
Section C - Effects Monitoring Programme

The following text comprises part of the **AMAP Trends and Effects Programme** documentation. As such, it should be read in conjunction with other sections of the documentation, in particular Section A (Introduction) which includes an explanation of some basic terms and concepts that are used in describing the AMAP programme. Other sections include: Section B (AMAP Trend Monitoring Programme); Section D (Supporting Studies); Section E (Quality Assurance and Quality Control); Section F (Data Reporting Issues); and Section G (Appendices - methodologies, references, etc.).

Introduction

This section (Section C) of the **AMAP Trends and Effects Programme** documentation presents the content of the **AMAP Effects Monitoring Programme**. Section C has 2 main parts, concerned, respectively, with *ecological effects monitoring* and *monitoring of effects in humans*. **Ecological effects monitoring** components are described according to subprogrammes dealing with the marine, freshwater and terrestrial environments. These subprogrammes are based on proposals developed initially in relation to monitoring effects due to the various pollution issues (POPs, metals, etc.). Additional programme components covering effects of climate change and UV radiation are based on proposals developed during a number of meetings, workshops and consultations that constitute part of the Arctic Climate Impacts Assessment (ACIA) process. The second part of the **AMAP Effects Monitoring Programme** is concerned with monitoring **effects on human health**.

Additional references to documentation on, e.g., recommended methodologies concerning specific programme components, sampling frequency, implementation strategies and methodologies, etc., can be found in Section G of the AMAP Trends and Effects Programme documentation.

At the end of this section, a series of supplementary tables are included, covering:

- **Table C.1. Table of selected effects endpoints**
- **Table C.2. List of areas considered essential for effects monitoring under subregional programmes.**

Abbreviations and notes employed in the tables

Tables presented in Section C include a number of explanatory footnotes. When reading the tables, please refer carefully to any relevant notes. Every attempt has been made to ensure consistent use of footnotes between tables. An overview of notes and abbreviations employed in the subprogramme tables is as follows:

- Status of parameters in monitoring programme (see Section A for further explanation):
 - E essential for all countries and key Arctic sites. These components of the programme are highlighted in the table by shading.
 - ES essential sub-regionally
 - R recommended

Footnotes to subprogramme tables:

- ④ Included in POPs programme for linkage to contaminants monitoring.
- ⑥ Whelks - Dogwhelk (*N. lapillus*), Whelks (*N. lima*), Common whelk (*B. undatum*).
- ♥ Arctic cod, Sculpin; other species such as cod, capelin, etc., that are important for human consumption may be used as alternatives if these are also used for contaminants monitoring.

- ♣ or other bivalve molluscs.
- ♦ Key food-chain species, e.g., krill (Euphausiacea), amphipods, shrimp, cod, capelin
- ♠ Pelagic communities, e.g., fish eggs (cod, haddock, capelin, etc.); dominant species of phyto- and zooplankton, molluscs, macroalgae, marine mammals.
- ⌘ Community analyses: community structure, species composition, abundance, etc.

Strategy Considerations

The primary aim of the **AMAP Effects Monitoring Programme** is to provide information that will help allow the impacts of contaminants (and other stressors) on Arctic biological systems, including humans, to be assessed, i.e. to address, in part, the question "what is the significance of the observed contamination of the Arctic?".

Under ecological monitoring components of the **AMAP Effects Monitoring Programme**, the use of the term '**effects studies**' is largely synonymous with that of '**biological effects studies**'; other types of effects (e.g., physical effects such as melting of ice and permafrost, sea level rise, etc.) are, however, addressed in connection with Climate Change issues.

A range of 'biological effects methods' are available, based on techniques measuring responses at the sub-cellular level to the population and ecosystem level. It is recognized that many of the biological effects techniques included in the programme have only recently developed to a state where they can be considered for use in monitoring programmes; some of the techniques included are still used predominantly in a research context. Similar considerations apply to methods used in studying effects on human health. Consequently **the AMAP Effects Monitoring Programme is initially intended to be implemented in areas of known elevated contamination**, including areas in the vicinity of point sources, and in species where the previous AMAP assessment work has shown concentrations at or near levels where effects are likely to occur. Human effect studies will also focus on areas where effects are most likely to be encountered, although some effect studies will be undertaken in all 'Key areas'.

As additional information on the practical utility of biological effects monitoring in the Arctic becomes available, the scope of the work may be extended.

Due to the generally low levels of contamination found in much of the Arctic region, **sublethal effects** are of particular concern, as are subtle effects on, for example, reproduction, that might have implications at the **population level**.

Background

The **AMAP Effects Monitoring Programme**, as described in this section, has been updated to reflect developments in the field of biological effects methods that have taken place since the initial AMAP Monitoring Programme was prepared in 1993. It has further been updated in response to the increasing emphasis that has been placed on the general issue of 'effects' in the future AMAP assessment work, in particular effects due to climate change and increasing UV. This concerns not only effects due to individual contaminants, but also effects of different contaminants, and other stressors, acting together (i.e., **combined effects**).

Issues

Method specificity

It is necessary to recognize from the outset that very few of the techniques included in the programme, when applied in the field to study natural ecosystems, can be considered '**contaminant specific**'. In particular, studies addressing effects at the population or ecosystem end of the spectrum, are almost always looking at indices that can be influenced by a range of factors that may be related, either directly or indirectly, to the (contaminant, etc.) issues that are being considered by AMAP.

Cause and Effect

Biological systems are complex, and identifying **cause-effect relationships** may well be an impossible goal for most effect studies (criteria for causal association exist, for example see, Hill, A.B. 1965. The environment and disease: association or causation? Proc. R. Soc Med. 58:295-300(1965)). Effects assessment will often, therefore, have to apply a **weight-of-evidence** based argumentation.

Several components of the **AMAP Effects Monitoring Programme** that address contaminants or groups of contaminants employ biomarkers, that is, biological effects techniques with endpoints that are measures of responses at the sub-cellular to individual level. The term '**biomarkers**' can be defined as '*a biochemical, physiological or behavioural response that can be measured in tissues, body fluids or at the level of the whole organism that provides evidence of exposure to, and/or adverse effects of, chemical pollution*'. Methods for studying population or ecosystem level effects are generally more applicable when considering 'combined effects' or effects due to climate change and/or increasing UV, etc.

Linkages with contaminants monitoring work

The major aim of monitoring contaminants in living organisms is ultimately to try to understand if the current levels are causing effects. Coupling information on contaminant levels with observed biological effects, however, remains a major knowledge gap in current assessments.

A basic principle of the AMAP Effects Monitoring Programme is that **biological effects monitoring and contaminants monitoring are complementary activities** which should be highly coordinated. Wherever practical/appropriate, paired sampling, with contaminants and effects measured in the same animal, is particularly recommended.

For this reason, all species considered essential or recommended within the biological effects monitoring programme (see tables below) are also considered essential at key Arctic sites (E) or essential subregional (ES) within the contaminants monitoring programme (see tables) presented in Section B of this document.

The fact that most of the effects measures are likely to respond to many stresses is advantageous for screening purposes, but has negative implications for assigning cause-effect relationships. A stepwise or hierarchical approach that integrates chemical analyses with biological effects measures is therefore advocated.

Reliable interpretation of biological effects data often requires access to related chemistry data. In some cases relevant contaminants data from the same general area in roughly the same period of study may suffice, however, in other cases, measurements of contaminants may be required in the same samples that are used for the effects studies (preferably the same tissues/organs of the same individual animals). To achieve this, it is important that, when planning effects work, due consideration is taken of the plans for contaminants monitoring work (and vice versa). Due to the fact that most biological effects monitoring programmes are at a somewhat earlier stage of development than (the more established) contaminants monitoring programmes, the latter may already be implemented and, in practise, difficult to influence. The same also applies in other areas, for example, UV effects monitoring studies in relation to programmes monitoring UV radiation. Consequently, proposals for biological effects monitoring have, to the extent possible, been developed taking into account the species that have already been selected for inclusion in contaminants monitoring programmes.

General considerations

The main objective of the *Effects Monitoring Programme* is to determine and evaluate the effects of contaminants on Arctic ecosystems, including humans, particularly the effects of low-dose chronic exposure.

A major source of uncertainty in ecological effects monitoring concerns the significant disconnection between laboratory dose-response studies and field studies. Both types of studies can be used to investigate biological effects, however, in the laboratory the response is related to known dosing,

whereas in the field, attempts are generally made to relate the response to tissue concentrations. The most efficient way to link these two types of work is for laboratory studies to report biological effects results in terms of tissue concentrations under known dosing regimes. However, there is a general lack of information on laboratory studies that can be directly associated with Arctic wildlife and exposures. This lack of information leads to extrapolations that may be inappropriate; there is an urgent need for laboratory studies that are relevant to Arctic conditions.

While some biological effects can be clearly linked to individual contaminants, many biological endpoints are less specific. Since most available methods employ biological endpoints that can be due to a range of contaminants (and other factors), biological effects studies for a specific contaminant or related group of contaminants should occur in close coordination with studies addressing combined effects issues.

Human health effects studies are no less challenging. Epidemiological and biomarker studies are involved, but face similar problems in relation to non-specific responses (see method specificity issues, above), not only to contaminants but also to other factors that can influence human health (general health and nutrition status, smoking habits, alcohol consumption, etc.). Epidemiological studies are additionally hampered by the small population sizes that are available for study in most Arctic areas.

The programme as specified below specifically employs an approach in which both specific and non-specific endpoints are studied. Endpoints such as gross histopathology or changes in behaviour, or changes in species composition, provide clues that something is changing.

Further development of the ecological biological effects programme should include attention to additional types of endpoints such as behavioural effects related to foraging, predator avoidance, and mating; and population parameters such as age structure.

Several of the biological effects techniques that are identified have associated practical consequences with respect to the design of monitoring programmes. These are particularly relevant considering the logistical constraints imposed by working under Arctic conditions. One example is the sampling of material for biochemical assays (biomarkers) where it may be necessary for samples be processed immediately or frozen in liquid nitrogen.

There is also an urgent need to introduce and implement appropriate QA/QC activities to ensure that results of biological effects studies are reliable and comparable. Some of the methods described below are now being addressed, for example under the EU BEQUALM programme, and NIST/MMHSRP programmes concerning QA/QC in marine mammal studies. Laboratories involved in the **AMAP Effects Monitoring Programme** should take full advantage of such initiatives.

Methodological issues

Methodological issues are discussed below with reference to different contaminant groups and pollution issues. A number of the points raised are generic to several of the contaminant groups (particularly those concerning POPs, heavy metals and oil/PAHs), for example the different types of methods recommended for application at different levels of biological organization (from the cellular to the population level), and the advantages and disadvantages noted under the POPs methodological section. In general, all biochemical and histological methods involve sample treatment following collection that may be (logistically) difficult to perform under Arctic field conditions.

Furthermore, there is a general recommendation that effects studies are combined with monitoring of contaminants, to provide complementary information, also including collection of information on a range of explanatory variables and factors (such as organism size, age, sex, reproductive status, etc.; and environmental variables, temperature regime, etc.) that may be required for valid interpretation of both effects and contaminants monitoring data.

Readers are therefore recommended to consider the cross-issue relevance of information presented under various headings.

Acidification effects

This section describes general methodological issues relating to the detection and evaluation of biological effects of acidification on ecosystems.

Several gaps in knowledge were identified in the first AMAP assessment of acidification in the field of biological effects. In particular, the dose-response relationships in Arctic conditions, the effects of acid surges during the period of snow melt, and the effects of natural sulphur emissions are poorly understood. These research topics call for a concerted research effort.

The table below provides an overview of biological effects monitoring proposed for inclusion in the future work of AMAP. Two strategies are involved: (a) intensive multi-parameter studies at frequent intervals at a limited number of selected sites, and (b) more limited studies involving less frequent sampling but at a larger number of sites.

The sampling network in the main area of concern (northern Fennoscandia and the Kola Peninsula) should be based on the International Cooperative Programmes (ICP) network. The ICP, comprising ICP-forests, ICP-waters, and ICP-integrated monitoring, is a sub-programme under the UN ECE LRTAP Convention. Further station networks need to be established in the area around Norilsk. In North American areas where potential for acidification problems exist (e.g. on the basis of sensitivity mapping), station networks designed to provide screening and early-warning of development of acidification problems should be established.

Each of the ICP programmes (ICP-forests, ICP-waters, and ICP-integrated monitoring) have their own QA/QC programmes and methodologies (see references in Section G). The AMAP acidification effects monitoring activities should, to the greatest extent possible, follow the methodological and QA/QC requirements described in ICP programme documentation.

Additionally, the AMAP effects monitoring programme includes community parameters, such as species composition, for epiphytic lichens. Lichens react very specifically towards acidification, are relatively easy to sample and established methods are implemented in the main area of concern.

Heavy metals effects

This section describes general methodological issues relating to the detection and evaluation of biological effects of heavy metals on ecosystems; the metals of primary concern being Hg, Cd, Pb, As, and Se.

Heavy metals have been observed to cause effects on various faunal species and organ systems, particularly at acute high doses. Less information is available, however, for sublethal effects. In the Arctic, levels of Cd and Hg in some marine birds and mammals are high enough to be of concern, based on laboratory studies. Although there are no documented effects that have been attributed to heavy metals from regional (as opposed to local industrial) contamination, this may be a false negative, since it is not known what proportion of Arctic plant and animal populations might have been lost or are currently being lost but not noticed.

Of the more metal specific techniques, endpoints such as δ -aminolevulinic acid dehydratase (ALA-D) in blood provide evidence of Pb exposure leading to potential Pb inhibition of heme synthesis (and thereby to another non-specific endpoint, anemia). Metallothionein induction (MT) measures exposure to metals and disturbance of the copper and zinc metabolism and is one of the most specific methods available for demonstrating effects due to exposure to heavy metals. Additional methods regarded as promising and potentially applicable include heme oxygenase and porphyrin profiles that, e.g., correlate Hg contaminant levels in wild birds and mammals with laboratory studies

Methods to detect sublethal biological effects of mercury are currently lacking. Part of the problem is that Hg acts primarily on the central nervous system (CNS), and therefore the earliest effects may relate to behavioural endpoints that are difficult to define and study, but which are potentially of great importance to the maintenance of healthy animal populations.

POPs effects

This section describes general methodological issues relating to the detection and evaluation of biological effects of POPs on ecosystems. Since it is difficult to single out the effects of specific pollutants, these studies should occur in close coordination with those addressing combined effects.

Lipid-rich foodwebs of the Arctic imply a certain risk at the top of the food web. Current concentrations of some OCs in several Arctic species are at or above the known thresholds associated with effects that have been seen in other species studied either in the laboratory or in the field. Several Arctic species appear to be at risk for primarily reproductive, immunosuppressive and/or neurobehavioural effects from current levels of DDT, PCBs and/or dioxin-like substances.

