assessments on heavy metal load transported to the Arctic by ocean currents.
- net budget estimates for heavy metals transported to and from the Arctic via ocean currents,
- coupled atmospheric and oceanic models to assess transport pathways and behavior of heavy metals within the Arctic environment.

2.3.3. Ice Transport of Heavy Metals

Ice serves both as a medium for transport, dispersing heavy metals and other pollutants across the Arctic, providing a source of heavy metals to water and air during melt of heavy metals. It is also a habitat for a number of organisms. These issues need to be considered.

A quantitative assessment of heavy metal dispersion with ice, and contamination of water and air were the most important needs identified by the Group in order to obtain a total budget of heavy metals in the Arctic.

2.3.4. Biological Transport of Heavy Metals

The Group also recognized that animals can accumulate heavy metals in tissues while living in one area, then due to life history characteristics, transport those contaminants to another area within the Arctic environment. Fish, particularly the anadromous salmon, can be regarded as a potential transport medium re-distributing heavy metals in the Arctic. Unfortunately quantitative data on this mechanism of transport are not available. However, this transport mechanism can have significant relevance to local human populations dependent on salmon and other potentially contaminated subsistence resources.

2.4. Quality Assurance and Data Reporting

Quality assurance issues were discussed by the Group which led to a set of recommendations directed toward AMAP researchers. General recommendations are provided below. More specific recommendations are delineated in the AMAP Phase II Heavy Metals Plan found in Section 2.5.

The low concentrations of heavy metals in the Arctic prompts the need for more sensitive and reliable methods for measuring concentrations. The Group recommended that more inter-comparison of sampling procedures and analytical methods be completed to improve the quality of measures. This is particularly important for Hg measurements in air and precipitation samples. The Group specifically targeted researchers conducting work on atmospheric sampling at the locations noted in Section 2.2.5 where inter-comparison of sampling would be valuable. Along with this work, an effort to select standard materials that better reflect conditions in the Arctic is needed.

The Group called for harmonization among AMAP research teams on methods for assessing the age of target species of animals. The Group recommended that specialty workshops be organized to accomplish harmonization and the results be shared with all AMAP research teams.

2.5. AMAP Phase II Plan: Trends and Monitoring for Exposure

The AMAP Heavy Metal Exposure team reviewed the draft document: AMAP Monitoring and Effects Programme 1998-2003 and generated specific program recommendations for media and parameters for the atmospheric, marine, freshwater, terrestrial and human subgroups. The aim was to propose to AMAP countries a program that would be both sufficient and feasible for implementation. It was assumed that AMAP nations would themselves prioritize the proposed program as appropriate for their national monitoring programs.

Below is the AMAP Heavy Metal Trend Monitoring plan with overview tables for media and parameters for different subprograms. A description of each subprogram is followed by a revised table.

The media and parameters specifications in the tables represent the set of measurements from which Arctic countries can select for their respective National Implementation Plans.

The Group focused on monitoring for trends in spatial distribution and historical deposition of heavy metals over time. Data that serve as the foundation for establishing geographical and temporal trends are provided in text box 2.7. The plan is also intended to provide supporting information for assessing the effects of Arctic contamination. The priority metal was mercury.

Text Box 2.7. Key Data for Spatial and Temporal Trend Studies.

Spatial

- *bird tissue*
- *fish livers*
- *sediment cores*

Temporal

- *sediment cores*
- *bird feathers (potentially important- especially black guillemot)*
- *museum mammal skin collections (hair may hold a record over time for Hg)*

2.5.1 Atmospheric Program

Revisions to the atmospheric program included changes in where and how monitoring should occur. Specific methods for data collection were suggested (see text box 2.8).

2.5.1.1. New Monitoring Stations. A critical component of the atmospheric program includes the network of stations monitoring background contamination levels of heavy metals subject to long range transport. The Plan now includes the following set of stations as recommended additions to the AMAP heavy metals sampling network to provide better coverage:

Barrow, Alaska	Alert, Canada
Ny _lesund, Norway	Nord, Denmark
Pallas, Finland	Anderma, Russia
Ioni Lake, Russia (Chukotka)	

2.5.1.2. Mercury Speciation. The level of toxicity of mercury is directly linked to the chemical and physical form contaminating the environment. Thus more than one form of mercury needs to be measured. In the atmosphere, forms of mercury suggested for measurement at monitoring stations include:

- elemental mercury
- divalent mercury in gas phase, and
- total mercury on particles.

Data collected at monitoring stations in the network should selectively measure species of Hg (see Table 2.1)

2.5.1.3. Mercury and Other Heavy Metal Atmospheric Monitoring at Key Arctic Stations. The objective of this subprogram is to estimate atmospheric loading of heavy metals into the Arctic environment. The monitoring program is designed to develop a database that includes continuous time-integrated measurements of heavy metals concentrations in air and precipitation. Data should include total metals and speciated Hg where possible at a series of sites representative of the AMAP Key Areas.

Total gaseous mercury (TGM) should be measured at minimum. It is strongly suggested that some sites include measures of Reactive Gaseous Mercury (RGM). RGM, due to its reactivity and water solubility may strongly influence deposition. Recommended methods for monitoring heavy metals in air and precipitation are provided in Text Box 2.8

Text Box 2.8. Recommended Methods for Air and Precipitation**Mercury**

The Tekran 2537a automated gold trap or manual gold trap methods, both analyzed by C VAFS (Cold Vapor Atomic Fluorescence Spectroscopy) Tekran data should be collected at 15 min. intervals (some sites now sample at 5 min.) while manual traps could be collected on a weekly interval. TGM should be measured year-round. Sample should be collected at a height of 2-4 m above ground away from structures. RGM can be sampled either by automated denuder (Tekran 1130 analyzer) or manual denuder methods, located adjacent to the TGM sample. RGM should be collected on a 2-4 hour interval year round. The most critical time to measure is during polar springtime (polar sunrise to snow melt). Particulate Hg can be sampled using standard filtration methods on 1-7 day interval but a Tekran 1135 automated analyzer will soon be available. Sites that measure RGM should also sample total particulate mercury. Estimated start-up equipment costs (excluding manpower of operation):

Tekran 2537a: US\$ 35,000 Automated TGM analyzer
 Tekran 1130: US\$ 40,000 Automated RGM Denuder System
 Tekran 1135 US\$20,000 Automated Particulate Hg Sampler
 Manual gold trap: US\$ 20,000 Automated Particulate Hg Sampler
 Gold trap analyze: US\$ 7,000 Laboratory CVAFS system
 Manual TPM sampler US\$ 2,000 Filter System
 Manual RGM denuder US\$ 5,000 Quartz Annular Denuder

Other Metals: Cd, Pb, Se, As

Aerosol sampling should be performed for this suite of metals using standard filtration methods. Samples should be collected on a 1-7 day interval for total aerosol. Researchers are encouraged to use size-segregated PM_{2.5} sampling equipment which yields crude separation of fine and coarse size classes. This information would improve modeling of aerosol deposition at these sites. Samplers should be exposed at a height of 1-2 m above ground and

outfitted with contamination-free wired shields made of inert material (e.g., Nipher shield). Collection of falling snow by bulk collectors is highly inefficient in high winds common in Arctic sites. Alternative methods need to be developed.

