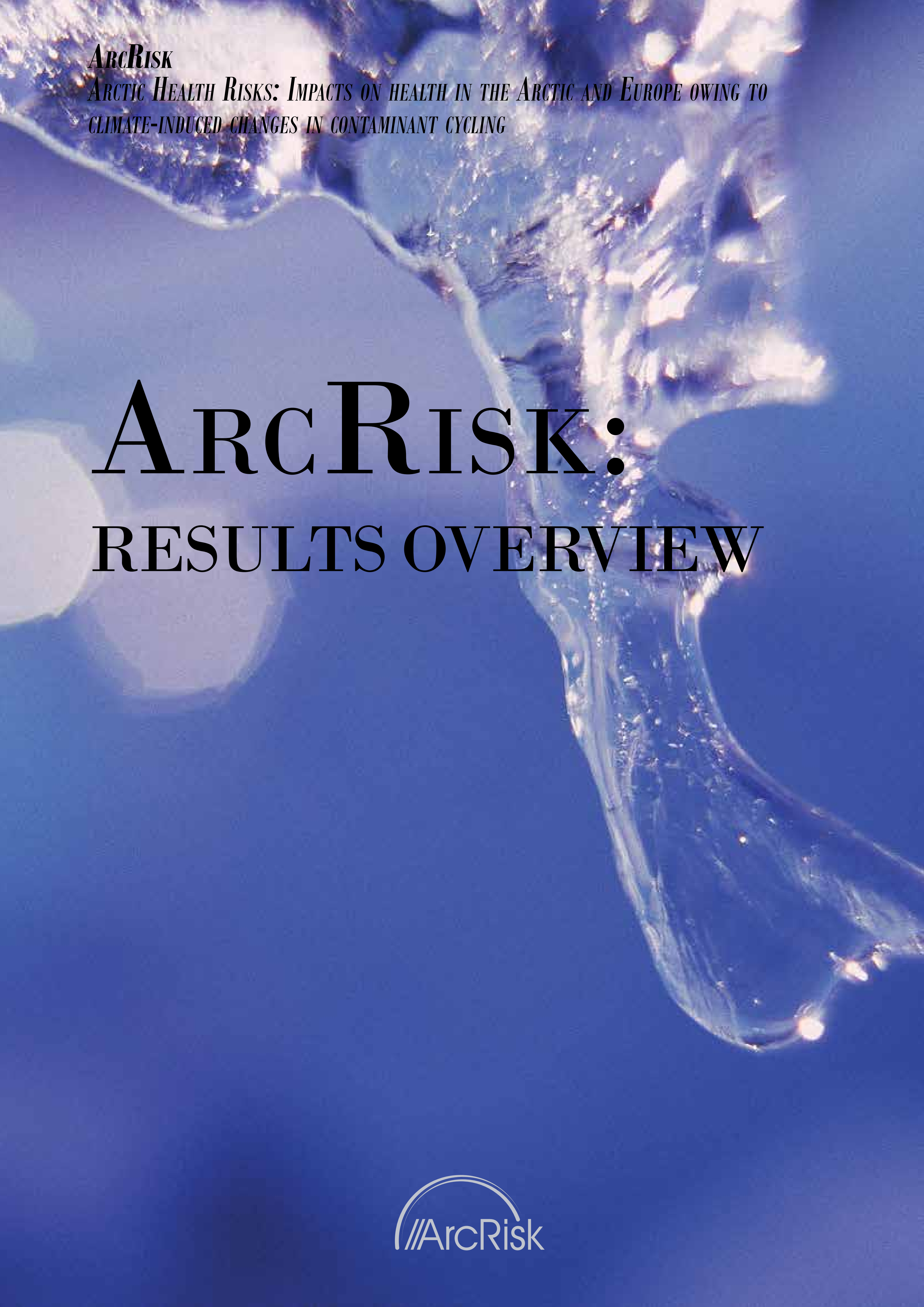


ArcRisk

Arctic Health Risks: Impacts on health in the Arctic and Europe owing to climate-induced changes in contaminant cycling

ArcRisk:
RESULTS OVERVIEW

ArcRisk

WHAT IS THE ArcRisk PROJECT?

ArcRisk is an international EU FP7-funded research activity looking at the linkages between environmental contaminants, climate change and human health – aimed at supporting European policy development in these areas. The Arctic setting provides unique opportunities for research in these fields. The project was implemented between mid-2009 and 2014 and involved 21 institutes from 12 countries.