Biological effects can be measured at different levels of organization. The following are suggested as the types of studies that could or are being used to study biological effects of POPs. Population studies include population statistics, reproduction and survival. Reproductive success includes studies of the number of young hatched/born and survival of young. In birds affected by DDE, decreased eggshell thickness indicates reduced reproductive success. Observations of animal behaviour in the field or when brought into the laboratory support studies of contaminants with neurological modes of action. Gross pathology includes physical changes, some of which may be easily visible, such as fin erosion, limb deformities, beak deformities or other external deformities, or which may require more careful scrutiny, e.g., hermaphroditism in polar bears. Disease studies include diagnoses and documentation of the frequency and severity of known diseases, reporting of new diseases, investigations of mortality events or die off and the presence of parasites. Morphometrics includes individual age, sex, reproductive condition, nutritional status, body condition, length, weight, organ weights and measurements, and external measurements. Biochemical measurements include Cytochrome P4501A enzyme activities, hormonal status, particularly thyroid and reproductive hormones, vitamins, particularly retinol (vitamin A) and immune function.

Advantages:

- In mammals and birds, effects of reactive metabolites of POPs can be studied together with un-degraded POPs. Experience from human and veterinarian medicine can be used especially in studies on mammals and birds.
- Local fish populations can be used at hot spots, and reference sites are then needed. If viviparous species or species having internal fertilization are used, effect studies can be carried out on an individual basis.
- Studies on pathology are useful and international experiences can be used.

Disadvantages:

- In some cases methods for biomarker studies are not well developed. For some types of biomarkers, it is difficult to obtain and transfer samples from the field to the lab in a proper way. Many biomarkers have not been standardized, and adequate QA/QC needs to be developed to ensure comparability.

Oil/PAH effects

Monitoring effects related to oil and PAH contamination in the Arctic can be carried out for different purposes: monitoring of general environmental PAH contamination, monitoring in areas where activities (oil exploration, exploitation, transportation) may give potential for contamination by oil and related PAHs, and monitoring in areas affected by oil spills, etc. Different effects methods may be appropriate under these different circumstances.

While much attention has been given to studies of catastrophic releases of oil to the environment caused by shipping activity and pipeline ruptures, less attention has been devoted to the effects of prolonged chronic exposure of oil and PAHs to the Arctic biota. Special effects studies should therefore be initiated to investigate:

- The acute and chronic effects of oil pollution on epontic (multiyear sea ice) communities.

- The long-term nearfield and farfield ecological effects of marine oil spills, or spills/discharges on land (such as the Usinsk oil spills) on freshwater and terrestrial populations and communities.
- Potential population and community effects of the severe PAHs pollution condition in the sediments of certain hotspot harbour areas of northern Norway and Russia.

Some of these areas are suitable for concerted studies regarding combined effects of contaminants.

In addition, toxicological effects of PAHs in Arctic species need to be studied (e.g. DNA adduct formation).

Experimental studies on chronic/acute toxicity of different PAHs components for Arctic aquatic organisms are complementary to effects studies in the field. Data on chronic/acute toxicity of different PAHs components to Arctic organisms are extremely scarce, and extrapolating results from temperate regions to the Arctic is highly uncertain.

Biological effects monitoring should be connected to (contaminant) trend monitoring in regions already impacted by petroleum hydrocarbons or PAH. Integrated biological and chemical monitoring is strongly advocated for both marine and terrestrial/freshwater ecosystems.

Several biological effects monitoring techniques are well established for aquatic organisms and systems. Some are associated with PAHs, such as Cytochrome P4501A induction in vertebrates, DNA adduct formation in fish and bivalves, PAH metabolites in fish bile, and liver lesions in fish (see Annex 1 to Section G), with differing degrees of specificity. Monitoring of PAHs metabolites in fish bile, combined with the Cytochrome P4501A, may provide an alternative to measuring concentrations of PAHs in other tissues and organs of freshwater and marine fish.

A range of non-specific biological effects techniques are also applicable to oil and PAHs, e.g. whole sediment bioassays, growth and metabolism studies (physiological scope-for-growth in mussels), and benthic community analysis. Such techniques should be considered in connection to the special studies listed above.

Benthic community analysis, and water and sediment bioassays using organisms sensitive to oil are methods that are typically employed in monitoring in areas of oil related activities (for examples, see PARCOM 1989). The causative coupling between sedimentary point sources of PAHs and benthic biochemical and community effects has been studied in situ in temperate marine systems both in Norway and Canada (Paine et al. 1996).

Monitoring the ratio of oiled bird carcasses relative to the total number of carcasses censused is identified as a technique with potential in relation to assessing the impacts of oil contamination in areas subject to chronic oil pollution. Potential problems due to scavenging of carcasses would need to be taken into account.

Radioactivity effects

Established non-specific methods exist for measuring effects of radiation exposure on reproduction, and for geno- and immunotoxic effects. Screening for immunotoxic effects involves measuring the relative number of monocytes, total T-cells, total B-cells, etc. Immunological effects have been observed in humans in highly polluted areas (e.g. Chernobyl) and it is therefore likely that effects can also occur in other biota. Genotoxic effects of radiation are manifested as mutations in specific genloci, which makes identification of the effects possible. Concerning methods for detecting reproductive effects, the tests are general. For effects on the foetus, it is the time of exposure that is important, and several different substances can lead to the same effects. Apart, therefore, from non-specific methods with endpoints measuring organ/tissue damage, disease incidence (cancer), and immune or reproductive system failure, biological effects methods aimed specifically at effects of radionuclides are generally lacking. Consequently, much of the effects work relating to radionuclide contamination is related to exposure/dose modelling in connection with radiological assessment.

Several areas have been identified as requiring attention in the development of more sophisticated and realistic radiological assessment models, both in relation to the calculation of exposures and doses to biota and in assessment of 'vulnerability'.

In terms of assessing risk to man, radiological protection practises are far advanced by comparison with the assessment tools available for other groups of contaminants. However, an improved set of criteria describing the potential impact of radionuclides on the environment are required to allow a comprehensive, integrated approach to impact assessment. Part of this impact assessment should include a tool for the determination of exposure and doses to biota. Data on the concentrations of radionuclides in biota and in abiotic environment (water, sediments) required for the calculation of doses to biota are provided directly by the AMAP Trend Monitoring Programme or derived by modelling the time-dependent transport and fate of radionuclides in ecosystems under different release scenarios. Information from radiological assessment models and calculation of doses to biota will facilitate more sophisticated identification of vulnerable areas.

For both terrestrial/freshwater and marine ecosystems, therefore, there is a need to:

- Develop the concept of doses to biota.
- Modify existing models to quantify doses to biota.
- Calculate doses to biota based on real (monitoring) data and data derived from the modelling of released scenarios.

Effects on flora and fauna

Of particular interest is the study of dose effect relationships in connection with the following end points: mortality, reproduction, genotoxicity and immunotoxicity in animals and plants. Furthermore, measurement of dose rates and radiological sensitivity among different animal and plant species, which have not previously been studied, is of interest.

Marine environment:

Establishment of dose effect relationships for exposure of fish eggs and reproductive organs in fish, mussels and large mammals is a priority. Such investigations would preferably also include studies on foetus of large mammals.

Terrestrial environment:

Monitoring coniferous vegetation for possible effects of radiation is a potential area of work that could be further investigated since, compared to deciduous trees, conifers are more vulnerable to radiation. In some highly polluted areas, such as that around Mayak, deforestation has been observed as a result of exposure to radiation. Reindeer/caribou are sensitive as a result of the efficient transfer of radionuclides from lichen to reindeer, and studying the effects on the reproductive organs and foetus of reindeer is therefore of interest. Monitoring biological effects in small terrestrial animals, plants (lichen), birds and freshwater fish should also be considered.

TBT effects

One of the main objectives of proposals concerning TBT is to monitor possible biological effects of organotins on Arctic biota.

Gastropod molluscs (Meso- and Neogastropods) have widely been used for monitoring of TBT (tributyltin) contamination in marine waters. Gastropods are particularly useful because of their sensitivity to TBT contamination and the fact that TBT results in the easily detected formation of male characteristics (penis and vas deferens), termed imposex, or progressive replacement of female reproductive tract by male sexual organs, termed intersex. Advanced development of these phenomena results in sterility of the female snails. The imposex phenomenon has been known since 1970, but only in 1986 was the development of male characteristics attributed to TBT contamination.

Imposex and intersex are now used for monitoring TBT contamination in the OSPAR area. The recommendations concerning TBT are based on outcome of a OSPAR workshop held in Aberdeen,

24-26 September 1997 using much of the text resulting from that meeting. As some of the countries within AMAP will monitor imposex, it is important to hold recommendations as similar as possible.

Biological effects of TBT in snails (Imposex) should be monitored in the AMAP area within the following gastropod species: Dogwhelk (*Nucella lapillus*), Whelk (*Nucella lima*) and Common whelk (*Buccinum undatum*), in the areas listed below.

Dogwhelk (*Nucella lapillus*) - Despite a diverse mollusc fauna within the AMAP area, large gastropod molluscs are not particularly common intertidally in the High Arctic. This is presumably due in part to ice-scouring. Further, some of the species best known in terms of the effects of TBT do not occur in the Arctic or have their northern limits only extending partly into the AMAP study area.

The dogwhelk, in addition to the periwinkle (*Littorina littorea*) and the common whelk, has been used as an indicator of TBT pollution in the OSPAR area. The dogwhelk is well suited for identifying gradients in exposure and the resulting biological effects. Oil terminals and large harbours (commercial, naval) should be investigated as special cases.

Whelk (*Nucella lima*) - Imposex has been studied within the gastropods *Nucella emarginata*, *Nucella canaliculata*, *Nucella lima* and *Nucella lamellosa* in the East Pacific (Short et al. 1989, Stickle et al. 1990, Tester and Ellis 1995). Of these *Nucella lima* extends presumably furthest to the north (see Austin 1985). That species occurs higher in the intertidal zone than does for instance *Nucella lamellosa*.

Common whelk (*Buccinum undatum*) - The common whelk has been used as an indicator of TBT pollution in the OSPAR area and may be useful as an indicator of TBT contamination in offshore areas and along shipping lanes.

It is proposed that the AMAP region should be surveyed as soon as possible, using methods indicated below (detailed in Annex 2 to Section G). The biological monitoring should be coordinated with chemical monitoring for TBT (see Section B). In light of the results of this survey areas showing high contamination of TBT should be examined in closer detail. Those areas, in addition to moderately affected areas, should be revisited after 5 years. Due to the close relationship of organotins such as TBT with POPs, heavy metals, and petroleum hydrocarbons, active co-ordination and harmonization is required to maximize program effectiveness and efficiency.

Sampling locations

Samples should be collected in coastal areas on both sides of the facility (e.g. harbours, oil terminals) in order to describe the gradients of contamination. At least six sample sites should be located on each side of the facility, covering the gradients between the highest level of effect to the local background level of effect. The sample sites should be clearly identified in order to enable repeat sampling, for example to investigate temporal trends in contamination and effects. *Nucella lapillus* should be collected from below midtide level, while *Nucella lima* should be sampled in the upper intertidal.

In light of a sparsely populated regions within the AMAP area, monitoring should focus on areas near "hot spots". The sampling undertaken around harbours/oil terminals should be such that interpolated values for the Vas Deferens Sequence Index (VDSI) are within 0.5 units of the true value with 90% confidence in the range VDSI 2-6.

Ecological Effects Monitoring Programme - Summary Tables

Effects Media and Parameters - Terrestrial

Media → Contaminant ↓ group		Forest, intensive	Forest, regional	Coniferous vegetation (spruce)	Soil living organisms	Mosses and lichens	Caribou / Reindeer	Rock ptarmigan	Snow bunting	Peregrine falcon	Merlin	White- tailed sea eagle
Acidification	Defoliation	ES	ES									
	Discoloration	ES	ES									
	Easily identifiable damage	ES	ES									
	Foliar analyses	ES										
	Ground vegetation	ES										
	Increment	ES										
	Community analyses						Epiphytic lichens – ES					
POPs	Population studies									ES	ES	ES
	Reproductive success									ES	ES	ES
	Egg-shell thickness									ES	ES	ES
Heavy metals	Community analyses					ES						
	Growth rate, etc.					R						
	Gross morphology, organ integrity, fat content						R					
	Morphometrics							R	R			
	Histopathology (kidney)						R	R	R			
	ALA-D (in blood)						R	R	R			
	Metallothionein (in kidney)						R	R	R			
	Porphyryns						R	R	R			
	Heme-oxygenase						R	R	R			
Radioactivity	Exposure, dose*					ES (lichens)	ES					
	Flux vulnerability**				R	R	R					

Media → Contaminant ↓ group		Forest, intensive	Forest, regional	Coniferous vegetation (spruce)	Soil living organisms	Mosses and lichens	Caribou / Reindeer	Rock ptarmigan	Snow bunting	Peregrine falcon	Merlin	White- tailed sea eagle
	Mortality				R	R						
	Reproduction			R	R		R					
	Genotoxicity			R	R		R					
	Immunotoxicity				R		R					

* Exposure (trend monitoring); dose calculation, dose modelling, impact assessment based on release scenarios.

** Flux of radioactivity via food chain (uptake experiments, retention and distribution in organs/tissues).

Effects Media and Parameters - Freshwater

Media → Contaminant ↓ group		Lakes selected	Streams selected	Freshwater algae	Benthic invertebrates	Landlocked Arctic char	Selected species of fish and invertebrates (in case of oil spills and discharges)	Pacific loon or Arctic tern
Acidification	Diatom inferred acidification history from sediment cores	R						
	Fish population trends	ES						
	Benthic invertebrate population trends		R					
POPs	Population studies					E ④		
	Gross pathology					E ④		
	Disease					E ④		
	Cytochrome P4501A					E ④		
Oil/PAH	Community analysis				R		R	
	EROD/Cytochrome P4501A induction						R	
	Benzo(a)pyrene hydroxylase				R			
Heavy metals	Community analyses			R	R			
	Morphometrics							R
	Histopathology (kidney)							R
	ALA-D (in blood)					R		R
	Metallothionein (in liver of fish, kidney of birds, gills of freshwater bivalves)				R	R		R
	Membrane stability (blood)				R			
	Condition factor					R		
	Scope for growth				R			
	Porphyrins					R		R
	Heme-oxygenase					R		R

E essential for all countries and key Arctic sites. These components of the programme are highlighted in the table by shading.

ES essential sub-regionally

R recommended

④ Included in POPs programme for linkage to contaminants monitoring.