Precipitation for All Metals

Automated wet-only collectors are preferred, but the remote nature of these sites may preclude such sampling which is widely used in temperate regions. Snow pack and bulk samplers may give acceptable estimates of wet deposition loading under Arctic conditions. Manual collections using glass (Hg) or HDPE (other metals) should be exposed for one week, and may be used for monthly analyses using standard methods (e.g., CVAS for Hg, ICPMS).

Alternatives for Measuring Precipitation

The challenge of measure precipitation, primarily snow, in Arctic locations using conventional methods is problematic. Snow "cores" are offered as an alternative source of data. Two approaches can be taken. Sequential sampling of snow accumulated on an inert surface, monthly, and sampling whole snow cores prior to snow melt during spring-summer transition. Cores should be carefully collected in clean core tubes from replicate sites (min. 5 sites), stored frozen, then carefully melted and analyzed for heavy metals. Deposition is estimated using mean concentrations with independent estimates of precipitation volume.

Meteorological Parameters

Data collection at all sites should include measures of global solar radiation, precipitation, wind speed and direction and air temperature.

Table 2.1

Mercury Speciation Measurement Selection

Compartment	Hg _g ^o	Hg _g [#]	Hg _p ^{TOT}	THg	MeHg
Air	X	X	X		
Precipitation				X	
Sediments				X	
Fish				X	X ^{*1}
Birds					X ^{*1}
Mammals				X	X ^{*1}
Invertebrates				X	X ^{*1}
Plants				X	
Other biota				X	

Hg_g^o elemental mercury in gaseous form

Hg_g[#] bivalent mercury in gaseous form

Hg_p^{TOT} total mercury on particles

THg total mercury

MeHg methyl mercury

*1 relates to measurements at selected sites, e.g. contaminated sites with significant contribution of inorganic mercury

2.5.1.4. Atmospheric Media and Parameters.

Proposed changes to the Atmospheric media parameters are recommended for bulk precipitation and snow pack:

- **Bulk precipitation:** Hg will be regarded as essential for all countries (E), not ES, to enhance understanding of chemistry, behaviour and fate of Hg in the air.
- **Snow pack:** Cd, Hg, Pb, As and Se will be regarded as essential sub-regionally (ES) and not R because of need for more information to assess atmospheric. deposition of heavy metals.

The revised subprogram for atmospheric media parameters are shown in Table 2.2

2.5.2. Marine Program

Inputs of heavy metals from freshwater inputs and sediments are both important for understanding potential contamination in the marine environment.

Table 2.2
Heavy Metal Atmospheric Media and Parameters

Metals	Air/Aerosol	Bulk precipitation	Snow pack
Cd	E	ES	ES
Cu	ES	ES	R
Hg	E	E	ES
Pb	E	ES	ES
Zn	ES	ES	R
Cr	ES	ES	R
Ni	ES	ES	R
As	ES	ES	ES
Se	ES	ES	ES
Al	ES	ES	R
V	ES	ES	R
Annual Temporal Trend (HMs)	E (All Metals)		

E = essential for all countries and key Arctic sites.

ES = essential sub-regionally.

R = recommended.

2.5.2.1. River Input. The Marine Program focus is on monitoring background levels of contamination and identifying key impact areas, such as coastal and shelf areas. The principal recommended change to the plan was to include assessments of inputs of heavy metals to the arctic seas and Arctic ocean from rivers. The following rivers from Russian, Canada and the US were recommended for further assessment:

Russia: Kolima, Lena, Ob, Pechora, Yenisey

US: Yukon River

Canada: Main rivers including those draining into Hudson Bay

2.5.2.2. Marine Abiotic Media and Parameters Recommended changes for abiotic media and parameters were specific to sediment. They included:

- Moving all metals originally listed in “sediments” to the column “sediment cores”. This was done because sediment core data are needed for trend studies.
- Cd is now regarded as essential sub-regionally (ES). There is no justification for regarding Cd differently than other metals.

Table 2.3 provides the revised Marine abiotic subprogram plan.

Table 2.3

Marine (abiotic media) - Heavy Metal Media and Parameters

2.5.2.3. Marine Biotic Media and Parameters. Changes were made in the marine biotic subprogram specifically for Beluga whales where Cd is now regarded as essential sub-regionally (ES). Measurements are recommended on liver (L) and kidney (K), all regarded as ES (L,K). The Group also noted the importance of taking measurements of heavy metals in marine mammal muscle tissues. In particular, Cd and Hg should be proposed essential sub-regionally because of the use of Beluga whales for subsistence. These data should be collected until an adequate set of data is acquired and assessed. Table 2.4 provides the revised subprogram plan for Marine biotic media and parameters.

Metal	Sediment cores
Cd	ES_
Cu	ES ¢
Hg	ES ¢
Pb	ES ¢
Zn	ES ¢
Al	ES ¢
Ag	ES ¢
Annual Temporal Trend (HMs)	ES ¢

E = essential for all countries and key Arctic sites.
 ES = essential sub-regionally.
 R = recommended.
 ¢ Cores should be sampled at intervals of not less than 5 years; in most cases > 10 years.

Recognition of the importance of birds as indicators of trace metal pollution in arctic ecosystems emerged from discussion. Changes were made in the bird species and tissues recommended for sampling in marine, as well as freshwater and terrestrial systems. Although migratory, birds can be used effectively when their life stage at collection is considered. The following points were considered when choosing bird tissues and species for the monitoring and effects programs:

- Tissue: feathers provide a non-invasive sampling tissue that reflects trace metal contamination in an individual. Most arctic birds molt their feathers twice annually, so feathers reflect mercury ingestion since last molt. Feather sampling can allow evaluation of geographic and temporal variations in contamination. Since first replaced feathers will contain higher concentrations, agreement on which feathers to collect are needed in the monitoring program.
- Life stage: a sampling of older nestlings or recently fledged chicks in mid to late summer is recommended since young birds contain contaminants from a known geographic locality.
- Prey and trophic position: a determination of trophic level or principal prey is important for interpreting contaminant levels in avian predators. Species with extended nestling periods that feed chicks individual visible prey are preferred over those where young leave the nest early or are fed regurgitated food.

The above criteria were used during selection of avian species for the monitoring and effects programs.

Table 2.4

Marine (biotic media) - Heavy Metal Media and Parameters

Media	Metal	Blue mussels	Marine sculpin	Arctic cod or Cod	Ringed seal ¥	Harbor porpoise ¥	Beluga ¥	Pilot whale	Walrus	Polar bear ¥	Eider	Black guillemot /Alcids	Glaucous gull ¥
Tissue		Soft tissue	Liver	Liver	(see notes)	(see notes)	(see notes)	(see notes)	(see notes)	(see notes)	(see notes)	(see notes)	(see notes)
	Cd	ES	E		E (L) ES (K)	ES (L)	ES (L,K)	ES (L, K)	ES (L, K)	ES (L)	ES (K)	E (L) ES (K)	ES (L)
	Cu												
	Hg (1)	ES	E		E (L) ES (B)	ES (L)	ES (L, B, BB)	ES (L, B)		ES (L, K, H)		E (L) R(F)	ES(L) R(F)
	Pb	R		R	R (L)								R (L)
	Se		E		E (L) ES (B)	ES (L)	ES (L, B, BB)	ES (L, B)		ES (L, K, B)		E (L)	ES (L)
	Annual Temporal Trend (HMs)	ES	ES		ES (L, K, B)		ES (L)						

(1) – Mercury speciation to be analysed for is described in the Mercury Speciation Table.