All of us are exposed to those environmental contaminants that persist in the environment for long periods. In some cases, exposure to such chemicals is high enough to raise concerns about possible effects on human health. Climate change has the potential to alter the pathways by which these harmful chemicals cycle through the environment and enter food chains.

The selection of environmental contaminants for study in the ArcRisk project was based on the broad aim that they could be studied in all parts of the project: modelling their transport, measuring their environmental behavior and fate, and evaluating human exposure and potential health effects; as well as evaluating each of these steps in terms of the possible implications of climate change. For most contaminants, the information needed to follow this step-wise approach was lacking. Sufficient information was, however, available for PCBs (polychlorinated biphenyls) and mercury, and these were therefore chosen for the preparation of case studies to illustrate how climate change can be expected to influence pollutant behavior, fate and human health impacts. Other contaminants chosen for study are listed on page 9.

Research was organized under three main work areas:

1. ArcRisk researchers used models to study the impacts of climate change on pollutant transport to and fate in the Arctic and the transfer of pollutants through food chains to humans; comparisons were made between the Arctic and selected areas in Europe.

   When considering what will happen in the future, there is no crystal ball. Scientists make use of what they know, what they can observe from the present situation, and what they can infer from past changes to construct computer 'models' that simulate real world processes using numerical calculations. They also develop and employ 'scenarios'. Scenarios are essentially a set of assumptions about factors that are important for determining the model outcome. Scenarios can be designed to reflect different policy decisions, for example, regarding future population growth, sources of energy, and economic growth. Models produce 'projections' of future conditions for a given scenario. Modellers are careful to say that they are making projections and not predictions. Whether models produce results that ultimately turn out to be realistic depends on how appropriate the scenario assumptions were, and how well the model represents critical processes at appropriate scales. Checking (validating) models to see how well they are able to represent current 'real world' observations or changes that have occurred in the past increases confidence in their ability to produce reasonable projections of future conditions. Good models quantify and acknowledge the uncertainties associated with their projections for the future. Most modellers would subscribe to the view that "All models are wrong – some are useful" (George Box, 1987).

2. ArcRisk researchers conducted field studies and evaluated observational data to improve understanding of the ways in which chemical contaminants transfer between the atmosphere and marine and terrestrial environments and their uptake into food chains, all within the context of a changing climate.

Many measurements have been made of contaminant levels in Arctic air, water, sediments and soils, and biota (including human tissues) and extensive research has been conducted in recent years to better understand the processes that determine the cycling and fate of contaminants in the Arctic. Much of this work has been coordinated under the auspices of the Arctic Monitoring and Assessment Programme (AMAP). Similar studies have been conducted throughout Europe – many with EU funding. However, significant gaps in knowledge remain, and targeted research and observations are necessary to fill these gaps, among other things to improve the ability of models to capture key processes, such as the role of ice in contaminant transport and fate. New chemicals are constantly being introduced onto the market; some of these will be used in large quantities. The presence in the Arctic of chemicals used in other parts of the world (including their precursors or breakdown products) is an important indication of their widespread use and persistence in the environment.

3. ArcRisk researchers analyzed the results of a number of studies on the effects of contaminants on people in the Arctic and in selected areas in Europe, evaluated sources of dietary exposure, and considered the potential influence of climate change on exposure and human health outcomes.

People everywhere are exposed to a 'cocktail' of environmental contaminants – in the air they breathe, in their drinking water, and in their food. Human health concerns relating to chemical contaminants that have accumulated in the Arctic environment and subsequently found their way into the fish, marine mammals and reindeer used by some Arctic people as sources of traditional food lie at the core of the ArcRisk project. Although these issues have been documented and to some extent addressed through, for example, food consumption advisories, there are questions regarding how climate change may alter circumstances in the future, and whether lessons from the Arctic can be applied to other regions.

The Arctic was generally considered to be pristine until observations in the latter decades of the 20th century found many environmental contaminants present in the Arctic – largely as a consequence of long-range transport. However, most of these chemicals are found in Arctic waters, ice, soils and sediments – and in lower organisms – at very low concentrations. The fact that some Arctic populations are considered to be at risk for health effects from contaminants is through a conspiracy of circumstances, involving, in particular, strong biomagnification in Arctic food webs and traditional diets based on consumption of large amounts of lipid-rich foods from animals that feed high up in the food chain. At the same time, it is known that other population groups in Europe may face similar concerns, especially groups that eat large amounts of certain fish.