Effects Media and Parameters - Marine (seabirds, fish, invertebrates and lower organisms)

Media → Contaminant ↓ group		Under ice algae	Benthic communities	Pelagic organisms ♠	Key food- chain species ◆	Blue mussel	Whelks ⑥	Fish	Seabirds (any species)	Eider	Black guillemot / Thick-billed murre	Glaucous gull
POPs	Population studies											ES
	Reproductive success											ES
	Behaviour											ES
	Gross pathology											ES
	Disease											ES
	Hormonal status											ES
	Vitamin status (retinol)											ES
	Immunotoxicity											ES
TBT	Imposex						E					
Oil/PAH	Bulky DNA adducts			R		R ♣		R				
	EROD/Cytochrome P4501A induction							R				R
	Fluorescent bile metabolites							R				
	Histopathology (liver)							R				
	Community analyses		R									
	Scope for growth					R						
	Oiled:non-oiled bird ratio								R			
Heavy metals	Community analyses ⌘	R	R									
	Morphometrics									R	R	
	Histopathology									R	R	
	ALA-D (in blood)					R		R ♥		R	R	
	Metallothionein					R		R ♥		R	R	
	Membrane stability (blood)					R						
	Condition factor							R ♥				
	Scope for growth					R						

Media →		Under ice algae	Benthic communities	Pelagic organisms ♠	Key food-chain species ◆	Blue mussel	Whelks ⑥	Fish	Seabirds (any species)	Eider	Black guillemot / Thick-billed murre	Glaucous gull
Contaminant group ↓								R ♥				
	Porphyrins							R ♥				
	Heme-oxygenase							R ♥				
Radioactivity	Exposure, dose*		ES	ES		ES***						
	Flux vulnerability**				R							
	Mortality					R***						
	Reproduction			ES	R	ES***						
	Genotoxicity											
	Immunotoxicity											

E essential for all countries and key Arctic sites. These components of the programme are highlighted in the table by shading.

ES essential sub-regionally

R recommended

④ Included in POPs programme for linkage to contaminants monitoring.

⑥ Whelks - Dogwhelk (*N. lapillus*), Whelks (*N. lima*), Common whelk (*B. undatum*).

♥ Arctic cod, Sculpin; other species such as cod, capelin, etc., that are important for human consumption may be used as alternatives if these are also used for contaminants monitoring.

♣ or other bivalve molluscs.

◆ Key food-chain species, e.g., krill (Euphausiacea), amphipods, shrimp, cod, capelin

♠ Pelagic organisms, e.g., fish eggs (cod, haddock, capelin, etc.); dominant species of phyto- and zooplankton, molluscs, macroalgae, marine mammals.

⌘ Community analyses: community structure, species composition, abundance, etc.

* Exposure (trend monitoring); dose calculation, dose modelling, impact assessment based on release scenarios.

** Flux of radioactivity via food chain (uptake experiments, retention and distribution in organs/tissues).

*** Mussels, crabs and lobster.

Effects Media and Parameters - Marine (marine mammals)

Media		Ringed seal	Walrus	Harbour porpoise	Beluga	Pilot whale	Polar bear	Arctic fox (as part of marine food web)
POPs	Population studies	R		R	E ④		E ④	R
	Reproductive success						E ④	R
	Behaviour							R
	Gross pathology	E ④		ES	E ④		E ④	R
	Disease	E ④		ES	E ④		E ④	R
	Morphometrics	E ④		ES	E ④		E ④	
	Cytochrome P4501A	E ④		ES	E ④			
	Hormonal status	E ④		ES	E ④		E ④	R
	Vitamin status (retinol)	E ④		ES			E ④	
	Immunotoxicity				E ④		E ④	R
Heavy metals	Morphometrics	R	R		R	R	R	
	Histopathology	R	R		R	R	R	
	ALA-D (blood)	R	R		R	R	R	
	Metallothionein (kidney)	R	R		R	R	R	
	Condition factor	R	R		R	R	R	

E essential for all countries and key Arctic sites. These components of the programme are highlighted in the table by shading.

ES essential sub-regionally

R recommended

④ Included in POPs programme for linkage to contaminants monitoring.

Effect-endpoint specifications

The following tables provide further information on effects endpoints included under the ecological effects monitoring subprogrammes for the terrestrial, freshwater and marine environments for the various groups of contaminants. Information concerning recommended methodologies, etc. can be found in Section G.

Under all subprogramme components, collection of relevant information on a range of explanatory variables and factors (such as organism size, age, sex, reproductive status, etc.; and environmental variables, temperature regime, etc.) that may be required for valid interpretation of both effects and contaminants monitoring data. Furthermore, there is a general recommendation that effects studies are combined with monitoring of contaminants, to provide complementary information.,

Terrestrial environment

Monitoring biological effects of Acidification in the Arctic

Media	Effect Endpoint	Frequency	Priority
Forest, intensive (fewer sites, more parameters with greater frequency)	Defoliation	annual	ES
	Discoloration	annual	ES
	Easily identifiable damage	annual	ES
	Foliar analyses	bi-annual	ES
	Ground vegetation	5-yearly	ES
	Increment	5-yearly	ES
Forest, regional (many sites, less parameters)	Defoliation	annual	ES
	Discoloration	annual	ES
	Easily identifiable damage	annual	ES
Epiphytic lichens	Community analyses (species composition)	5-yearly	ES

Monitoring biological effects of Heavy Metals in the Arctic

Species	Effects Endpoints
Mosses and lichens - Epiphytes (where present); ground dwelling lichens or ground dwelling bryophytes.	<ul style="list-style-type: none"> Species composition, relative abundance, vitality of 3-5 selected common macrolichens Growth rate (1-2 common species), chlorophyll content (1-2 common species), electrolyte leakage (1-2 common species) Fertility (mosses and lichens) <p>Note: Methods for studying biological effects using mosses and lichens are described in K.V. Olsen (ed.) 1995 (Biological Methods for use in Monitoring the Arctic. Proceedings of the AMAP/CAFF workshop, Svanvik, March 1995).</p>
Rock ptarmigan (<i>Lagopus mutus</i>) (Grouse may be considered as an alternative species where these are used in contaminants monitoring programmes.) Snow bunting (<i>Plectrophenax nivalis</i>)	<ul style="list-style-type: none"> Wing length/body weight in chicks, subcutaneous fat (adults and chicks) Kidney histopathology ALA-D in blood Metallothionein (MT in kidney) Explanatory information: size, age, sex, season, reproductive condition Porphyryns, heme-oxygenase (methods require developmental work)

Caribou/reindeer (<i>Rangifer tarandus</i>)	<ul style="list-style-type: none"> • Gross morphology, organ integrity, fat content • Kidney histopathology • ALA-D (blood) • Metallothionein (kidney) • Explanatory information: size, age, sex, season, reproductive condition • Porphyrins, heme-oxygenase (methods require developmental work)
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Monitoring biological effects of POPs in the Arctic

Species	Effects Endpoints
Peregrine falcon (<i>Falco peregrinus</i>) Merlin (<i>Falco columbarius</i>) White-tailed sea eagles (<i>Haliaeetus albicilla</i>)	<ol style="list-style-type: none"> 1. Monitoring of population status and reproductive success. 2. Subregional sampling of eggs and feathers from nests. 3. Measurements of eggs (length, breadth) with vernier calipers and weighing before emptying (Nygård 1997). 4. Measurement of eggshell thickness using micrometers. Correction for the size of the blow-hole and eccentricity according to standardized mathematical formulas (Nygård 1997) <p>Chemical analysis of egg content (DDT, DDD, DDE, PCB (28 congeners), dieldrin, HCB, HCH, aldrin, endrin, chlordane and mirex).</p>

Monitoring biological effects of Radionuclides in the Arctic

Species	Effects Endpoints
Soil living biota	<ul style="list-style-type: none"> • Mortality • Reproduction • Genotoxicity • Immunotoxicity
Lichens	<ul style="list-style-type: none"> • Mortality
Spruce	<ul style="list-style-type: none"> • Reproduction • Genotoxicity
Caribou/reindeer (<i>Rangifer tarandus</i>)	<ul style="list-style-type: none"> • Population studies • Reproduction • Genotoxicity • Immunotoxicity

Freshwater environment

Monitoring biological effects of Acidification in the Arctic

Media	Effect	Frequency	Priority
Selected lakes (few sites where biology is monitored)	Diatom inferred acidification history from sediment cores	ca. every 10 - 20 years	R
	Fish population trends	ca. Every 5 - 10 years	ES
Selected streams (few sites where biology is monitored)	Benthic invertebrate population trends (to investigate acidic pulses)	6 monthly	R

Monitoring biological effects of Heavy Metals in the Arctic

Species	Effects Endpoints
Freshwater algae	<ul style="list-style-type: none"> Community composition (Algae community composition is a demonstrated (non-specific) technique, with potential as an early-warning signal.)
Freshwater benthic invertebrates	<ul style="list-style-type: none"> Community composition (Community composition in streams is a demonstrated (non-specific) technique, with potential as an early-warning signal. In lakes, bivalves and gastropods are important food-web species) Metallothionein (bivalves and gastropods in lakes) (bivalve gills) Membrane stability (bivalves and gastropods in lakes) (bivalve hemocytes) Scope for growth (bivalves and gastropods in lakes)
Landlocked Arctic char (<i>Salvelinus alpinus</i>)	<ul style="list-style-type: none"> Metallothionein (liver) ALA-D (blood) Explanatory information: size, age, sex, season, reproductive condition Porphyrins, heme-oxygenase (liver) - methods require developmental work
Pacific loon (<i>Gavia pacifica</i>) / Arctic tern (<i>Sterna paradisaea</i>) (The study of Pacific loon may be constrained by logistical or (in some countries) conservation issues. Arctic tern take smaller fish, so may not bioaccumulate to the same extent as Pacific loon.)	<ul style="list-style-type: none"> Wing length/body weight in chicks, subcutaneous fat (adults and chicks) Kidney histopathology ALA-D (blood) Metallothionein (kidney) Explanatory information: size, age, sex, season, reproductive condition Porphyrins, heme-oxygenase (liver) - methods require developmental work

Monitoring biological effects of POPs in the Arctic

Species	Effects Endpoints
<p>Landlocked Arctic char (<i>Salvelinus alpinus</i>)</p> <p>(In some areas, it may be appropriate to include anadromous Arctic char in the programmes, in particular where this species is utilised for human consumption.)</p>	<ul style="list-style-type: none"> • Ecological, physiological and ecotoxicological studies • Effects on gross pathology and disease susceptibility • Cytochrome P4501A enzyme activity (liver) • Ecological responses (demography, reproduction, etc.) and individual effects (bioenergetics, hormone disruption, immuno-competence).

Monitoring biological effects of oil and PAH in the Arctic

Species	Effects Endpoints
Fish	<ul style="list-style-type: none"> • EROD or Cytochrome P4501A induction
Benthic communities	<ul style="list-style-type: none"> • Benthic community structure
Selected species of fish and invertebrates (in case of oil spills and/or discharges)	<ul style="list-style-type: none"> • EROD or Cytochrome P4501A induction • Community analysis
Sediment/pore water and test organisms	<ul style="list-style-type: none"> • Whole sediment/sediment pore water bioassays

Marine environment

Monitoring biological effects of Heavy Metals in the Arctic

Species	Effects Endpoints
Under-ice algae	<ul style="list-style-type: none"> • Community composition and productivity
Blue mussel (<i>Mytilus edulis</i>)	<ul style="list-style-type: none"> • Metallothionein (gills) • Membrane stability (hemocytes) • Scope for growth
Arctic cod (<i>Boreogadus saida</i>) and sculpin spp. (or alternative monitoring species)	<ul style="list-style-type: none"> • Metallothionein (liver) • ALA-D (blood) • Explanatory information: size, age, sex, season, reproductive condition • Porphyrins, heme-oxygenase (liver) - methods require developmental work
Eider (<i>Somateria spp.</i>) (Eider may be useful in studies aimed at identifying potential (local) problems due to lead shot contamination.) Black guillemot (<i>Cepphus grylle</i>) / Thick-billed murre (<i>Uria lomvia</i>) -	<ul style="list-style-type: none"> • Wing length/body weight in chicks, subcutaneous fat (adults and chicks) • Kidney histopathology • ALA-D (blood) • Metallothionein (kidney) • Explanatory information: size, age, sex, season,

Black guillemot are selected for contaminants monitoring, however, thick-billed murre may be more abundant and easier to study in biological effects work.	reproductive condition
Ringed seal (<i>Phoca hispida</i>) Walrus (<i>Odobenus rosmarus</i>) Beluga (<i>Delphinapterus leucas</i>) Pilot whale (<i>Globicephala melaena</i>) Polar bear (<i>Ursus maritimus</i>)	<ul style="list-style-type: none"> • Gross morphology, organ integrity, fat content • Kidney histopathology • ALA-D (blood) • Metallothionein (kidney)

The heavy metals component of the effects programme also focuses on efforts to address concerns of communities about health effects and to utilize monitoring data from the *AMAP Trend Monitoring Programme* to understand effects. Several of these studies are ongoing, but others should be implemented or expanded to include additional areas.

Analysis of potential health effects in biota using biomonitoring and special studies - to correlate or detect the effects of metals (Hg and Cd) on individuals or populations. For all biological spatial and temporal monitoring, certain minimal data should be collected. These data are essential for the interpretation of levels and trends as well as determining potential biological effects. Special studies should be designed or performed to determine specific organ (including reproductive organs), organism or population effects of Hg or Cd or combined effects. There are specific requirements depending on the class of biota. These studies should be performed in long term biomonitoring sites and in selected special studies.

Impacts of heavy metals on marine mammals - to monitor spatial and temporal trends, to evaluate potential impacts on marine mammals, to understand food web, and to provide data for human health risk assessments. The goal is to utilize live capture release programmes, strandings, and subsistence animals to evaluate contaminant levels (Hg, Ag, Cd, Se and other essential and non-essential elements), health effects (pathology and disease) and biomarker levels. Recommended species include ringed seal, beluga whale, polar bear, walrus and pilot whale. Recommended additions are bowhead whales and Northern fur seal. These studies should cover the Beaufort Sea; Bering Sea; Chukchi Sea; eastern Canada, northwest Greenland, Chukotka. The activity is currently ongoing in some areas.

Studies of lead pellet effects in birds and on risk to human consumption - are ongoing in Canada, Greenland and US, and should be continued and if necessary expanded to other relevant Arctic areas. Such studies should be coordinated with the effects studies on human populations.