E = essential for all countries and key Arctic sites.

ES = essential sub-regionally.

R = recommended.

BB Blubber/blood

BEL Blood/eggs/liver

L Liver

H Hair

FB Fat/blood

EG Eggs

K Kidney

? Tissue undefined

BL Blubber

M Muscle

B Brain

F Feathers

2.5.3. Freshwater Program. While the freshwater program targets the freshwater environment, it must be integrated with the terrestrial and atmospheric programs. The major river

systems discussed in section 2.5.2.1 provide one area of focus. There were several media and parameter changes recommended including:

- Sediments: all metals originally listed under “sediments” were moved to “sediment cores” to provide appropriate data for trend analysis.
- Lake Trout: Hg, Se and Annual Temporal Trends (ATT) are essential sub-regional (ES) to assess the distribution of heavy metals (lake trout do not migrate)
- Pike: Hg, Se and Annual Temporal Trends (ATT) are also considered essential sub-regional (ES) to assess the distribution of heavy metals.
- Loon: loon chick feathers are proposed as essential sub-regional (ES) because of their high freshwater fish diet and mercury can be monitored in feathers.

The revised set of media and parameters is provided in Table 2.5.

Table 2.5
Fresh Water - Heavy Metal Media and Parameters

Media	Metal	Sediment cores	(Land-locked) Arctic char	Burbot	Lake trout	Pike	Loon
Tissue			Muscle	Liver	Muscle	Muscle	Feathers
	Cd	E ¢					
	Cu	E ¢					
	Hg	E ¢	E		ES	ES	ES
	Pb	E ¢					
	Zn	E ¢					
	Cr	E ¢					
	Ni	E ¢					
	As	E ¢					
	Se	E ¢	ES		ES	ES	
	Al	R ¢					
	Fe	R ¢					
	Annual Temporal Trend (HMs)	E ¢	ES			ES	

E = essential for all countries and key Arctic sites.

ES = essential sub-regionally.

R = recommended.

¢ Cores should be sampled at intervals of not less than 5 years; in most cases > 10 years.

¥ Included in POPs program for biological effects monitoring.

2.5.4. Terrestrial Program The integration of the terrestrial program with the atmospheric and freshwater programs is considered essential for the assessment process. The terrestrial media and parameters for **abiotic** media (soil, peat cores and ice cores) are provided in table 2.6.

Table 2.6

Terrestrial (abiotic media) - Media and Parameters

Metals	Soil	Peat cores	Ice cap cores
Cd	ES &	ES ϕ	ES ϕ
Cu	ES &	ES ϕ	ES ϕ
Hg	ES &	ES ϕ	ES ϕ
Pb	ES &	ES ϕ	ES ϕ
Zn	ES &	ES ϕ	ES ϕ
Cr	ES &	ES ϕ	ES ϕ
Ni	ES &	ES ϕ	ES ϕ
As	ES &	ES ϕ	ES ϕ
Se	ES &	ES ϕ	ES ϕ
Annual Temporal Trend (HMs)		ES ϕ	ES ϕ

E = essential for all countries and key Arctic sites.

ES = essential sub-regionally.

R = recommended.

ϕ Cores should be sampled at intervals of not less than 5 years; in most cases > 10 years. & topsoil

Media and parameters for **biotic** media were changed as follows:

- Lichens and mosses: Se should be regarded as essential (E) due to its synergy with Hg.
- Mushrooms: Cd, Hg, and Se is considered essential sub-regional (ES) to account for their consumption by terrestrial animals and humans
- Rock ptarmigan: Hg measurements in liver (L) should be essential (E) and in kidney (K) essential sub-regional (ES). Hg should be measured in the same manner as Cd and Se.

The revised plan for terrestrial media and parameters for biotic media are found in Table 2.7.

Table 2.7

Media and Parameters - Terrestrial (biotic media)

Media	Metals	Lichens & Mosses	Mushrooms	Reindeer/ caribou	Rock ptarmigan / Grouse
Tissue		Whole (L) Green Parts (M)		(see notes)	(see notes)
Heavy metals	Cd	E @	ES@	E (L) ES (K)	E (L) ES (K)
	Hg	E @	ES@	E(L)	E (L) ES (K) R(F)
	Se	E@	ES@	E (L) ES (K)	E (L) ES (K)
	Annual Temporal Trend (HMs)			ES (L) ES (K)	

E = essential for all countries and key Arctic sites.
 ES = essential sub-regionally.
 R = recommended.
 @ As part of food web studies.
 L Liver.
 K Kidney
 F Feathers

3.0. Effects

The “Effects Group” (see text box 3.1) discussed the current state of knowledge about biological effects of heavy metals in the Arctic, recommended changes to the existing draft AMAP Monitoring and Effects Programme 1998-2003, and offered a specific recommendation about how to approach the assessment of effects in the Arctic under AMAP. The Effects Group’s discussion is summarized below and includes their rationale for changes made to generate this AMAP Phase II Heavy Metals Plan for Effects. The specific plan with table 3.1 is provided in Section 3.5.

3.1. Discussion Focus

AMAP Phase I targeted spatial trends of contaminants in the Arctic abiotic and biotic environment. However, the effects of contaminants on individuals and populations of organisms were not addressed. Thus the principal focus of the Effects Group was directed by the “effects” goal of AMAP Phase II: *The assessment of cumulative impacts of arctic contaminants on biological organisms, particularly sub-lethal effects.*

The Group discussed: 1) current state of knowledge and data gaps for biological effects, and 2) current AMAP related activities on biological effects of heavy metals. From these discussions the Group:

- Determined that a consolidated biological effects team would be more effective than several contaminant-specific workgroups for future planning;
- Created a heavy metals plan for biological effects to meet the immediate needs for AMAP Phase II (see Section 3.5) and offered insights for a future strategy.
- Noted several existing QA/QC programs available in which AMAP related programs are encouraged to participate

Text Box 3.1. Biological Effects Group

John Bengston (USA)
Birgit Braune (Canada) facilitator
Wayne Crayton (USA)
Rune Dietz (Denmark)
George Divoky (USA)
Lawrence Duffy (USA)
Jesse Ford (USA) facilitator
Carl Hild (USA)
Ketil Hylland (Norway)
Todd O’Hara (USA)
Suzanne Marcy (USA)
Richard Prentki (USA)
Teri Rowles (USA)
Marianne See (USA)
Lori Verbrugge (USA)
Simon Wilson (AMAP Secretariat)

3.2. Background

The Effects Group recognized previous AMAP related work in biological effects including the 1995 *Workshop on Biological Methods for use in Monitoring of the Arctic Terrestrial Environment* held in Svanvik, Norway, and the 1998 *Combined Effects in the Marine Environment*, held in Copenhagen, Denmark. To target discussions, the Effects Group used the prioritized base program, developed at the 1998 AMAP meeting in Girdwood, Alaska, as a framework for their analysis of heavy metals.