Monitoring biological effects of POPs in the Arctic

Species	Effects Endpoints
Glaucous gull (<i>Larus hyperboreus</i>)	<ul style="list-style-type: none"> • Population studies • Reproductive success • Behaviour • Immunotoxicity • Cytochrome P4501A enzyme activity (liver) • Hormone status, retinol • Parasites and diseases

Ringed seal (<i>Phoca hispida</i>) Harbour porpoise (<i>Phocoena phocoena</i>)	<ul style="list-style-type: none"> • Population studies • Gross pathology, disease and morphometrics on necroscopy • Cytochrome P4501A enzyme activity (liver) • thyroid hormone status and retinol.
Beluga (<i>Delphinapterus leucas</i>)	<ul style="list-style-type: none"> • Population studies • Gross pathology • Cytochrome P4501A enzyme activity (liver) • Disease • Morphometrics • Hormonal status • Immunotoxicity
Arctic fox (<i>Alopex lagopus</i>) (marine food web)	<ul style="list-style-type: none"> • Immunotoxicological effects • Changes in blood parameters and body composition (captive foxes)
Polar bear (<i>Ursus maritimus</i>)	<ul style="list-style-type: none"> • Immune function / immune response to antigens for immunotoxicity dose-response relationships • Analysis of blood samples (from the immunotoxicity study above and archived samples from previous studies) for vitamin A, T4 and hydroxy-PCBs to study the interrelationships between these and possible reproductive/developmental problems

Monitoring biological effects of oil and PAH in the Arctic

Species	Effects Endpoints
Sediment/pore water and test organisms	<ul style="list-style-type: none"> • Whole sediment/sediment pore water bioassays
Benthic communities	<ul style="list-style-type: none"> • Benthic community structure
Bivalve molluscs, mussels	<ul style="list-style-type: none"> • Scope for growth • Bulky DNA adduct formation
Fish¹	<ul style="list-style-type: none"> • Bulky DNA adduct formation • EROD / Cytochrome P4501A induction (liver) • Neoplastic and pre-neoplastic liver histopathology • Fluorescent bile metabolites
Seabirds	<ul style="list-style-type: none"> • Ratio of oiled to non- oiled bird carcasses

¹May also be applicable to mammals and birds

Monitoring biological effects of Radionuclides in the Arctic

Species	Effects Endpoints
Marine benthic invertebrates (crabs, mussels)	<ul style="list-style-type: none"> • Mortality • Reproduction
Mussels, crabs, lobster	<ul style="list-style-type: none"> • Reproductive success • Population studies
Fish eggs	<ul style="list-style-type: none"> • Reproduction
Fish (cod)	<ul style="list-style-type: none"> • Reproduction (eggs and larvae)
Key food chain species (e.g. krill (<i>Euphausiacea</i>), amphipods, shrimp, cod, capelin)	<ul style="list-style-type: none"> • Reproduction • Reproductive success • Population studies

Monitoring biological effects of TBT in the Arctic

Species	Effects Endpoints
Dogwhelk (<i>Nucella lapillus</i>) Whelk (<i>Nucella lima</i>) Common whelk (<i>Buccinum undatum</i>)	<ul style="list-style-type: none"> • Imposex (see Annex 2 to Section G) and measurements of organotin compounds in whole animals.

Note: additional species recommended for TBT exposure monitoring are included in the **AMAP Trend Monitoring Programme** (see Section B).

Climate Change effects

Under the **AMAP Effects Monitoring Programme**, monitoring the effects of climate change is an activity to support the Arctic Climate Impact Assessment (ACIA) and is harmonized with work on, e.g. biodiversity monitoring being conducted under the auspices of CAFF (see *CAFF/AMAP Workshop on a Circumpolar Biodiversity Monitoring Program : Summary Report*. AMAP Report 02:2000). More information on ACIA can be found in the *Arctic Climate Impact Assessment (ACIA) - Implementation Plan*, available from AMAP website - www.amap.no - or ACIA Secretariat website - www.acia.uaf.edu/default.html.

In the context of the development of a programme to monitor the effects of climate change in the Arctic, despite the many uncertainties, there is now a reasonable 'vision' of the main future changes. Waiting until the uncertainties are removed before starting monitoring is not a sensible option. But it argues for a cautious, step-by-step approach with flexibility to adapt to new circumstances. The current vision includes recognition of both the relative importance of particular climatic factors and the actual and potential consequences of change. It is this insight, developed over the last decade, which has helped to focus consideration within AMAP and CAFF of an Arctic effects monitoring programme. The following sections outline the current state and needs for an effects monitoring programme. The aim is to identify main priorities and approaches, and options for development.

Monitoring Climate Variability and Change

General considerations

Some of the key features of the Arctic climate variability and change that are important in determining effective monitoring are:

- Large temporal variability (diurnal, seasonal, annual) with long-term oscillations and trends, but with capacity to 'flip' within a decade.
- Large regional variability e.g. some regions warming while others are cooling, plus meso-scale gradients within regions (oceanic – continental; altitude) and micro-scale topographic variation. Climate change is not uniform over these scales.
- Climatic events (e.g. gales, storms, drought) are expected to increase in frequency in some areas with important implications for ecology and people.
- Timing of freeze-up and thaw on land and the extent and thickness of sea ice will respond to both changing air temperature and precipitation.
- Precipitation is expected to increase generally in high latitudes, particularly in winter, through increased vigour of the hydrological cycle in a warmer atmosphere. Increased cloud cover through warmer air temperatures will modify surface temperatures. Both quality and quantity of snow are expected to change.
- Changes in land cover and sea ice will tend to have feedback effects on local and regional climate through changes in albedo, evapotranspiration and emission of greenhouse gases. Melting of sea ice, ice caps, glaciers and permafrost will increase river flow and reduce sea temperatures and salinity, to some extent compensating for changes in radiation balance.

The short summary of some of the main climate features of the Arctic shows the intimate, atmosphere-ice-land-ocean coupling which characterises the Cryosphere. Monitoring of the effects of climate change depends on understanding of this intimate relationship and it is unrealistic to separate changes in the atmosphere from the immediate physical changes on land and sea. There are large uncertainties in the timing, distribution and intensity of climate change and hence the likely effects. The uncertainty relates to i) the complexity of the system, ii) the sparse monitoring of climate and related physical conditions, iii) the limited effort in modelling at regional and local scales.

Marine climate

For the marine climate, the table (A) below reflects the general importance of observations on temperature and salinity related to standard sections and fixed stations. In contrast, sea ice extent and concentrations are regularly measured by remote sensing. More intensive observations of the fronts between warm and cold water masses and the volume flux at main 'gateways' are important targets.

Sea level is an important physical variable which, while not specifically a climatic factor, is closely related to it, and, like other marine physical variables, is an important driver of biotic and ecosystem change. It should be included as a generally measured variable, possibly by remote sensing.

Observations	Approach	Additional information
Temperature and salinity	Regular observations along standard sections and at fixed stations	Nutrients, current patterns
Position of fronts	Particularly in Barents and Labrador Seas	Current patterns and flux measurements
Sea ice extent, thickness, concentration and mass fluxes	Remote sensing and upward looking sonar	Vessel/aircraft ice observations
Freshwater outflow	Particularly in Norwegian and Greenland Sea area	Current patterns and flux measurements
Other parameters		Sea level (rise), meteorological parameters including winds, carbon and CO ₂

Terrestrial and freshwater climate

Marine observations show a distinction between i) intensive observations at particular stations and sections and ii) more limited observations over extensive areas, using ships and/or remote sensing techniques. A similar principle or sampling strategy has been developed for monitoring terrestrial and freshwater systems. On the principle that **'it is not possible to measure everything, everywhere, all the time'** the Global Hierarchical Observing Strategy (GHOST 1997), with 5 sampling tiers, has been developed jointly by the Global Climate Observing System (GCOS) and the Global Terrestrial Observing System (GTOS) (ICSU et al 1995; WMO 1997). The GTOS programme provides a reasonably detailed list of variables to be measured at each Tier and the frequency of recording (Appendix 5 in ICSU et al 1995).

Tiers 1 and 2 are not particularly relevant to the Arctic because they represent experiments over large areas and major research centres respectively. But other tiers represent distinct observing intensities:

- Tier 3. Field Stations with resident personal to supervise local frequent and intensive observations, usually related with associated research.
- Tier 4. Periodic sample sites, unmanned, and systematically distributed over a region. Observations are less intensive but provide statistically valid information over large areas.
- Tier 5. Complete coverage of a few variables at low resolution by remote sensing. Options for frequent or infrequent observations and can include specific target areas.

Climate and related physical variables identified as key cryospheric properties for monitoring climate variability and change are identified in relation to this flexible hierarchy in the table (B) below.

Table B. Recommended climatic and physical parameters of importance for monitoring climate change in the terrestrial/freshwater environment		
Parameter	Relevant Tier	Comments
Radiation	3, 4	UV-B radiation; short wave + photosynthetically active radiation
Temperature ²	3, 4, (5)	Vertical profiles into soil and water
Precipitation ¹	3, 4, (5)	
Wind speed	3, (4)	Rate and direction
Snow cover ^{1,2}	3, 5	Depth, extent, duration, quality
Ice cover ¹	3, 5	Depth & extent. Freeze-thaw time (Tier 3)
Glaciers	(3), 4, 5	Mass and extent
Permafrost	3, 4	Distribution, thermal state
Active layer ¹	3, (4)	Thickness, water content
Water table ²	3, (4)	Depth from surface
Water outflow ¹	3, (4)	Discharge and sediment load

Table B based on Holten et al 1998 and GHOST 1997.

() indicates potential observations.

¹ Measurements of pH, CEC, major nutrients and pollutants would naturally be associated with these observations.

² Variation over small distances (10s of cm) can be greater than between mesic/zonal sites at different latitudes.

These observations allow calculation of energy and water balance as well as being considered important influences on biological and human change. In many cases, it is the timing, frequency or duration of particular conditions which are of interest, e.g., the timing of ice melt or the frequency of freeze-thaw events or the combination of wind direction and precipitation. Such requirements are mainly generated only from intensive Tier 3 sites although automated recording can be used at the more dispersed Tier 4. However, the difficulty and expense of access will severely limited the number of sample sites at Tier 4 and greater reliance must be placed on remote sensing options at Tier 5.

Extreme events (climatic anomalies) are of particular importance to ecology and people. Localised events which may have significance over wider areas, e.g., slush flow or extreme precipitation, are often undetected by the sparse network of Field Stations. Flexibility in observation is necessary to record such events by examining weather models, field parties and analysis of satellite imagery.

The Field Stations (Tier 3) provide a critical infrastructure in terrestrial and freshwater monitoring. Whilst taking responsibility for intensive monitoring they can also provide 'nodes' for more extensive monitoring (Tier 4) which may require site visits annually or even less frequently. This will often require a greater regional responsibility for the Field Stations and potentially with increased responsibility for data management.

Many of the observations listed in the table above are currently made by national organisations, especially at Tier 3, with wider co-ordination, quality control, data analysis and interpretation provided by international organisations such as WMO. However, other more specific sectoral international organisations have an important role to play. For example, the International Permafrost Association (IPA) organises the Circumpolar Active Layer Monitoring (CALM) programme involving 12 countries and 80 sites and has identified some 200 boreholes available for monitoring permafrost temperature. IPA has also compiled a circum-Arctic map of permafrost and ground ice conditions (Brown et al 1997). This map is an important example of basic information needed to assess the

regional distribution of observation sites and to assist extrapolation of information from intensive site observations. Other research-based networks, often of limited duration, provide potential foci for securing long-term monitoring climatic and related variables, e.g., The International Tundra Experiment (ITEX) with its focus on plant response to climate change (Henry 1997) and the ALPE project on remote mountain lakes as indicators of air pollution and climate change which includes a number of northern lakes in Europe (ALPE 1996).

Monitoring Effects of Climate Change on Biota and Ecosystems

General considerations.

Some basic principles emerge from the background documents and from the experience of other monitoring programmes:

- Monitoring should be designed to answer specific questions and targeted by explicit consideration of expected or desired change (hypotheses, scenarios, models or policy targets).
- Sampling strategies (experimental design) should be designed i) To provide adequate replication over the systems. ii) To include key sources of environmental variation within and between systems or sites (altitude, sea depth, or other gradients) to provide comparative information. iii) To distinguish between causes of change (elements of climate; pollution; natural fluctuation; exploitation). iv) To provide observations at appropriate times and frequencies in relation to expected change.
- Maximum use should be made of information on past changes (e.g., long-term experiments, historical records, tree rings, sediment and ice cores, etc.) and linking these with current trends and model predictions of future changes which can be validated by monitoring.
- Variables selected should be relevant to the target question; sensitive to the particular driver under consideration; and interpretable in terms of the consequences of change to the system. In relation to the latter, it is vital to select species with a strong (physiological, demographical, etc.) 'signal to noise ratio'. Furthermore, longer term dynamics must be understood before attempts are made to interpret future trends in the context of climate change. Many Arctic species exhibit dramatic fluctuations in populations (e.g. lemmings) or in developmental processes, and in other cases, systems or populations show a long ecological memory, possibly following a trend initiated by events at the end of the Little Ice Age.
- Methods of measurements should be repeatable over decades with minimal operator or instrument error; robust so that there is flexibility in timing of observations; accurate enough to detect change; inexpensive and undemanding of time and skill.

These principles may be obvious – and sometimes conflicting – but they help to distinguish competing interests, e.g., the enthusiasm of the specialist who wants his organism or site to be included and the realist who wants only the most appropriate elements to be included!

Marine Biota and Ecosystems

Detection of long-term changes in marine ecosystems have very different implications for monitoring, relative to terrestrial systems. Fundamentally, the large-scale dynamics of physical, chemical and biotic components of oceans require sophisticated sampling and detection systems and use of purpose built vessels and satellites. Such facilities, particularly in polar waters, are associated with major research programmes which are often international. Compared to terrestrial systems, marine environments also provide very limited opportunity for experimental manipulation to isolate the effects of specific factors.

Current understanding highlights a number of key physical factors which drive actual or potential biotic responses, particularly in the Barents and Bering Sea regions (e.g. Weatherhead 1998). Some key factors identified are higher ocean temperatures and lower salinity; contraction of the extent of seasonal sea ice; shifts in the exchange of water masses between neighbouring seas; increased mixing

of surface waters due to changing wind regimes; rising sea levels. These, combined with El Nino, are known to significantly affect the biota, and some indicative changes have been detected.

Quantification of specific interactions is largely a matter of theory and confounded by the influence of unrelated factors (resource exploitation, pollution, increased UV-B etc). However, the observed and expected changes are important in targeting monitoring, as shown for monitoring of climate and related physical variables (Table A, above).

In considering the biotic effects of climate change a simple but important distinction can be made between direct and indirect responses through food web interactions. This distinction has specific implications for monitoring.

- Changing physical conditions act directly on the distribution and performance of individual species. For example, many gadoids, herring, salmonids and other fish species have specific temperature limits and are known to respond directly to changing conditions. Ringed seals, walrus and polar bear are particularly dependent on the sea ice edge habitat and are directly affected by changes in its extent.
- Implications for monitoring include: i) Direct effects of changes in temperature and/or salinity are likely to be detected (in species with defined tolerance limits) by changes in distribution at the geographical edge of their range (both northern and southern). ii) Responses to temperature are likely to be detected in changes in timing of specific events (phenology) such as arrival/departure at breeding sites, time of nesting, or moult.
- The intimate food web relationships result in a complex of interactions between species. Thus there can be an indirect 'domino' effect as a result of one species being affected by climate change. A particular distinction can be made between food webs in the open ocean and those at the sea ice edge, but in both cases the effects are most obvious at the higher trophic levels. As a result of the interactions it is difficult to determine the extent to which species changes are the result of response to climate change or to one of the many other natural or anthropogenic drivers of change.

This summary is a gross simplification and needs to be improved by relevant specialist. Although marine research is strong and there is a high level of international co-operation, there is no established monitoring programme for the effects of climate change on the ecosystems. Elements exist in some regions and for some sectors which may be targeted because of their sensitivity to climate. For example member countries of ICES and PICES regularly monitor commercial fish stocks.

Sea bird and marine mammal monitoring is also undertaken in connection with a number of international instruments (conventions, protocols) related to their conservation. However, many factors are involved in changes in species dynamics of which climate change is only one. More precise information on the effects of climate change can be obtained by targeting particular species, climate sensitive phenological variables and the climatically sensitive edges of species range.

Potential effects on	Species groups	Effects
Biodiversity	Benthos, plankton, fish populations	Changed species composition
Distribution area	Plankton, commercial fish stocks, marine mammals, sea birds.	New species introductions, reduction in existing species.
Growth	Fish stocks	Change in maturation timing.
Reproduction	Plankton, fish stocks, sea birds.	Change in recruitment.

Terrestrial and Freshwater Biota and Ecosystems

Understanding of the effects of climate variability and change in terrestrial and freshwater systems has probably been more fragmented than that for marine systems. This may be because access to biological sites on land is easier, allowing greater opportunity for individual studies, and there has been more limited incentives for international co-operation. Therefore, given the need for more comparative circumpolar information, there is probably more opportunity for improvements in monitoring systems on land than at sea.

Synthesis of understanding of observed and expected changes is now providing a reasonable basis for design of monitoring programmes. Due to the fact that field validation of computer model output lags far behind the development of these models, which in turn leads to possible large errors (e.g., errors in the sign/direction of the change), reviews and scenarios also provide important information to focus monitoring. Such scenario models have been developed on the basis of a combination of physiological and ecological information to summarise the sequence of responses to warming in tundra ecosystems, including feedback to the atmosphere and associated information on the certainty and magnitude of change (Chapin et al 1992). Subsequent syntheses have emphasised the diversity of response. For example:

- that species (and physiological) responses are highly individualistic;
- environmental gradients have marked effects on responses;
- the response of species dominant in their communities are likely to be particularly apparent at the northern/upper edges of their ranges, and different from within the range, but the responses of subdominant species (affected more by the responses of dominant species rather than their own direct responses to climate) can be important throughout their ranges;
- actual changes in species distribution will lag behind changes in climate;
- winter conditions, snow and ice cover, and extreme climatic events will be at least as important as changes in mean climate;
- unexpected species introductions and epidemics (including pest and diseases) will occur;
- migratory species are vulnerable to differential climate changes within their range.

There is a general need for both validation and refinement of existing models and the development of new models, reviews and scenarios.

The effects of climate change in Alpine regions are also likely to be applicable to the mountain areas in the Arctic and there are many similarities with expected and observed effects of climate change in freshwaters.

The understanding of the effects of climate change, outlined above as hypotheses, have been used to identify biological variables for monitoring at particular levels of resolution, see Table D, below. Measuring all of these variables is desirable, however, intercorrelations between parameters should be made in large databases so that a limited number of proxies for effects can be used in the longer.

The variables listed in Table D can be separated into those designed to address particular questions, still based on the hypotheses. An illustration of this process is given in Table E. Other questions could be similarly addressed, for example in relation to feedback effects to the atmosphere which would involve monitoring of processes rather than organisms.

Table D. Major biotic variables (organisms and processes) to be considered for detecting the effects of climate change on terrestrial/freshwater ecosystems		
Variable	Relevant Tier ¹	Ecosystems (T = terrestrial, F = Freshwater) / Comments
<i>Plant properties:</i>		
Leaf area index/chlorophyll concentrations of communities	3, (4)	T / at peak biomass
Peak shoot and root biomass	3, 4	T
Net primary production	3	F / derived or measured
Surface roughness	3, (5)	T
Spectral vegetation greenness	5	T / throughout the growing season
Chlorophyll concentration	5	F
Nutrient pools in soil and plants	3, 4	T
Nutrient pools in organic and inorganic matter	3, 4	F
Max. stomatal conductance	3	T
<i>Plant and animal:</i>		
Species richness, abundance and distribution	3, 4	T, F
Demographic processes (selected species)	3	T, F
Phenology (selected species)	3	T, F
Displacement of ecotones	3, 4, 5	T, F / Changes at edges of range
<i>Processes:</i>		
CO ₂ , CH ₄ , and N ₂ O flux	3, 4	T, (F) / Especially wetlands; soil and above canopy; other gases?
Decomposition	3, 4	T, (F) / Organic matter accumulation
N mineralisation	3	T

Table D based on Holten et al 1998 and GHOST 1997.

() indicates potential observations.

¹ See text to Table B for explanation of 'Tiers'.

Table E. Example question-based requirements for assessment and monitoring of climate change impacts			
	Target levels of organisation		
Priority issues	Species	Functional types	Habitats
Biodiversity and conservation	Geese, waders	Cryptogams	Wetlands Dry heaths
Ecosystem function	Sphagnum spp.	Mosses, lichens.	Dry heaths

and feedback		Small rodents, insect pests	Wetlands
Resources for humans	Ice breeding seals	Reindeer-lichens and mosses. Trees	In-shore fast ice. Lichen heaths. Forests.
Best signals of change	Species with specific biogeographies.	Cryptogams. Plankton in lakes (palaeo records). Top predators.	Discontinuous permafrost. Dry habitats. Wetlands.
Vulnerable systems	Snow bed plants	Understorey species	Riparian and river systems. Wetlands. Discontinuous permafrost
Identified currently changing systems	Puffin, Little auk.	Mosses, lichens, dwarf shrubs, forest insect pests.	High Arctic oligotrophic lakes. Treeline.

Table E based on Weller and Lange 1999.

The scale at which it is appropriate to monitor different parameters is also an important consideration. Table F, below, summarises the key parameters to be measured under the AMAP/CAFF joint programmes for monitoring climate change effects in the terrestrial/freshwater environments, and the relevant scales associated with these parameters.

Table F. Key parameters to be measured (cf. Tables B and D), and related scales, under the AMAP/CAFF joint programmes for monitoring climate change effects in the terrestrial/freshwater environments.				
	Micro/species /population level (<10 cm - 100 m)	Community/ landscape level (100 m - 10 km)	Intensive (regional) level (100 km - 500 km)	Circumpolar level (modelling effort)
	Extensive level (using the ITEX existing sites network)			
Abiotic parameters:				
Radiation (short-wave and terrestrial)		X	X	
Temperature	X (air + soil)	X	(X)	(X)
Precipitation		X	X	X
Snow cover (pattern, depth, duration)		X	X	X
Permafrost (extent/pattern)		X	X	X
Active layer (depth)	X	X	X (CALM)	
Groundwater level	X	X		
Nitrogen deposition	(X)	X	X	
Pollutants (see Section B)	X	X	X	X

Soil organic carbon content	X	X		
Mineralisation rates	X	X		
Biotic parameters:				
Species richness, abundance, distribution	(X)	X	X	(X)
Demography (selected species)	X			
Habitat diversity and distribution		X	X	X
Species phenology (selected species)	X	X	X	X
Vegetation phenology		X	X	X
Displacement of ecotones (e.g. timberlines, snow-bed - ridge ecotone)	(X)	X	(X)	(X)
Ecosystem processes (nitrogen transformations, productivity, decomposition, trace gas fluxes)	X	X	(X)	(X)

CALM = Circumpolar Active Layer Monitoring Programme

Basic Site Characterisation

In addition to the parameters recorded regularly, a number of basic one-time observations are essential at terrestrial and freshwater sites. These define site conditions and are important for between-site comparisons of responses, for assessing gaps in the environmental coverage, and for setting initial conditions in models. General information required is:

- Site location and descriptors: Name, latitude/longitude, elevation, slope, aspect and topographic map.
- Parent material: Type of bedrock, soil depth and profile description, texture (particle and mineral composition), organic matter content; basic chemical composition of soil or water.
- Hydrology: Catchment and lake area; average precipitation, runoff etc; soil water holding, retention etc; permafrost condition.
- Land use: Main land use and history; biome and soil types (by % cover).

Protocols and Procedures.

A significant number of protocols and procedures exist and deserve critical appraisal. Information and references to recommended methodologies can be found in Section G. Key source documents include:

- Biological Methods for use in Monitoring the Arctic (Olsen 1995). The review shows the range of techniques available to detect change in different, mainly terrestrial, plant and animal groups. Importantly, the ecological rationale for these observations is often provided along with examples.
- The ITEX Manual (Molau and Molgaard 1996) details the basic hypotheses, experimental design, physical and biological observations, additional options and reporting procedures. Individual plant species are targeted. The Manual is subject to continuous refinement and expansion.
- The Manuals for the UN ECE Integrated Monitoring Programme (ICP IM Manual, 1998) provides detailed methods for recording hydrological, physical, chemical and biological variables at catchment levels.

Quality Control results highlight the variability which occurs between laboratories in chemical analysis. This example illustrates the need not only for training but also for selection of robust variables and techniques of measurement. Observation of relative changes in a variable may be more informative than the absolute value.

Options for a Terrestrial and Freshwater Sampling Strategy

A large number of terrestrial and freshwater observing sites exist and many are linked in particular national and international networks. The advantages of such networks are that they improve the comparability of results, access to those results and provide a sample of observations for a particular region. However, the number of observing sites is small relative to the circumpolar area. Probably the only circumpolar network which is primarily focussed on the effects of climate change is ITEX.

Given the assumption of a hierarchical system, an adaptive strategy is the most pragmatic option for development at Tier 3 is to enhance the co-operation within major regions, building on existing national and regional programmes, to increase compatibility of observations. Opportunities for support, communication and interpretation are probably optimal at regional level.

Development at Tier 4 of less frequent and fewer observations over larger areas, preferably with a more statistically valid design, is more difficult. However, many Field Stations and established organisations are being encouraged to 'regionalise' their observations. With the stimulus of improving regional climatic models and increased use of GIS, more extensive observations could be developed based on the Field Stations of Tier 3. Such a development is likely to be slower than the integration into regional networks at Tier 3. However, one aspect which may well be given priority is the detection of changes in migratory species of birds and mammals. This requires co-ordinated geographically dispersed observations, including areas outside the Arctic. Fortunately, there is already considerable co-operation in the subject and priority could be given to securing this for indicator species, combined with additional observations on environmental and habitat conditions at key points over the species range.

At Tier 5, with a focus on Remote Sensing, already has the capability and is generating information for the circumpolar Arctic. The capacity exists and the case is strengthened by extreme difficulty of ground and sea access in the Arctic. The range of observations of change may be limited but the provision of baseline geographical information to provide a framework for ground and sea based observations and vice versa adds significant value. A circumpolar programme, possibly based at only two or three major facilities is an attractive proposition for early implementation.

The adaptive development of Regional Site Networks at Tier 3 and a Circumpolar Remote Sensing Programme at Tier 5 (e.g., of treeline dynamics) are highly complementary and feasible, with more gradual development at Tier 4, initiated through observation of migratory species.

Conclusions

A brief review of existing information indicates that:

Marine research, with its specialised requirements, is effectively generating much of the necessary information on long-term dynamics through support from the relevant national and international research organisations. Commercial and conservation organisations also contribute significant data on long-term change. The main needs identified are i) To improve the focus and distribution of selected observations (e.g., position of fronts and fluxes at gateways; sea ice extent and concentration; response of temperature sensitive species at margins of their range), ii) To stabilise support for long-term observations and data and information systems, and iii) To improve co-operation and access to information between national and international agencies.

Long-term observations of terrestrial and freshwater systems are more fragmented than those in marine systems. However, significant improvements could be made by adopting a hierarchical sampling strategy with i) Regional networks of Field Stations responsible for intensive observations of response variables of limited distribution ii) Remote sensing of a limited range of variables but with circumpolar coverage and iii) A more limited effort at an intermediate level focussed on observation of migratory animals. Many elements of such a programme already exist and would be significant added value in a combined approach, including participation of indigenous peoples. Current understanding of actual and potential change provides criteria for selection of variables, strengthened by existing measurement protocols.

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UV-B effects

UV levels in the Arctic have been increasing over the past two decades because of decreases in ozone. In 6 of the last 9 years of the 1990s severe stratospheric ozone depletion episodes were observed during the Arctic late-winter / spring periods. Current springtime ozone levels for the Arctic are between 25 and 50 Dobson units below normal.

The most optimistic estimates for the future are that ozone recovery will take place at a rate of less than five Dobson units per decade. These estimates imply that Arctic UV will be elevated through 2050. The estimates for recovery rate are considered optimistic because they do not include the effects of climate change that may exacerbate ozone depletion in the Arctic. Global warming results in cooler stratospheric temperatures and may affect atmospheric dynamics. In the Arctic, cooler stratospheric temperatures along with changes in atmospheric circulation can cause greatly increased ozone destruction, particularly in the presence of polar stratospheric clouds. The frequency of occurrence of polar stratospheric clouds has increased in the past decade and is expected to continue to increase with climate change. Therefore, the Arctic is likely to have elevated UV levels for the foreseeable future. There is also considerable uncertainty about future Arctic ozone levels due to natural variations caused by meteorological conditions. It is presently unclear what the full impacts of climate and meteorological variations will be.

Climate change also has a direct effect on UV levels in the Arctic. Predicted climate change includes not only temperature changes but also changes to clouds, precipitation and snow cover extent. As these parameters change, UV reaching the biosphere is also expected to change. The effects of climate change can also combine non-linearly with UV in plants and animals.

UV levels have long been an important environmental stressor in the Arctic. With increased UV levels, not only must human health effects be considered, but also the effects of UV on aquatic and terrestrial ecosystems. Initial studies have shown that UV levels can have detrimental effects on individual species and thus have a distinct pressure on balances among species within ecosystems. These effects have been observed and reported on phytoplankton, zooplankton, fish larvae, and terrestrial plants and animals. UV can cause cataract formation in a number of mammals.

Human health effects include sunburn and other skin damage due to UV exposure. Changes in the elasticity of the skin of the Greenland Inuit population have been reported. These changes can be linked to UV exposure. Likewise, UV radiation is also a causation of erythema (sunburn), which is linked to malignant melanoma. Frequent incidences of actinic prurigo, an idiopathic photodermatosis, have been reported in the Canadian Inuit population and linked to UV sensitivity.