It was agreed by the Effects Group that workshop results would constitute an initial effort to provide recommendations to AMAP regarding biological effects, recognizing the need for additional expert input, particularly from Iceland, Finland, Russia and Sweden, whose experts were not represented in the work group.

3.2.1 Current Knowledge

Available information on sub-lethal biological effects in Arctic organisms is limited for a number of reasons (see text box 3.2). The most readily available information on the effects of heavy metals is at the level of individual tissues.

Based on laboratory studies, observed levels of Cd and Hg in some Arctic marine birds and mammals are high enough to be of concern. However, observable effects in wild animal populations have been a challenge to find. Exceptions exist in heavily contaminated sites such as Minamata, Japan, where acute mercury related effects were seen in human and wildlife populations due to high industrial discharges of mercury.

Difficulties in detecting effects are related to several issues. There is a significant lack of correspondence between laboratory dose-response studies, where responses are linked to known dosing, and field studies where body tissues are analyzed to determine tissue concentrations. Without data relating dose to tissue concentrations, field scientists cannot back calculate exposure from their data. Laboratory scientists could do much by analyzing and reporting tissue concentrations under known dosing regimens. Without such information, the relevance of laboratory data for assessing the biological effects of heavy metals in Arctic wildlife will remain limited.

Text Box 3.2. Limitations on Advancing Knowledge of Effects

- *Sub-lethal biological effects are a challenge to detect in wild populations*
- *Data on sub-lethal biological effects are difficult to collect*
- *Arctic species are not typically included in contaminant effects work*
- *Laboratory studies collect data of limited value for application in the wild.*

Mercury is a contaminant of great potential concern in the Arctic, for which no methods for detecting sub-lethal effects exist. This may be because the principal target is the central nervous system and therefore the earliest effects of Hg are likely behavioral. Behavioral effects are particularly difficult to observe and study, yet can have significant adverse effects on individuals and alter the maintenance of viable animal populations. For example, sub-lethal effects of mercury are believed to have led to the decline of a freshwater (landlocked) population of ringed seal in Finland during the 1960's and 1970's as documented in *AMAP Assessment Report: Arctic Pollution Issues*. It was hypothesized that Hg contamination, and lack of Se to detoxify it, made seals more sensitive to Hg effects and led to premature "still" births among the seals. Such results have important implications for organisms living in, or using Arctic freshwater sources, and upper trophic level predators eating Hg contaminated fish in areas with low Se levels.

3.2.2. Current Activities by AMAP Countries

The Effects Group reviewed available information on current AMAP relevant research ongoing in each Arctic nation to assess how current AMAP activities complement identified needs. This activity laid the groundwork to produce a set of recommendations for assessing effects and to target areas of particular concern. Tables were produced at the meeting as an aid, but the group recognized the limitations of the group composition in their ability to adequately complete them. These tables will be reviewed, revised and presented in future updates.

What follows is a brief summary of the results of this discussion fully recognizing that this is not comprehensive but needs to be distributed to all Arctic nations for modification and embellishment.

3.2.2.1. Fish. Effects in fish from heavy metal contamination are studied in some capacity by all Arctic nations. In the *US*, freshwater fish studies are being conducted to address surface runoff of heavy metals from the Red Dog Mine. Necropsies, histology, and some biochemical endpoint measures are being undertaken for marine fish from other areas. In Prince William Sound, herring are being collected to evaluate the long term effects of oil exposure. The work involves gross body and histologic assessments. *Canada* is incorporating traditional knowledge in their study of gross abnormalities in freshwater fish. *Greenland, Sweden, Iceland, Faroe Islands*, and *Canada* are working toward implementing the "Global Sculpin Program." In *Sweden* and *Iceland* this includes CYP1A, antioxidants, and GST as markers. *Norway* is measuring metallothionein (MT) in freshwater trout in waters containing mining discharges. Arctic char are assessed for CYP1A and other CYPs. In flounder and Atlantic cod, MT and d-aminolevulinic acid dehydratase (ALA-D), CYP1A, and gross pathology are being assessed. *Russia* is assessing fish in Arctic rivers and lakes, measuring gross and histologic characteristics in association with POPs, PAHs, and HM.

3.2.2.2. Birds. The *US* is conducting research on marine birds, principally eiders. Research on Spectacled eiders includes blood work (i.e., element levels and biomarkers), radiography, pathology, and telemetry. The major concern is Pb from lead shot. King eiders are being evaluated using necropsy, pathology, histology, and telemetry for Pb and Cd effects. Steller's eiders are being monitored for population status (blood, biochemistry, necropsy). Studies of black guillemots have been proposed for Hg temporal trends and effects, but are not currently funded. *Canada* is also working with King and common eiders to look for effects from Cd exposure using immunotoxicology, histopathology, endocrine, and nutritional studies; telemetry studies are proposed. *Russia*, in collaboration with others, is working on marine birds in association with Murmansk Biological Institute. *Norway* is assessing marine seabirds for CYP1A, and non-Arctic ptarmigan for MT and histopathology.

3.2.2.3. Plants. Very little could be identified for plants. In *Russia*, the Norilsk Far North Agricultural Institute has evaluated the effects of the Norilsk industrial plume on exposed lichens and mosses. Researchers at the Komorov Institute in St. Petersburg have decades of research in heavy metal effects on plant communities, particularly on the Kola Peninsula.

3.2.2.4. Mammals. Most ongoing research on effects is being conducted on terrestrial and marine mammals.

Terrestrial: In the *US*, mortality of caribou and moose is being investigated using gross and histologic assessment and pathology. In Prince William Sound, river otters are being assessed to address the long term effects of oil. *Canada* is evaluating Hg speciation and population status in river otter and mink of southern non-Arctic Canada. Traditional Ecological Knowledge on caribou is being coupled with the assessment of gross and histologic parameters. Moose are being studied for skeletal lesions related to Cd in northern Manitoba. In *Greenland* and *Denmark* an assessment of caribou health status, feeding, and heavy metal concentrations in target organs is underway. In *Russia*, the Veterinary Institute in Moscow has work on heavy metals and POPs effects in progress.

Marine: In the *US*, work on marine mammals is driven by concerns about POPs and methyl mercury. Research is being conducted independently by multiple agencies. Harbor seal tissues are being archived with data on body condition. Steller sea lions are being monitored for general health, POPs contamination, and nutritional status. Northern fur seals are being examined for effects related to POP's concentrations. Ringed seals, walrus, beluga and bowhead whales, and polar bear are being necropsied with histology work-ups for many metals. Work with Beluga whales focuses on the distribution of metals in tissues. Proposed work will include immune system effects. Beluga whales are also being studied for Ag-Se-Hg interactions. Bowhead whales have been monitored since the 1980's for metals. Cadmium is a particular concern and is being investigated using histology, cell culture and MT (including in vitro HM challenges). POPs

analyses and body condition in gray whales is underway. Harbor porpoise will be addressed as part of the IWC Pollution 2000+ cooperative project. **Canada** has an extensive effects program for beluga whales that includes immune status, gross assessment and histopathology, retinal electron microscopy, detoxification mechanisms for Hg-Se in liver and brain, blood, and speciation of Hg in blood, brain, spinal cord and liver. Gross anatomy and examination of bowhead whale, walrus, bearded seal, and narwhal, while not an effects assessment, may be valuable. A POPs assessment of endocrine, nutritional, immuno histopathology effects is in progress for polar bear. Ringed seal work in **Greenland** is addressing renal histopathology, skeletal density and quality. Energy and telemetry studies are being conducted on walrus. Pilot whale renal histopathology and possibly mercury work is underway. In **Denmark**, harbor porpoise are being studied through IWC Pollution 2000+. Data include blood chemistries, telemetry, and general health information on captive animals. Polar bear pathology related to body burdens of POPs and metals is being coupled with traditional knowledge (gross signs) of change such as abnormal asymmetries, different bone densities, and examination of historic samples for effects such as lesions. The Veterinary Institute in Moscow is one principal focus for marine mammal work in **Russia**. **Norway** is conducting nutritional, retinol, CYP1A, immune function, and reproduction and recruitment studies in polar bears; ringed seal studies include analysis of CYPs.

3.2.2.5. Other. Other relevant studies are underway that could provide useful data. **Greenland** is investigating lead toxicity on kelp and invertebrates (e.g., Black Angel Mine). **Norway** implemented a mussel monitoring program using MT related to mine discharges. **Finland** is conducting acidification research that includes metal mobilization studies and possible effects on vegetation, soil microorganisms, and stream fish. **Germany** is studying the effects of heavy metals on zooplankton.

3.3. Strategy for Assessing Biological Effects

Current knowledge and ongoing and planned studies described above likely represents the principal content of the next AMAP Phase II report on the effects of heavy metals. However, the Effects group also took a long range view for developing a monitoring and assessment strategy. The proposal that follows provides a more broad-based look at the kinds of work that would be required for a long range program plan

The Effects group used as a framework, the list of species developed at the 1998 AMAP Working Group meeting in Girdwood AK. It was agreed, however, that proper development of a Biological Effects program would also include other endpoints (e.g., changes in individual, population and community characteristics). Under-ice algae was identified as a key component of the marine food web and other AMAP working groups (climate change/UV-B) may already be

studying this algae. The potential value of Traditional Ecological Knowledge in biological effects work was noted, and ongoing work in this area was identified by Denmark, Canada, and US.

3.3.1. Biological Effects Endpoints

The Heavy Metals table from the 1998 Girdwood meeting contained two principal gaps: the absence of any terrestrial predators and insufficient focus on freshwater environments. Keeping this in mind, the Group developed preliminary recommendations for biological effects endpoints to be considered for implementation within AMAP. Wherever possible, recommendations were linked to the 1998 AMAP Working Group list. Based on review and discussion, some species were added and some dropped. However this revisiting of target species was not definitive.

Suggestions in this report should be reviewed by an AMAP Biological Effects group, along with other relevant documents to generate more refined recommendations.

The Effects group noted with approval that species on the Girdwood list covered a diversity of habitats (e.g., arctic cod (*Boreogadus*), and targeted sculpin species (*Myoxocephalus*) from offshore vs. near shore environments. However, some species listed may not be sufficiently important to community function, may not be susceptible to contaminant loads, or may be logistically too challenging to collect and monitor. Consideration of these variables during species selection for a Biological Effects program would increase the power of detecting biological effects (see text box 3.3).

Text Box 3.3. Species Characteristics Appropriate for an Effects Program

- *Species that are important functional components of a community (e.g., Keystone)*
- *Species that are susceptible to the heavy metal (sensitive and likely to be exposed)*
- *Species that are logistically amenable to study (can be found, obtained, used).*

Text Box 3.4. Methods Ready for Use in Detecting Biological Effects

- *Body condition (e.g., mass to body size ratios, weight and fat indices for condition in mammals; condition metrics, weight to length ratios, caloric value, and proximate analysis for fish; condition metrics that include size (mass and length of wing cord, culmen, and tarsus), plumage (breeding and non-breeding; stage of molt), subcutaneous and visceral fat, and breeding condition (size of testes or ovaries, largest follicle diameter in birds.)*
- *Lesions*
- *Metallothionein (MT) involved in Cu and Zn metabolism; binds Cr, Zn, Cd, Ag, and Hg; reduces Cd toxicity (and possibly Ag and Hg toxicity)*
- *d-aminolevulinic acid dehydratase (ALA-D): a step in heme synthesis inhibited by Pb which can lead to anemia in birds and mammals*
- *Histopathology: gross morphological change, indicator of enzyme and immunological disease or compromise (e.g., cancer)*

3.3.2. Methods

Several methods for determining biological effects were considered to be at a satisfactory stage of development for implementation in Biological Effects monitoring for AMAP. Those are provided in Text Box 3.4. They include both physiological indicators of exposure to particular metals, and changes in body morphology and incidence of disease that may be linked to heavy metals exposure.

Several other methods for assessing biological effects were regarded as promising and potentially applicable. These include:

- Heme oxygenase
- Porphyrin profiles that correlate Hg contaminant levels in wild birds and mammals with laboratory studies

Additional methods were recognized as potentially powerful, but implementation and interpretation would require further work. These include:

- Change in immune function including IgG relative to contaminant loadings and nutrition in deer and birds
- Plasma protein profile changes relative to contaminant levels in mammals and birds
- reproductive parameters
- developmental effects
- neurotoxicity
- behavior change

3.3.3. Establishing Cause and Effect

In order to link changes in animal and plant populations to heavy metals exposure, a linkage must be made between known exposures, to observed changes (see text box 3.5). The Effects group strongly recommends that when a particular animal species is being studied, both tissue concentrations and observed biological effects be recorded on the same animal.

Text Box 3.5. Hills Criteria for Evaluating Causal Associations

- *Strength: A high magnitude of effect is associated with exposure to the stressor*
- *Consistency: The association is repeatedly observed under different circumstances*
- *Specificity: The effect is diagnostic of a stressor*
- *Temporality: The stressor precedes the effect in time*
- *Presence of a biological gradient: A positive correlation between the stressor and response*
- *A plausible mechanism of action*
- *Coherence: The hypothesis does not conflict with knowledge of natural history and biology*
- *Experimental evidence*
- *Analogy: similar stressors cause similar responses*

Not all of these criteria must be satisfied but each incrementally reinforces evidence for causality. Negative evidence does not rule out causal association but may indicate incomplete knowledge of the relationship (Rothman, 1986)

Thus, animals used for tissue concentration studies should, wherever possible, first be examined for indications of biological effects. In addition, both tissue concentration studies and biological effects studies should routinely record age, size, sex, date of collection, and reproductive condition to provide a standard set of descriptive information.

Establishing a cause and effect relationship is challenging in natural populations subjected to multiple stressors. Field and laboratory studies used together to investigate effects are needed as well as the linkage of exposure and effects data described above. Many of the concepts used in human epidemiology can be valuable for evaluating causality in observational field studies. Hill (1965) suggested nine criteria (see text box 3.5)

3.3.4. Quality Assurance and Quality Control

There is a need for good quality assurance (QA) and quality control (QC) to meet requirements for AMAP Phase II. International intercalibration studies and robust internal QA/QC within countries are both needed. AMAP countries are strongly encouraged to join existing inter-comparison studies.