General considerations

Terrestrial ecosystems

Research on effects of UV-B on terrestrial ecosystems and plants and animals under field conditions started only one decade ago and, even worldwide, there are still relatively few studies. Studies under field conditions are essential because shading within natural canopies and interactive responses among species are difficult to simulate in laboratories. Existing studies show individualistic responses of plants and animals to UV-B and also individualistic responses of ecosystem processes such as decomposition, nutrient cycling and nitrogen fixation. In general, UV-B radiation is more difficult to measure than for example temperature, and responses of plants, animals and ecosystem processes to UV-B radiation are also more difficult to measure than for example, responses to temperature change or atmospheric nitrogen deposition. Generally, there is a lack of a highly specific response of organisms to UV-B which can be separated from concurrent responses to other environmental stressors. Because of these difficulties, there are currently few, if any, standard methodologies that can be easily and immediately applied to monitor UV-B effects. A strategy is therefore required within AMAP which:

- 1) Maintains long-running UV-B enhancement field experiments at a few sites with appropriate technological capabilities, in order to understand fundamental impacts of UV-B and then predict future responses to potential changes in UV-B levels. These experiments provide frameworks in which new and developing measurements of UV-B effects (e.g., frost sensitivity of plants, nitrogen fixation in lichens, etc.) can be made on systems which have recovered from the initial 'disturbance' of the imposition of experimental treatment.
- 2) Initiates UV-B filtration field experiments at a much wider range of sites to determine long term impacts of natural UV-B levels combined with short term filtration experiments and thus determine the effects of short term specific ozone depletion events.
- 3) Continues laboratory experiments to determine action spectra for species and processes under tightly controlled experimental conditions not achievable in the field.
- 4) Develops methodology for monitoring UV-B effects in the field. Of particular importance is the need to develop the methodology for screening a large number of species and ecosystems and to focus on response variables which will reliably indicate and quantify effects of UV-B. Levels of protective pigments such as flavenoids, previously found to be indicators of UV-B levels, mainly from laboratory experiments, are less reliable under field conditions and alternatives must be found.
- 5) Initiates a dialogue between the effects community and the atmospheric modelling community to ensure that effects investigators can be forewarned of specific ozone depletion events so that UV-B at the surface can be measured and potential short term effects on plants, animals and ecosystems can be quantified.

Aquatic ecosystems

Chemical and biological processes and foodwebs in Arctic marine and freshwater systems are clearly influenced by present day UV radiation (UV-R), and may be further so with a continued ozone thinning. While there are similarities in responses in planktonic and littoral biotic compartments, there are also a number of major differences. Minima in stratospheric ozone have been recorded in spring, when the marine productivity is approaching its peak but most freshwaters are still ice covered. Large scale environmental effects, such as reduced primary production (reduced CO₂ uptake) and effects on fisheries would also be most significant in marine areas. On the other hand, freshwater systems may be more vulnerable, they are generally shallower and hence lack depth refugium. A major determinant of UV-R penetration, and thus effects in aquatic systems, is the presence of dissolved organic carbon (DOC), notably humus compounds, that attenuates UV-R far more efficiently than particulate matter. Altered climate and hydrological patterns may substantially alter the flux of DOC from terrestrial to aquatic areas. For the Barents sea, the flux of DOC from the large Russian rivers is a major determinant of UV-R penetration, and changes in this DOC flux could be more important than actual changes in UV-R as a result of stratospheric ozone depletion.

Recent studies have verified the potential effects of UV-R on shallow freshwater ecosystems. For marine systems the data are more scattered, and there is a general lack of *in situ* studies confirming effects of UV-R in the Arctic. For marine systems, it is important to note that results from studies of the persistent ozone depletion over Antarctic areas cannot be directly applied to Arctic systems, due to the widely different species and food web structures involved.

It is also important to remember that aquatic systems can be affected not only by direct effects of UV-R on organisms, but also indirectly, for example through UV-R generating a complex photochemistry in reaction with organic substances such as DOC. Such reactions may create toxic compounds, free radicals and oxidants, but also increase availability of nutrients, trace metals and organic compounds.

For aquatic systems, there are at least three actions that should be given high priority:

- 1) Long-term monitoring of UV-R at selected freshwater and marine sites, including data on key variables such as DOC.
- 2) Study of covariation between UV-R and primary production (including pCO₂) as well as secondary production (bacteria, zooplankton and success of eggs and fish fry).
- 3) Determining the most susceptible components in food webs and energy transfer related to UV-R, such as photosynthesis and key biochemical compounds. Special emphasis should be devoted to

studying the role of UV-R on poly-unsaturated fatty acids that are key component in Arctic aquatic ecosystems.

UV effects monitoring under AMAP

UV effects monitoring under the **AMAP Effects Monitoring Programme** aims to address identified priorities concerning problems with respect to UV in the Arctic. These priorities are reflected in the following questions: What are current UV levels in the Arctic?, What will future Arctic ozone and UV levels be?, and What is the full impact of elevated UV levels in the Arctic?.

Consideration of these priorities has resulted in a number of recommendations concerning monitoring of UV and its effects. These recommendations can be grouped into four main categories: 1) UV and Ozone Research and Monitoring, 2) Effects on Aquatic Ecosystems, 3) Effects on Terrestrial Ecosystems, and 4) Effects on Human Health.

UV and Ozone Research and Monitoring

- **Continued monitoring of both ozone and UV at existing sites**

Along with continuation of long-term monitoring programs, increased efforts toward further intercalibration and coordination are essential to ensuring high-quality UV observations.

Additional surface UV monitoring is currently needed both at biological research sites and in areas where observations are currently lacking (the Russian Arctic) in order to understand the full impact of future changes to ozone and clouds in the Arctic.

- **Satellite monitoring combined with ground-based monitoring**

Current satellite estimates for UV levels are highly inaccurate in the Arctic where clouds are difficult to distinguish from snow and ice covered surfaces. Efforts to improve these estimates may help estimate UV over currently unmonitored areas. Satellite monitoring should also include optical properties of sea water (Chl.a., DOC) to provide information for resolving the food-web and other integrated effects.

- **Enhanced coordination between atmospheric scientists and biologists**

Effort should be made to study the effects of UV peaks during the springtime, when aquatic productivity is at a maximum and fish eggs and larvae are concentrated in the upper water layer. Models with the power to predict ozone depletion events should be developed so that these predictions, together with information from ozone monitoring, etc., can be made available to biologists, who can then mount field campaigns to quantify effects.

- **Efforts toward understanding past changes and current changes in ozone and UV levels, and the relationship between these.**

Paleorecords of UV-B effects need to be assessed on both land and in aquatic environments in order to place current effects of prevailing UV-B levels in context. Studies, such as those examining the relationships between UV levels and meteorological conditions, etc., on populations of fish larvae, plankton and other organisms, based on analysis of historical and emerging data, should be conducted and/or continued. Improved understanding of various species' responses to UV will provide insight into the potential overall connections between UV radiation and fish, seabird, and other populations. These types of studies provide information necessary for the development of more accurate predictions of interactions that are of major significance to those concerned with present and in the future effects.

- **Continuation of activities at the research sites at Abisko (Sweden), Toolik Lake (USA), Svalbard (Norway), Oulu (Finland), and Zackenberg (Greenland)**

The Abisko, Toolik Lake, Svalbard, Oulu, and Zackenberg sites provide long-term records of many biological variables. Additional UV monitoring and examination of data from these sites will enhance understanding of biologically effective UV levels and provide important information

concerning UV-ecosystem interactions. Additional research sites need to be identified and expanded on to provide a more circumpolar understanding of observed effects and future changes.

- **Development of a more solid understanding of UV changes in combination with climate changes**

UV-B radiation levels are changing concurrently with other environmental drivers such as temperature and precipitation. It is known from existing interaction experiments in the Arctic (temperature + UV-B and precipitation + UV-B) that there is the potential for these drivers to interact in complex ways. Interactions can be additive, synergistic or counteractive. Studies of such interactions are difficult to conduct, but are nonetheless important.

UV Effects on Terrestrial Ecosystems

- **Establishment of new long-term ecological monitoring sites to examine terrestrial UV effects**

Terrestrial UV effects include possible responses of the structure and function of a range of ecosystems from the High Arctic to the Subarctic. Long term ecological monitoring sites need to be established to (a) establish permanent plots in a range of plant communities; (b) record UV-B levels on top of, and under canopies; and (c) wherever possible also measure indicators of UV-B effects in the plots. This might include using response variables such as pigment concentration (flavonoids), nitrogen/lignin ratios, DNA damage, etc., and non-destructive measurements for other potential effects, such as annual shoot growth, development, reproduction, species richness and abundance, decomposition and possibly nitrogen fixation rates. These sites/plots would constitute controls for a circumpolar network of low maintenance UV-B filtration experiments (see below).

At a few sites, long-term UV-B enhancement plots should be maintained to (a) measure long-term effects; (b) initiate new short-term experiments within a stable system; and (c) develop methodologies for identifying and quantifying new parameters to monitor as improved indicators of UV-B impacts. Such sites would be consistent with the UV-International Research Centre concept advocated by IASC.

Small UV enhancement plots should be established in the field at a few sites to screen a large number of species for specific UV effects in order to be able to generalise on ecosystems, species and processes responsive to UV.

- **Circum-Arctic measurements of ecosystem responses**

A circumpolar network of low maintenance UV-B filtration experiments should be established to measure the same variables as in the 'treatment' plots. After receipt of information concerning possible extreme ozone depletion events, short-term (for the duration of the event) filtration experiments and controls should be quickly established to detect any short term effects.

A circum-Arctic measurement of plant protective pigments and/or plant DNA damage is also recommended; with a single laboratory responsible for all laboratory work for a broad-area study of the effects of UV. The single laboratory approach will ensure uniformity in treatment and interpretation of the samples. Studies into the occurrence of cataracts and other ocular disorders in terrestrial animals, such as dogs, as a result of UV exposure may also be warranted.

- **Manipulative experiments**

Intensive laboratory and field experiments to determine UV-B effects on specific processes such as action spectra, wavelength specificity of UV, spectroscopy research into response functions, effects on vertebrate and invertebrate animals (e.g., cataract formation and other ocular disorders – or indeed adaptations to withstand high UV-B, transmittance through skin, effects on the immune system, etc.) should be continued and expanded.

Experiments such as action spectrum studies and research on the wavelength specificity of the effects of UV, spectroscopy research into response functions, and studies of UV effects on biomass and photosynthesis are required to simulate field conditions and attempt to isolate the

variables most responsible for physiological or other changes in terrestrial ecosystems of the Arctic organisms.

UV Effects on Aquatic Ecosystems

- **Further measurements of underwater UV levels**

Systems such as those now being introduced in Europe to measure UV at a depth of 1 meter in the water (recording UV-B irradiance at one-minute intervals), and satellite monitoring of optical properties of sea water should be employed to quantify UV amounts and better define the tolerance thresholds of aquatic species. A particular task is to resolve integrated effects throughout the food web, for example, qualitative changes in the phytoplankton community may substantially affect higher trophic levels and add to the direct effects on each trophic level (e.g. zooplankton and fish). Effort should be made to study the effects of UV-peaks during springtime, when aquatic productivity peaks and many pelagic fishes spawn in the upper layer.

- **Improved knowledge of the relation between UV and detrimental effects to fish populations**

Biological monitoring is required to illuminate the effects of increased radiation on marine ecosystems, in particular studies should focus on commercial fishery species, such as Arctic cod and salmon, that are highly sensitive to changing UV levels. Efforts should focus on areas where existing research infrastructure exists and fish spawning is particularly important such as in the North Atlantic/Barents Sea and Bering Sea areas. Close collaboration among radiation scientists and biologists is essential.

- **Increased knowledge of the relationship between climate warming, dissolved organic carbon (DOC), and changes in underwater UV environments**

Studies relating changes in the above variables and their implications for planktonic, benthic, and fish communities are essential for understanding the response of freshwater ecosystems to the potentially synergistic effects of climate change and UV on freshwater ecosystems. These studies might focus on zooplankton as recent studies suggest that zooplankton are a particularly UV-sensitive link in freshwater food chains and more sensitive to UV than either primary producers or fish.

Recommendations for Studying Effects on Human Health

Components of the **AMAP Effects Monitoring Programme** that address UV effects on human health are covered in the next section of this document (Monitoring effects of contaminants in humans). These effects monitoring components are directly related to the following requirements and issues.

- **Effects of changing UV levels on human skin**

Establishment of baseline data on the prevalence of acute skin damage in the Arctic population is essential to understanding whether such cases are becoming more prevalent as UV levels increase.

- **Improved understanding of the relation between UV levels and ocular dysfunction**

Work is required to determine direct links between snow blindness, cataracts, and other ocular disorders and UV, including possible follow-up studies to earlier work such as that conducted by researchers in Alaska.

- **Additional work directed to understanding the role of UV radiation in immune suppression.**

To investigate the ability of UV radiation to induce changes in immune suppression.

Monitoring effects of contaminants on humans

Introduction

An increased incidence of infectious diseases in the Arctic area is reported. There is also evidence that levels of organochlorine contaminants in some Arctic mammals may influence their ability to mount an effective immune response (Simmonds and Mayer 1997). Knowledge gained from animal studies raises questions about whether similar effects might occur in humans. For example, experimental studies on seals have shown reduced levels of retinol (vitamin A) and thyroid hormones in blood of seals feeding on highly PCB-contaminated fish (Brouwer *et al.* 1989). Vitamin A deficiency can lead to alteration in immunity; thyroid hormones are important in development and growth including neurological development (Jenssen 1996). It has been suggested that reduced retinol and thyroid hormones may be involved in reproductive disorders and viral infections of mammals in the Arctic area.

Chemical contaminants in food (POPs and heavy metals including methylmercury) are among the most important sources of environmental exposure of Arctic populations (AMAP 1998). In general, the effects of heavy metals are well described. Methyl mercury exposure is a particular concern in the Arctic due to its neurotoxic effects. The relationship between environmental exposure to methylmercury and childrens' development has been documented in a number of studies, most recently in the Faeroe Islands (Grandjean *et al.* 1997, Murata *et al.* 1999). Whilst effects due to POPs are less well understood, it is known that some Arctic populations have very high intakes of certain POPs as a result of their biomagnification in food-chains. Consequently exposure to these contaminants has a high priority in relation to potential health effects in the Arctic populations. Although tissue levels in humans decreased from the 1960s to 1980s as a result of national and international bans and restrictions on use, trends during the past 15 years are less obvious. Continuing use of chemicals responsible for emissions of POPs, and continuing contamination of the Arctic as a result of long-range transport of these substances means that there is an urgent need for appropriate risk assessment and, if necessary, the development of appropriate health advice within the Arctic. Increasing the level of knowledge concerning human health impacts of dietary POP exposure through epidemiological studies of sensitive health outcomes in high-risk populations is therefore an essential activity under the **AMAP Effects Monitoring Programme**.

The objectives of the human health effects programme are:

- Analysis and quantification of the impact of environmental factors of human health.
- Establishment of methods to assess environmental hazards including mixed exposures, cumulative and low dose effects.

Expected outcomes of the human health effects programme are:

- Improved scientific and public knowledge on the links between exposure, health outcome and risk taking advantage of the cross-border environmental diversity of the Arctic.
- Identification of dose-response relationships between specific environmental exposures and health outcomes.
- Support to decision-making in environmental and health policies.
- Providing knowledge on links between diet and chronic diseases and disorders.