QA/QC programs for contaminant concentrations include the Archive program sponsored by the US National Oceanic and Atmospheric Administration, to which many AMAP programs subscribe. In cases where no existing standard material is available (e.g., for field levels of specific contaminants in specific tissue types), AMAP should encourage development of such reference materials, perhaps by providing some of the initial funding.

For Biological Effects QA/QC, the European Union's Biological Effects Quality Assurance in Marine Monitoring (BEQUALM) program was suggested. Information about this program can be found at the URL <http://www.cefas.co.uk/bequalm/>. It is open to AMAP countries, and participation is encouraged. Within the BEQUALM program there are methods in place to evaluate (see Text Box 3.6).

Text Box 3.6. BEQUALM Methods

- *Bioassays (water, sediment: UK)*
- *MT, ALA-D (fish: Norway)*
- *CYP1A/EROD (fish: Scotland (UK) & Sweden)*
- *Imposex/intersex (gastropods: Scotland (UK) & Sweden)*
- *Reproduction (fish: Sweden)*
- *Histopathology (fish: UK)*
- *Benthic community (Denmark)*
- *Algal assemblage/productivity (Germany)*
- *DNA adducts (fish: Sweden)*
- *Lysosomal stability (mussels: UK)*

3.4. Program Recommendations

The Effects Group generated several recommendations as part of their results. These supplement the AMAP Phase II Effects Plan in Sec. 3.5.

3.4.1. Recommendation: Combined Biological Effects Work Group

Among the most important conclusions reached by the Effects Group at the workshop was that an Effects group working on individual classes of contaminants would be less effective than one group working on effects for all contaminants under AMAP. While some biological effects can be clearly linked to individual contaminants, many biological endpoints are less specific. Arctic organisms are impacted by multiple stressors, thus effects observed will typically be the result of combined stressors. Based on this, the Effects Group recommends a crosscutting AMAP Biological Effects Group (see text box 3.7).

Text Box 3.7. Rationale for a Single Biological Effects Group for AMAP

- *Arctic organisms are impacted by multiple stressors and will show combined effects*
- *A combined biological effects group will focus on detecting effects rather than being contaminant driven.*
- *Few contaminant specific endpoints are available*
- *A combined biological effects team that integrates information across contaminant workgroups would be more effective and efficient.*

The AMAP Biological Effects Work Group should include marine, terrestrial and freshwater environments. Their work would provide a follow-on to the AMAP workshop on *Combined Effects* and an anticipated report for the marine environment as part of its co-sponsored work with ICES and the EU.

3.4.2. Addressing Effects of Heavy Metals: Meeting Current Needs

To address immediate concerns for meeting the needs of AMAP Phase II, the Effects Groups generated a table that delineates specific species, tissues and endpoints to establish a “working” effects plan that is presented in Section 3.5. The rationale for specific changes made in the plan are included there. For the purposes of generating that plan, the Effects group targeted five metals, recommended the need for contaminant specific and non-specific endpoints (see text box 3.4 for

Text Box 3.8. Program Recommendations for Effects from Heavy Metals

- *Target metals: Hg, Cd, Pb, As, Se*
- *Include both contaminant specific and general biological endpoints*
- *Develop non-lethal sampling methods for biological endpoints*

examples of measures currently available) and emphasized the need for non-lethal sampling methods to improve data collection opportunities

3.4.2.1. Target Metals. During initial review, the Effects Group confirmed that the focus for detecting biological effects in AMAP Phase II should be on mercury (Hg), cadmium (Cd), lead (Pb), arsenic (As) and selenium (Se). These are believed to be the elements most likely to be producing biological effects in the Arctic.

3.4.2.2. Contaminant Specific and General Endpoints. Biological effects endpoints need to include both contaminant specific endpoints (i.e. in this case those effects directly attributable to exposure to a specific heavy metal) and more general measures of effect at the individual, population and community level of biological organization (see text box 3.9). Contaminant specific endpoints provide a way to evaluate the potential cause for observed changes. More general endpoints are more effective in identifying the combined effects of multiple stressors and cumulative impacts.

Text Box 3.9. Potential Biological Effects Endpoints (General)

- **Community composition** (e.g., of algae, benthic invertebrates, lichens)
- **Population parameters** (e.g., age structure, population growth)
- **Individual endpoints** (e.g., foraging, predator avoidance, mating and other behavior, reproductive, endocrine and immune function, biomarkers, bioassays.

3.4.2.3. Non-lethal Sampling Methods. There is a clear need for the development of non-lethal sampling methods to assess contaminant effects in Arctic plant and animal populations. Many species are locally or regionally threatened or endangered and cannot, or should not, be sampled by lethal methods. Arctic ecosystems are fragile and once disturbed are slow to recover.

3.5. AMAP Phase II Plan

The Effects group combined results of the two break-out groups in recognition that there are ongoing studies that will form the bulk of the AMAP Phase II report on effects, and the need for a better strategy for assessing effects of Heavy Metals and other stressors. The draft plan generated at the workshop is best represented by Table 3.1. Table 3.1 includes specific changes made to the AMAP Phase II Trends and Monitoring 1998-2003 plan, and additions. The rationale for each change, addition and target species is included in the table for easy reference.

The Biological Effects Group considers the plan represented in Table 3.1 incomplete and would benefit from further discussion. Some specific topics for discussion include the following:

- Consideration of other important endpoints such as behavior, immune function, reproductive parameters, developmental effects, and neurotoxicity. These approaches need further evaluation and/or development.
- Endpoints at higher levels of biological organization including population (e.g., age structure), community (e.g., species composition/relative abundance), and ecosystem (e.g., energy flow, nutrient cycling) also need to be explored.
- Traditional knowledge and wisdom is a potential source of information for many if not most of the media listed in Table 3.1

The following recommendations are intended to inform future Biological Effects activities within AMAP. It is assumed that AMAP nations will prioritize the proposed program and add to it as appropriate for their national monitoring programs.

Table 3.1

Suggested Biological Effects Endpoints			
Program	Media	Endpoints	Rationale
Terrestrial	LICHENS AND MOSSES		
	epiphytes (where present)	Spp. composition, relative abundance, vitality of 3-5 selected common macrolichens	from 1995 AMAP Svanvik recommendations
		Growth rate (1-2 common spp), chlorophyll content (1-2 common spp), electrolyte leakage (1-2 common spp), fertility?	from 1995 AMAP Svanvik recommendations
	ground dwelling lichens or ground dwelling bryophytes	Spp. composition, relative abundance, vitality of 3-5 selected common macrolichens	from 1995 AMAP Svanvik recommendations
		Growth rate (1-2 common spp), chlorophyll content (1-2 common spp), electrolyte leakage (1-2 common spp), fertility?	from 1995 AMAP Svanvik recommendatio

Suggested Biological Effects Endpoints			
Program	Media	Endpoints	Rationale
Terrestrial	ROCK PTARMIGAN	Chick wing length/body mass, kidney histopathology, ALA-D in blood, MT; Condition: body mass, age, sex, season/stage of molt, breeding condition (if breeding, size of testes/largest follicle), length of wing cord, culmen and tarsus, subcut. and visc. fat	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Terrestrial	SNOW BUNTING	Chick wing length/body mass, kidney histopathology, ALA-D in blood, MT; Condition: body mass, age, sex, season/stage of molt, breeding condition (if breeding, size of testes/largest follicle), length of wing cord, culmen and tarsus, subcut. and visc. fat	Terrestrial insectivore (higher trophic status); is a cavity nester and could be attracted to artificial nests; methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Terrestrial	CARIBOU	Gross morphology, organ integrity, fat content, kidney histopathology, ALA-D in blood, MT; Condition factors: size, age, sex, season, reproductive condition, weight and fat condition indices	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Terrestrial	Drop: Grouse		Rock ptarmigan better choice
Freshwater	ALGAE	Community composition	Demonstrated (non-specific) technique; possible early warning signal
Freshwater	BENTHIC INVERTEBRATES (STREAMS)	Community composition	Demonstrated (non-specific) technique; possible early warning signal
Freshwater	BENTHIC INVERTEBRATES (LAKES: BIVALVES, GASTROPODS)	MT, membrane stability (blood), scope for growth (mussels)	Important food web component

Suggested Biological Effects Endpoints			
Program	Media	Endpoints	Rationale
Freshwater	(Resident) ARCTIC CHAR	MT, ALA-D (blood), standard condition factors (wt/length, caloric value, proximate analysis)	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Freshwater	PACIFIC LOON or ARCTIC TERN	Chick wing length/body mass, kidney histopathology, ALA-D in blood, MT; Condition: body mass, age, sex, season/stage of molt, breeding condition (if breeding, size of testes/largest follicle), length of wing cord, culmen and tarsus, subcut. and visc. fat	Both species are important food web component (piscivore), BUT study of Pacific loon may be constrained by logistic and/or (in some countries) conservation issues; Arctic terns take smaller fish than Pacific loon so may not bioaccumulate to same extent.
		porphyrins, heme-oxygenase	Methods development needed
Marine	UNDER-ICE ALGAE	Composition/productivity	Keystone food web component
Marine	BLUE MUSSEL	MT, membrane stability, scope for growth	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
Marine	ARCTIC COD (<i>Boreogadus</i>)	MT, ALA-D (blood), standard condition factors (wt/length, caloric value, proximate analysis)	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of
		porphyrins, heme-oxygenase	Methods development needed
Marine	SCULPIN SPP (<i>Myoxocephalus spp</i>)	MT, ALA-D (blood), standard condition factors (wt/length, caloric value, proximate analysis)	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed

Suggested Biological Effects Endpoints			
Program	Media	Endpoints	Rationale
Marine	BLACK GUILLEMOT or THICK BILLED MURRE	Chick wing length/body mass, kidney histopathology, ALA-D in blood, MT; Condition: body mass, age, sex, season/stage of molt, breeding condition (if breeding, size of testes/largest follicle), length of wing cord, culmen and tarsus, subcut. and visc. fat	Black guillemot recommended for study of contaminant levels (1998 AMAP Girdwood workshop) but thick-billed murre may be more abundant/easier to study; methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Marine	EIDER	Chick wing length/body mass, kidney histopathology, ALA-D in blood, MT; Condition: body mass, age, sex, season/stage of molt, breeding condition (if breeding, size of testes/largest follicle), length of wing cord, culmen and tarsus, subcut. and visc. fat	Species recommended for study of contaminant levels (1998 AMAP Girdwood workshop) but integrates both marine and freshwater environments; perhaps most suitable to ID potential (local) Pb shot problems; methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Marine	RINGED SEAL	Gross morphology, organ integrity, fat content, kidney histopathology, ALA-D in blood, MT; Condition factors: size, age, sex, season, reproductive condition, weight and fat condition indices	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Marine	WALRUS	Gross morphology, organ integrity, fat content, kidney histopathology, ALA-D in blood, MT; Condition factors: size, age, sex, season, reproductive condition, weight and fat condition indices	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed

Suggested Biological Effects Endpoints			
Program	Media	Endpoints	Rationale
Marine	BELUGA	Gross morphology, organ integrity, fat content, kidney histopathology, ALA-D in blood, MT; Condition factors: size, age, sex, season, reproductive condition, weight and fat condition indices	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Marine	PILOT WHALE	Gross morphology, organ integrity, fat content, kidney histopathology, ALA-D in blood, MT; Condition factors: size, age, sex, season, reproductive condition, weight and fat condition indices	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Marine	POLAR BEAR	Gross morphology, organ integrity, fat content, kidney histopathology, ALA-D in blood, MT; Condition factors: size, age, sex, season, reproductive condition, weight and fat condition indices	Species already recommended for study of contaminant levels (1998 AMAP Girdwood workshop); methods are at an appropriate stage of development
		porphyrins, heme-oxygenase	Methods development needed
Marine	Drop: Glaucous gull		Scavenger
Marine	Drop: Harbour porpoise		Not necessary
KEY		MT = metallothionein; ALA-D = d-aminolevulinic acid dehydratase	

4.0. Heavy Metals: Next Steps

The *Heavy Metals in the Arctic* International Workshop was an event on a continuum of effort to plan, collect data and summarize results of research on the exposure and effects of heavy metals in the Arctic. The revised exposure and effects plans in these proceedings will provide Arctic nations a framework for prioritizing heavy metals research in the future and basis for fitting past and current work within the international plan.

For successful implementation, this workshop event must be followed by others that involve all Arctic nations. There are currently three principal actions identified that will help ensure success for AMAP Phase II Heavy Metals:

- Establish an international Heavy Metals Team comprised of designated key experts from each Arctic nation.
- Complete the nation by nation inventory of ongoing work relevant to the revised Heavy Metals plan
- Identify what heavy metals work will be implemented over the next three years by each Arctic nation.

As an ongoing need, the Heavy Metals team will be looking for opportunities to further develop methods, monitoring sites and measures of effects.

4.1. Heavy Metals Team

A Heavy Metals Team is needed with members to coordinate work within each Arctic country and, as a team, provide the international perspective necessary for AMAP work. As lead country, the US will provide expertise and team management. However, for success in Phase II, anticipated needs from other nations include:

- Designated heavy metals experts from each Arctic nation, preferably one in exposure and one in effects
- Travel to a Heavy Metals meeting once per year; drafting subgroups meeting two additional times per year (time and travel expenses provided by each country for their experts)
- Commitment of approximately 10-15% time specifically for AMAP work on heavy metals to conduct data analysis, develop models and produce interim reports by designated experts.
- Occasional intense work to complete specific tasks for meeting AMAP reporting deadlines

Key experts who participated in the *Heavy Metals in the Arctic* workshop will be contacted to determine their interest and ability to participate in the future. Some have already expressed interest, and the need for within country financial support. For a successful AMAP Phase II Heavy Metals program, this commitment must be addressed by each nation.

4.2. National Inventories of Current Research

During the workshop, the Effects Group generated a draft table of current research believed to be relevant to the emerging plan. Because the experts at the workshop were limited in number, and representation by each nation was not possible, a comprehensive table could not be produced, but the value of the exercise was recognized. The Group recommended that the table be distributed to all nations each to add supplemental material that can be incorporated into a more comprehensive summary.

This table will be distributed to key experts designated by each Arctic country to continue the process.