The human health monitoring programme also covers UV effects on humans, and the collection of information that is required in relation to AMAP components under the Arctic Council's Children and Youth in the North programme.

Scientific background and innovative aspects

Assessment of the effects on reproduction and development are considered the most relevant in future epidemiological studies of human health impacts of POPs. Research into effects on fertility are particularly relevant because human fertility is known to be sensitive to certain environmental exposures; evidence from experimental and wild-life studies further supports this relationship (Guillette *et al.* 1995, Fry *et al.* 1995, Sumpter *et al.* 1995, Wolff *et al.* 1995, Carlsen *et al.* 1995). Few studies have, however, addressed the impact of environmental contaminants on reproductive health. Consequently the human health effects programme includes study of POPs impact on the entire range of female, male, and neonatal reproductive functions.

The combined effects on humans of complex mixtures of POPs present in food, a number of which exhibit estrogenic and anti-estrogenic, androgenic and anti-androgenic activity, cannot be directly deduced from single compound experiments using animals. A further complicating factor in animal to human extrapolation is pronounced interspecies variation in capacity to metabolize xenobiotic substances (AMAP 1998).

Although the male reproductive system may be more vulnerable to environmental disrupters during fetal development than after puberty, it is possible that POPs may interfere with the rapid cell proliferation during spermatogenesis in adult life. From occupational surveys there are several examples of substances causing suppression of spermatogenesis at exposure levels not associated with other known adverse health effects (Bonde 1995, Joffe 1995, Olsen 1999).

The public health impact of POP contamination of human food has been investigated in a few studies on cancer risk (Daston *et al.* 1997, Ekbohm *et al.* 1997), pregnancy failure (Rylander *et al.* 1998, Rylander *et al.* 1999, Rylander *et al.* 1995, Swain 1991), and developmental cognitive disturbances (Jacobsen and Jacobsen 1996), however, results are neither consistent or conclusive. A time-to-pregnancy study did not reveal delayed conception among consumers of fish from Lake Ontario (Buck *et al.* 1997), however duration of exposure was rather short and not quantified. Preliminary results of a Swedish time-to-pregnancy study indicates delayed conception related to POP body burden levels in smokers, but not in non-smokers. Animal experiments indicate reproductive toxicity following low level exposure to POPs, however, to date, epidemiological data have been too limited and gaps in knowledge too large to permit evidence based risk assessment and management.

Traditional foods consumed by Arctic indigenous and local populations, in particular marine foods, are of vital importance from a nutritional point of view because of their content of fatty acids, vitamins and trace elements. For social and cultural reasons these foods constitute the main dietary components of some Arctic indigenous peoples. However, these foods (marine foods in particular) are susceptible to contamination as a result of bioaccumulation and biomagnification in the food chain. It is therefore a matter of high priority to establish the extent to which the health benefits derived from consumption of traditional foods might be compromised by environmental contamination.

The AMAP Human Health Effect Monitoring Programme

A programme with the objective to reveal relationships between human exposure to xenobiotic substances and human health, based upon analyses of epidemiological data, existing as well as new, supported by analyses of relevant biomarkers of effects.

It is intended that the full programme should be carried out in selected key areas, however some effects studies are considered essential in all key areas.

Components of the programme are as follows:

A. Epidemiological Effect Markers

⇒ Morbidity/Mortality data

General morbidity/mortality data, also including incidence of skin cancer and cataracts (in relation to UV exposure).

⇒ Fertility studies

Effects of POPs on human fertility may be caused by toxicity to the male as well as to the female reproductive system; the time of highest susceptibility may include the pre-, peri- and postnatal period as well as gametogenesis during adulthood. Both sexes are exposed to contaminants during all periods of life.

- **Time to pregnancy (TTP)**

The time, or number of menstrual cycles, it takes for a couple to conceive following discontinuation of contraception. TTP is a measure of fertility at the couple level, which reflects impaired reproductive performance in both males and females regardless of prenatal or postnatal etiology. Early embryonic loss, which tends not to be recognized as such, is also reflected by a relatively longer TTP. TTP is therefore a crude but sensitive measure capturing several events which may lead to subfecundity.

- **Semen quality and quantity**

Sperm studies enable separation of male-mediated from female-mediated effects, since reduced male fecundity following toxic exposure is likely to be associated with reduced semen quality. Moreover, sperm studies may pick up effects which are not found in TTP studies since sperm count must be reduced below a certain level (ca. 40 million per ml) to cause reduced likelihood of pregnancy. The TTP and the sperm studies are therefore complimentary and provide a comprehensive measure of fertility.

- **Sex hormones**

Reproductive hormones. The serum concentrations of FSH, Inhibin-B, LH, testosterone, sex hormone binding globulin and estradiol are measured in blood samples from the male partners providing semen samples and their spouses. Analyses are carried out using standard ELISA techniques.

⇒ **Pregnancy outcome**

- **General indices:**

Abortion

Gestational-age

Placenta weight

Data on birthweight, birth length

Sex of child, single, multiple, liveborn, stillborn

- **Developmental anomalies:**

The offspring undergoes clinical examination for maldescent testis, hypospadias, epispadias and measurement of ano-genital distance, and other indices.

Cancer incidence.

⇒ **Immunological effects**

- Hospitalization
- Vaccination response
- Antibody HIB, Vitamin A and cytokines.

⇒ **Neurological effects**

- Milestones + age
- Pre-school tests:
 - Neurophysiological and neuropsychological tests
 - Auditory and visual tests
 - Thyroid hormone

B. Molecular/Genetic Effect Markers

Human Health and Chemical Mixtures: Xenohormone Effects

Objectives

To characterize the impact of dietary persistent organochlorines (POPs) on human reproduction and cancer risk in accordance to the xenohormone hypothesis by studies of circumpolar populations with within-country contrast exposure levels. The potential of POPs to interfere with reproductive hormone regulations will be evaluated by measurements of estrogenic and androgen activities in blood cleared for endogen steroid hormones

Project description

A number of lipophilic POPs possess estrogenic(anti) and/or androgenic(anti) properties. Some bind to the estrogen receptor (e.g. DDT, Toxaphene, PCB#126, #138, #153, #180) (Bonefeld Jørgensen et al. 1997, Bolger et al. 1998, Bonefeld-Jørgensen et al. 1999), some bind to the androgen receptor (e.g. DDE, PCB#138, vinclozolin) (Crisp et al. 1998, Kelce and Wilson 1997, Bonefeld-Jørgensen et al. 1999), others bind to both receptors (PCB#138 and, e.g., metabolites of methoxychlor). Moreover dioxins have been characterized as antiestrogenic due to their Ah-receptor mediated interference of estrogen receptor activities (Safe 1994, Kharat and Saatcioglu 1995).

Most studies have been carried out using single compounds, whereas humans are exposed to complex mixtures of chemicals.

To obtain an approximated real time “endocrine disruption”, organ target exposure methods have been developed to separate POPs from endogen steroids in human blood samples.

Screening for sexual hormone-like activities is carried out on blood samples that are HPLC fractionated into three fractions; steroid, lipid and water soluble (Sonnenschein et al. 1995). Estrogenic (anti) and/or androgenic (anti) activities in the lipid fraction will be measured using reporter-gene constructs and human cell culture systems. These techniques are presently validated for larger scale field studies in the programme “Health Promotion and Prevention Research” of the Danish Research Council.

Outline of a molecular/genetic programme for each key-sampling area (5 years intervals)

- *Blood tests from 200 subjects (100 men and 100 women)*
Requirements: subject interviews with standardized dietary questionnaire, POP measurements carried out by laboratories with documented AQ/AC.
- *Extraction and separation of endocrine disrupting substances (EDS) from natural hormones in human serum by solid-phase HPLC analyses.*
- *The potential of the EDS-fraction to effect estrogen receptor (ER) activities*
determined by validated cell proliferation and transient reporter-gene assays using a ERE-tk-Luciferase expression vector and human breast cancer cell lines. This assay is sensitive in the picomolar level.
- *Test for total (anti) androgenic activity*
determined by transient reporter-gene assays in Chinese Hamster Ovary (CHO) cells cotransfected with expression vectors for the human androgen receptor (AR) and mouse tumour virus (MMTV)-Luciferase. This assay respond at the 100 ppb level, and is estimated to respond to androgen effect in serum concentrated 5-fold.
- *Test for total dioxin-like AH-receptor activity*
determined by the use of cell lines carrying a stable integrated AHRE-Luciferase reporter-gene construct, the rat hepatom cell H4IIE and human hepatom cells TV101L, respectively. The first assay is sensitive at 0.3 fmol 2,3,7,8-TCDD, and has been used for test of blood samples.

Deliverables

Data on estrogenic, androgenic and dioxin-like activity of blood samples from 200 individuals (men and women) half high and half low exposed load/burden respectively.

Expected results

Total estrogenic, androgenic, and dioxin-like activities in human blood available for epidemiological data analysis

The programme will be evaluated and if necessary adjusted according to recommendation arising from the Biomarker Conference (Anchorage, May 2000).

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Human Effect Monitoring Programme

Bio-Physical Indicators		Epidemiological Effect Markers		Molecular/Genetic Effect Markers
Health Statistics	E E	Morbidity/Mortality data Incidence of skin cancer and cataract (UV effects)		
Fertility studies				Receptor/hormone toxicology - 'Real time' measurements in steroid hormone cleared blood samples
<ul style="list-style-type: none"> Time to pregnancy (TTP) 	R	Time or number of menstrual cycles it takes a couple to conceive from discontinuation of contraception	R	Estrogenic-, androgenic- and dioxin-like activities
<ul style="list-style-type: none"> Semen quality and quantity 	R	Sperm count/volume Sperm quality/mobility	R	Estrogenic-, androgenic- and dioxin-like activities
<ul style="list-style-type: none"> Sex hormones (in blood from male partners providing semen samples and their spouses) 	R	Serum concentrations of FSH, Inhibin-B, LH, testosterone, sex hormone binding globulin and estradiol		
Pregnancy outcome				
<ul style="list-style-type: none"> General indices: 	E	Abortion Gestational age Birth weight/length Sex (single/multiple) Placenta weight	R	Estrogenic-, androgenic- and dioxin-like activities
<ul style="list-style-type: none"> Developmental anomalies 	R	Maldescent testis Hypospadias Epispadias Ano-genital distance and other indices Cancer incidence	R	Estrogenic-, androgenic- and dioxin-like activities
Immunological effects	R	Hospitalization Vaccination response Antibody (HIB), Vitamin A and Cytokines	R	Dioxin-like activities
Neurological effects	R R	Milestones + age Pre-school tests: Neurophysiological tests Neuropsychological tests Audiogram and visual tests Thyroid hormone	R	Estrogenic-, androgenic- and dioxin-like activities

Rational and issues concerning selection of species

There are several basic considerations that determine selection of species for inclusion in the **AMAP Effects Monitoring Programme**. Given the difficult field conditions that prevail in the Arctic, a main criteria is clearly that species collected/studied in the wild are logistically amenable to study (can be found, obtained, used, etc.). Species must also be susceptible to the contaminants and/or other stressors that are being considered (i.e., sensitive, and likely to be exposed). In addition, other factors need to be taken into account. In order to link effects studies and contaminants monitoring studies (including that undertaken under the **AMAP Trend Monitoring Programme**), it is clearly a high priority to select the same species for both the effects and contaminants monitoring work. In some cases, therefore, the species selected for the effects components represent a compromise between the requirements of the effects study and those of the trend monitoring programmes. It may be relevant to select species that are important functional components of a community or ecosystem (e.g. keystone species).

For the **study of climate change effects**, identifying the organisms and species that are most sensitive to climate change is a difficult task. The selection of indicator species should, therefore, be based on a wide range of criteria, including: (i) selecting species at the extreme ends of their range, on the basis that outlier populations are typically the most sensitive to climate change, and extinctions or invasions are easier to quantify at range limits; (ii) selecting both dominant, common and rare species; (iii) selecting both long- and short-lived species; (iv) selecting both migratory and non-migratory species; (v) selecting species amenable to monitoring/research; (vi) including all main plant life-form types that occur in Arctic areas (dwarf-shrubs, evergreen plants, graminoid plants, cushion plants, herbaceous plants, lichens, mosses - acrocarpous and pleurocarpous - and liverworts); and (vii) selecting species that are representative of ecological webs (key-stone species, functional groups) and represent different trophic levels (above ground: large- and small-herbivores, birds, vascular plants, mosses and lichens; below ground: invertebrates, bacteria).

Where possible, the programme promotes the use of non-lethal sampling methods for biological effects endpoints, in particular for species that may be endangered such as some eiders, and polar bears and other marine mammals. Consideration should also be given to life stage of animals used, both to minimize the possible impact of the effects study and also to ensure that appropriate life stages are used (e.g., for migratory birds a sampling of older nestlings or recently fledged chicks in mid to late summer may be preferred since young birds contain contaminants from a known geographic locality). It is important also to recognize that in some types of study, for example examination of recovered corpses of stranded marine mammals or dead birds, the sample may be intrinsically biased towards less healthy animals.

Rational for selection of biological effects techniques

Drawing mainly from work on biological effects in the marine environment, a number of available biological effects methods are listed in Annex 1 to Section G; this list also includes comments concerning the state of development of the methods and QA/QC considerations etc., and their applicability in monitoring programmes.

It should be stressed that many of the listed methods have been developed for application under temperate regimes and may need to be further developed/refined for application under Arctic conditions.

Considering analysis of changes in population and community structure (i.e., population density, species composition/diversity), these methods are generally most appropriate for relatively short-lived invertebrates or algal species. The benthic community is particularly well suited, as methods for assessing changes in benthic community structure are well established with a long history of application.

Scope for growth is one of the most widely and well-developed of the physiological effects measures. Metabolic rate measures may also be sensitive indicators of physiological stress and could be included in a scope-for-growth assessment.

A suite of available cellular and biochemical methods are now suitable for inclusion in monitoring programmes. These include lysosomal stability, AchE inhibition, metallothionein, EROD, and PAH bile metabolites (although only for a limited number of laboratories). Of these, lysosomal stability and AchE inhibition can be applied in routine monitoring programmes provided practicalities involved in sampling can be accommodated; EROD/ Cytochrome P4501A induction should be included in the suite to interpret results. Methods for the measurement of DNA damage and/or alkali elution methods will soon be available for routine use. In considering how such a suite of methods might best be combined within a monitoring strategy, lysosomal stability (by the assessment of neutral red leakage) has been recognized as a technique known to respond to a wide range of contaminants, and to be relatively rapid and inexpensive. The measurement of lysosomal stability in mussels and a fish species is therefore considered suitable as a first tier screening procedure. At the same time, it is important to recognize that a screening strategy using only one test may run the risk of failing to detect toxicants at significant levels, thus necessitating inclusion of other methods in a battery of screening techniques, or a supporting chemical monitoring programme.