4.3. Research Plans and Summaries for Heavy Metals

To begin framing the AMAP Phase II heavy metals report it is important to know what research is ongoing, as noted above, and what is likely to be available in the future. To complete the interim and final reports on heavy metals for AMAP, draft annual reports are needed by each nation to summarize results and future plans.

The National Implementation Plans produced for AMAP provide baseline information on planned research. The heavy metals team will consolidate information from the individual plans and embellish the information where possible to characterize heavy metals research in the Arctic. This will help inform experts about research on heavy metals in other nations and facilitate the writing of the heavy metals report for AMAP Phase II.

Appendix A

HEAVY METALS IN THE ARCTIC

AMAP Heavy Metals Working Group
Sheraton Anchorage Hotel, Alaska, September 7-10, 1999

Agenda

September 7: Tuesday

- 2:00 pm Welcome and Introductions
- 2:25 pm Meeting objectives, overview of agenda, charge to participants (S. Marcy)
- 2:50 pm *Break*
- 3:00 pm Arctic Values: Traditional Talking Circle (lead: Patricia Cochran, Executive Director, Alaska Native Science Commission)
- 5:00 pm *Adjourn or continue as needed*
- 6:00 pm *Welcome reception: Sheraton Anchorage Hotel*

September 8: Wednesday

- 8:30 am Overview of Arctic Council, AMAP and Participant goals; current status (S. Marcy)
- 8:50 am Overview of AMAP Phase I; other international activities (J. Pacyna; R. Dietz)
- 9:30 am Research reports: Canada, Denmark, Faroe Islands
- 10:15 am *Break*
- 10:30 am Research reports: Finland, Norway, Russia, United States
- 12:00 pm *Lunch on your own*
- 1:30 pm Problem Formulation for assessing risk to the Arctic (S. Marcy)
- 2:30 pm Discussion of Participant interests and recommendations to structure work
- 2:55 am Break-out groups assigned and tasked: What do we know, what do we need to know, how do we best fill the gaps?
- 3:00 pm *Break*
- 3:15 pm Break-out groups
- 4:45 pm *Adjourn to Alaska Native Cultural Center; dinner on your own following visit*

September 9: Thursday

- 8:30 am Plenary update: Groups reconfigure into one exposure and one effects group to target work.
- 9:00 am Break-out groups
- 10:00 am *Break*
- 10:15 am Break-out groups
- 12:00 pm *Lunch on your own*
- 1:30 pm Plenary report out; effects group reconfigures into two groups to refine tasks. Break-out groups continue work
- 3:30 pm *Break*
- 3:45 pm Break out groups
- 4:45 pm *Berry picking, mountain hike and light picnic supper*
- 7:00 pm *Anchorage Museum "Jazz Night" and self-guided exhibit tour; dessert café open*

September 10: Friday

- 8:30 am Plenary reports by three groups (newly assigned US Consul General to Russian Federation participated)
- 9:30 am Break out groups
- 10:15 am *Break*
- 10:30 am Break out groups
- 12:00 pm *Lunch on your own*
- 1:30 pm Small groups define areas of essential research
- 2:45 pm *Break*
- 3:00 pm Plenary: prioritize research and build Heavy Metals plan
- 4:45 pm Summarize meeting results and confirm follow-on assignments
- 5:00 pm *Meeting adjourned*



Appendix B

Participants for “Heavy Metals In The Arctic”

Participant	Country	Date In	Date Out
Dr. Suzanne K.M. Marcy, Chair Arctic Program Manager & Senior Scientist National Center for Environmental Assessment U.S. Environmental Protection Agency 222 West 7th Avenue #19 Anchorage, AK 99513 Tel: 907/271-2895 Fax: 907/271-3424 e-mail: marcy.suzanne@epa.gov	USA	Sept 7	Sept 10
Dr. Andrew Robertson, Key Expert National Oceanic & Atmospheric Administration N/SCI 1, Room 10110, SSMC4 1305 East-West Highway Silver Spring, MD 20910 Tel: 301/713-3028 ext. 162 Fax: 301/713-4388 e-mail: andrew.robertson@noaa.gov	USA	Sept 6	Sept 11
Douglas Dasher, P.E., Recorder Alaska Department Of Environmental Conservation 610 University Avenue Fairbanks, AK 99709 Tel: 907/451-2172 Fax: 907/451-2187 e-mail: ddasher@envircon.state.ak.us	USA	Sept 6	Sept 11
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Lyle Lockhart Freshwater Institute Fisheries and Oceans Canada 501 University Cr. Winnipeg, Manitoba R3T 2NG Tel: 204/983-7113 Fax: 204/984-2403 e-mail: lockhartl@dfo-mpo.gc.ca	Canada	Sept 6	Sept 11
Dr. Maria Dam Food and Environmental Agency Debesartrod FO-100 Torshavn Faroe Islands Tel: 298-31-5300 Fax: 298-31-0508 e-mail: mariadam@hfs.fo	Denmark/ Faroe Isl.	Sept 6	Sept 11
Rune Dietz Department of Arctic Environment National Environmental Research Institute Tagensvej 135 IV DK-2200 Copenhagen N, Denmark Tel: 45-35-82-1415 Fax: 45-35-82-1420 e-mail: rdi@dmu.dk	Denmark/ Greenland	Sept 5	Sept 9
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Appendix C

Workshop Activities

As part of the workshop, activities were scheduled to encourage group interaction and provide a congenial setting for informal discussions.

Opening Reception

On Tuesday evening, directly following the Talking Circle, workshop participants enjoyed an outstanding buffet of Alaska smoked salmon, international cheeses, fruits of the season, Caesar salad and other delicacies courtesy of the *North Slope Borough Department of Wildlife Management*. A very special “*thank you*” to Mr. Charles Brower, Director, who made this possible for our foreign and US guests.

Tour of the Alaska Native Heritage Center

Wednesday evening, workshop participants were transported, courtesy of the hotel shuttle, to the newly opened Alaska Native Heritage Center. The Center is a gathering place that celebrates, perpetuates and shares Alaska Native tradition. Participants arrived in time to see singing and dancing by Native Alaskans of both traditional and new songs. Participants then strolled the outdoor exhibits encircling a small lake that feature traditional full scale lodges of the principal Native groups in Alaska including Tlingit/Haida, Athabascan, Inupiat, Yu’pik/Cu’pik, and Aleut. Native interpreters at each village site described the traditional ways of their people. Participants then visited the indoor exhibits of art and history that were augmented by Native artists actively demonstrating their skills.

Mountain Hike and Wild Berry Picking

Thursday evening, participants joined in a short drive to the south fork of Eagle River cutting through the heart of the Chugach Mountains and The Chugach State Park. Participants gathered around for a “tailgate” dinner of turkey and cheese roll-ups, carrots, fruits and cookies courtesy of Suzanne Marcy, workshop chair. With appetite abated, all headed up the mountain to enjoy the view and pick an assortment of berries in season including crow (moss) berries, low bush blueberries, low and high bush cranberries, salmon berries and in one case, a variety of mushrooms. Some climbed high to see vistas across the mountains. One carload drove on and sighted a moose in Arctic Valley. Those that chose instead to go to the Anchorage Museum for “Jazz Night” were able to relax to lovely piano while enjoying Alaska exhibits and the rich desserts and coffee the Café Gallery had to offer.