Investigations should preferably include both monitoring/research techniques using methods of early warning and 'end-point' effects. Early warning indicators include behavioural responses, imposex/intersex or lysosomal changes. Examples of 'end points' include disease (such as carcinogenesis, necrosis, as an end point of cellular interference or Cytochrome P4501A changes) and some population changes.

Different types of sampling conditions may influence the suite of effects biomarkers that are utilised in a given study. For example, effects studies on marine mammals may be conducted under several types of circumstances: live captive animals in aquaria/sanctuaries (e.g. behavioural and feeding experiments); live capture/release (e.g. blood/blubber biopsy and morphometrics on animals captured for radio-tagging studies); samples from animals collected during subsistence hunting; stranded animals (possibly semi-decomposed specimens, impaired health/condition may have led to stranding); biopsy samples taken from animals in wild.

General monitoring strategy for combined effects studies

The AMAP workshop on '*Combined effects in the marine environment*' (Copenhagen, November 1998), the full report of which can be found on <http://www.amap.no> (under the links to on-line documents) proposed a general strategy for the application of combined effects assessment (see Figure C1, below). This strategy follows a step-wise approach recognizing that the assessment may be initiated under different starting conditions in relation to the amount of knowledge that already exists about the sources and types of contamination that are influencing the system under consideration.

Although developed in relation to assessment of combined effects in the marine environment, the general strategy outlined in Figure C1, may also be applied to combined effects studies in terrestrial/freshwater environments.

The amount of information available prior to the start of the effects assessment will have an important influence on the types of effects measured and on the extent to which general screening tests will be required. In some situations, an effects assessment may be initiated with contaminant(s) and/or contaminant source(s) already known/identified (e.g. oil exploitation or mining areas, areas affected by an oil spill, DEW (distant early warning radar) line sites, areas identified as having elevated contamination under AMAP first phase activities, etc.). Under these scenarios, the question of 'are there ecological effects' may still be an issue. However, where this question has been answered, the objective of the effects assessment may rather be to quantify (in space and time) the severity of the effects.

As indicated in Annex 1 to Section G, a wide variety of effects measures are available (for the marine environment) from which an appropriate combination of tests may be selected depending on whether a general **screening** or more **focussed testing** (in terms of contaminant, species, or level of organization) is desirable. Although different tests may be appropriate for specific scenarios under consideration, it is possible to identify general attributes of effects measures that should be sought at the screening stage and to perform a more focussed effects assessment.

Screening tests should:

- Be practical for routine use, using well-established methods that are efficient in time and cost, have good quality control, and do not have special requirements with respect to sample handling in the field
- Be able to detect a wide variety of effects
- Have high statistical power
- Include all potentially relevant compartments (i.e., water, sediment, food)
- Avoid using endangered species (where this is not possible, only approaches using non-invasive techniques should be employed)

Focussed tests should:

- Provide confirmation of screening results
- Establish the spatial/temporal scale of effects
- Enable quantification of the severity of effects in terms of likely risks to ecological systems or human health
- Identify species or populations most likely to be at risk
- Identify or confirm causal agents

For general screening purposes, in the marine environment, tests representing four different types of approach are recommended, as follows:

I. Bioassay:

- Whole sediment bioassay
- Porewater bioassay
- Water bioassay
- Simple behaviour test (invertebrates)
- Early life stage tests (invertebrates, fish)

II. Biomarker:

- Reproductive success (fish, birds)
- Clinical variables/hormones (birds, mammals)
- Endocrine disruption (e.g., vitellogenin, imposex)

III. Population/community:

- Fish disease prevalence (gross pathology)
- Benthic community structure
- Seabird/mammal counting (e.g., oiled bird ratios)

IV. Chemical monitoring:

- Focussing primarily on sediment and tissues of key trophic groups

Once the magnitude of effects has been quantified, the next step in the effects assessment is to identify the causes of the observed effects where these are not known. This may initially involve reducing the list of possible contaminants based on knowledge of local activities or environmental contaminant levels, possibly employing the type of approach outlined in Figure C2 to aid in eliminating unlikely agents.

A final step in the combined effects assessment will be to identify the source(s) of the causal agent(s). This could involve the application of various types of transport models and/or chemical fingerprinting techniques.

The results of the effects assessment are used to develop management strategies. These may often involve continued monitoring, using a selection of screening tests or more focussed measures, to provide feedback on the effectiveness of the management efforts and facilitate adjustments in management actions as necessary.

Strategy for monitoring biological effects in the marine environment

Following an evaluation of available biological effects methodologies for the marine environment, the workshop on '*Combined effects in the marine environment*' recommended the following strategy for biological effects monitoring. The lysosomal stability (by the assessment of neutral red leakage) technique is known to respond to a wide range of contaminants, to be relatively rapid and inexpensive, and to be suitable as a screening procedure.

Other techniques are generally more demanding on facilities and resources, but also tend to be more specific with regard to the contaminants to which they respond. Measurement of lysosomal stability in the common mussel and a fish were therefore proposed as first tier screening tools, with more specific methods then employed as a second tier in response to positive results from the lysosomal stability test. The structure is given in more detail in below.

Biomarker strategy

Measurement	Mechanism of toxicity, or process assessed	Matrix	
		Mussel	Fish
Lysosomal membrane stability	Leakage of lysosomal membranes	Yes	Yes
AchE	Neurotoxicity	Yes	Yes
Metallothionein	Detoxification of metals	Yes	Yes
EROD	MFO Phase 1 enzymes		Yes
Bile PAH metabolites	Metabolism of PAH		Yes
DNA damage	Genotoxicity	Yes	Yes
Lipofuscin and neutral lipid accumulation, phospholipidosis	Pathology of lysosomes (metals, ROS)	Yes	Yes
Vitellogenin	Female reproductive hormone levels in males		Yes

It must be recognized that relying solely on lysosomal stability as a screening procedure runs a significant risk of failing to detect toxicants at significant levels. In general, however, positive results from this test are closely correlated with adverse effects in the test organism, and false positives are therefore unlikely to be a common occurrence. The test appears to reflect a generalised response to toxin stress and is known to respond to a wide range of organic toxicants and also to various heavy metals. There is also some possibility of false negatives, for example TBT at environmentally significant levels does not cause a response in an earlier lysosomal stability test, however it is not known whether the current (neutral red retention) test shares this feature. Further experience in the use of the method is therefore desirable to clarify the frequency and significance of false negatives.

The methods included in the recommended strategy cover a range of mechanisms of toxicity and of adaptive responses, however it lacks assays for the potentially important mechanisms of immunotoxicity or for the disruption of hormone systems other than the effects of environmental estrogens on sex hormone system.

It must also be remembered that methods developed for application under temperate regimes need to be verified and if necessary further developed for application under Arctic conditions.

Figure C1. Strategy for Combined Effects Assessment

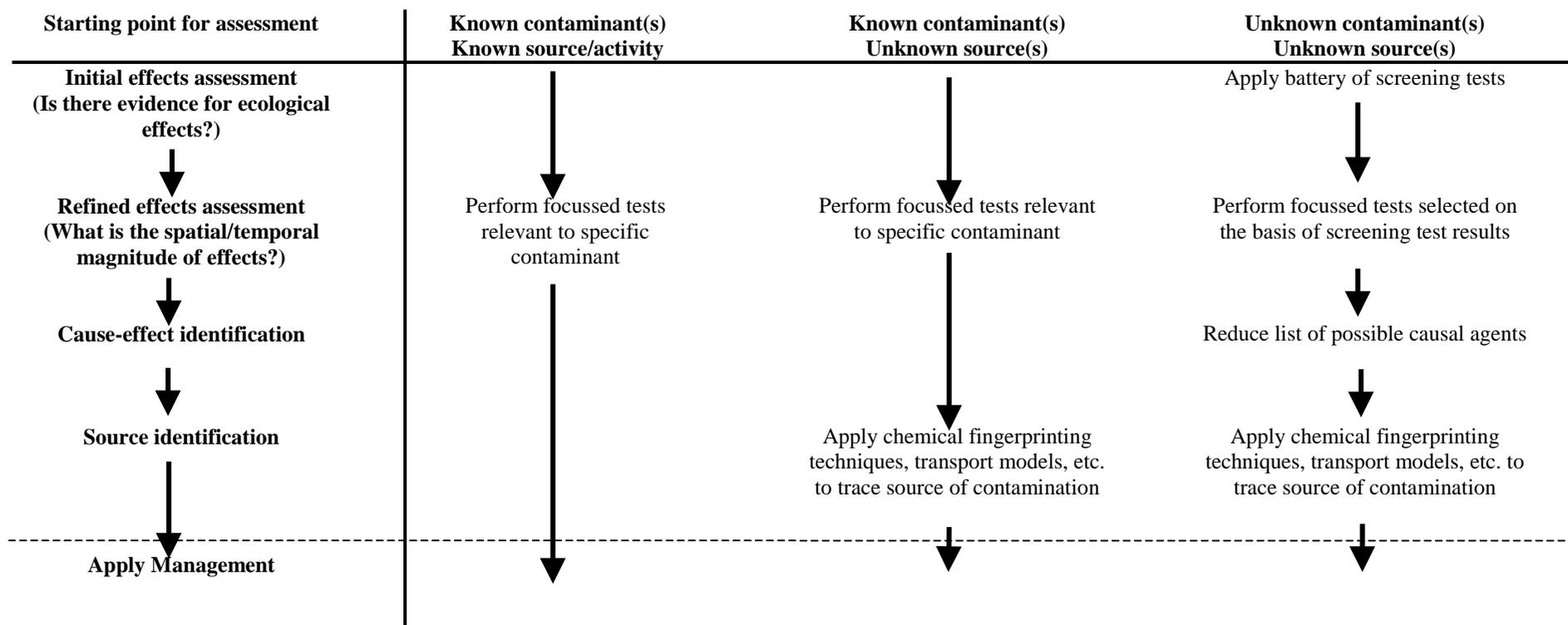


Figure C2. Identifying possible causes of pollution and prioritizing them for combined effects assessment.

1. Search international lists of hazardous substances.
2. Identify contenders for a regional or subregional priority list by considering if any substance from point 1 is likely to arise from industrial activities in and around the region or subregion. Most will be rejected as low or zero priority.
3. Are those from point 2 recorded within the region or subregion?
 - If yes:** compare environmental concentrations with likely effects levels
 - If no:** is this because there have been no attempts to monitor?
 - If no:** discard as low or zero priority.
 - If yes:** is the substance likely to be persistent?
 - If no:** discard as low priority.
 - If yes:** proceed with focussed effects measures.
 - If effects not detected:** discard as low or zero priority.
 - If effects detected:** perform refined effects assessment.

Table C.1. Table of selected effects endpoints

Ecological response endpoints			
Population/community level	Population studies	Population trends	
		Species richness and distribution	
		Demography	
		Habitat diversity and distribution	
		Species phrenology Vegetation phrenology	
		Ecotone displacement	
		Changed biodiversity/composition	
		New species introductions Reduction in existing species	
	Community analyses	Species composition Community composition Community structure	
	Reproduction and growth	Reproductive success Fertility Growth rate	Eggshell thickness Mosses, lichens
		Growth in population/stock	Changes in maturation timing Changes in recruitment Egg/larval/fetal disturbances and mortality
	Vegetation damage	Defoliation, discoloration, easily identifiable damage, foliar analysis, ground vegetation (composition) Diatom acidification history	
Individual level	Growth	Scope for growth	
	Exposure	Dose Flux vulnerability	Radioactivity
		Oiled to non-oiled bird ratios	Oil
		Incidence of cataract in animals	UV
	Morphometrics	Gross morphology Organ integrity Fat-content	Age, sex, reproductive condition, nutritional status, body condition, length,

		Egg size, shape	weight, organ weights and measurements, and external measurements
		Condition indices	
		Condition factor	liver wt / total weight
	Pathology and disease	Gross pathology Disease Histology / Histopathology	
	Immunological effects	Immunocompetence Immunotoxicity Vitamin status (retinol)	
	Molecular/Genetic effect markers	Hormone status	
	Behaviour	Avoidance Feeding	
	Cellular and biochemical methods, including enzymatic activities	ALA-D (δ -aminolevulinic acid inhibition)	
		Metallothionein induction (MT)	
		EROD (Ethoxyresorufin-O-deethylase) or cytochrome P4501A induction*	
		Bulky DNA adduct formation	
		Fluorescent bile metabolites	
		Lysosomal stability Membrane stability	
		Heme-oxygenase Porphyrins	
		Imposex	TBT
	Bioassays	Sediment pore water bioassay	
Human health effects endpoints			
	Health statistics	Mortality / morbidity statistics	
		Incidence of skin cancer and cataract	UV
	Fertility studies	Time to pregnancy (TTP)	
		Semen quality and quantity	Sperm count/volume Sperm quality/ mobility
		Sex hormones	Serum

			concentrations of FSH, Inhibin-B, LH, testosterone, sex hormone binding globulin and estradiol
	Pregnancy outcome	General indices:	Abortion Gestational age Birth weight/length Sex (single/multiple) Placenta weight
		Developmental anomalies	Maldescent testis Hypospadias Epispadias Ano-genital distance and other indicies Cancer incidence
	Immunological effects	Hospitalization Vaccination response Antibody (HIB), Vitamin A and Cytokines	
	Neurological effects	Milestones + age	
		Pre-school tests	Neurophysiological and neuropsychological tests Audiogram and visual tests Thyroid hormone
	Molecular/Genetic effect markers	Hormone disruption	Receptor/hormone toxicology
		Endocrine disruption	Estrogenic-, androgenic- and dioxin-like activities

Table C.2. List of areas considered essential for monitoring under subregional programmes

Ecological effects monitoring:

Marine

Glaucous gull - Norway (in connection with effects studies)

Freshwater

Lake and river water - Russia

Terrestrial

Peregrine falcon - Sweden, Canada, US

Merlin - Norway

Sea eagle - Sweden, Norway

Acidification effects:

Kola peninsula, Norwegian-Finnish-Swedish-Russian border area, Norilsk

Radioactivity:

Marine

Crawfish, crabs and mussels, fish eggs - Norwegian coast, Ob and Yenisey estuaries, Novaya Semlya, Bylot sound (Thule)

Terrestrial

Reindeer/caribou - Canada, Greenland, Arctic Sweden, Arctic Norway, Arctic Finland, Western Arctic Russia.

Lichen - grazing land for reindeer/caribou

TBT:

Harbours and shipping routes

Climate change and climate change effects:

Marine climate

To be defined

Freshwater/terrestrial climate

To be defined

Marine climate effects

To be defined

Freshwater/terrestrial climate effects

To be defined

UV effects:

To be defined

Monitoring effects of contaminants on humans:

Selected key areas (including Kola peninsula/northern Norway, selected regions of Greenland and northern Canada), however some effects studies are considered essential in all key areas.