Health studies take many forms, some are based on laboratory studies, others look at specific study groups of people (especially vulnerable groups), and some follow the study groups over time. In controlled (e.g., laboratory) studies, effects can be more easily identified, but questions still arise about the extrapolation of results, for example, from animal experiments to humans or to real-world situations. In human studies, the complex interactions between chemical effects and other factors influencing human health and research results make it almost impossible to establish causal relationships for low-dose, chronic exposure situations. In such cases, statistical approaches to combine results from multiple studies (meta-analyses) can be useful for establishing at least some potential cause-effect relationships based on weight-of-evidence. These approaches have been employed in the ArcRisk work.

An overarching goal of the ArcRisk project was to bring together and convey scientific information to policy-makers, stakeholders and other interested parties about how climate change might alter our exposure to those environmental contaminants that can affect human health.

Most of the conclusions of the ArcRisk studies relate to legacy POPs and mercury – contaminants that undergo long-range transport and for which the information base is largest. For other contaminants, extrapolations and inferences can be made about their environmental behavior and fate, and transfer though food webs based on similarities between their properties and those of legacy POPs (see chemical space diagram on page 8). However, making similar extrapolations in relation to toxicological effects and human health effects in particular is much more difficult.

Biomagnification is the name given to the process whereby top predators not only consume their prey, but also the contaminants that their prey have accumulated from organisms lower in the food chain. It is the reason why animals feeding at the top of the food chain can receive very high contaminant exposure through their diets. This includes people, both in the Arctic and elsewhere, who consume large amounts of predatory fish.

Some people in the Arctic occupy the top position in this exposure pyramid through their consumption of marine mammals that feed high in the food chain, such as polar bears, seals and toothed whales.

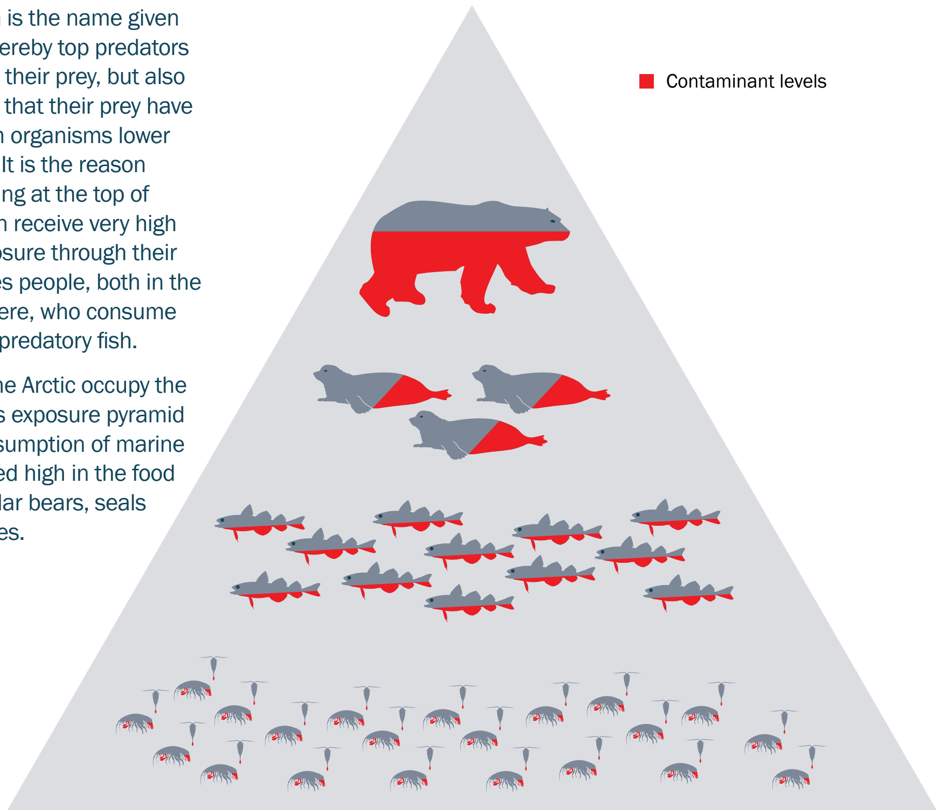


Photo: B & C Alexander/Arctic Photo

WHY FOCUS ON THE ARCTIC?

The Arctic is a region where the environmental and social impacts of climate change are making themselves apparent on a daily basis. **In recent decades, temperatures in the Arctic have risen at twice the global average, ice and snow loss is progressing at unprecedented rates, and the speed of change is exceeding even recent expectations. These changes are bringing associated societal challenges and opportunities.**

When it comes to climate impacts, the Arctic is an important and integral component of the global system. **Through linkages referred to as 'teleconnections', what happens in the Arctic influences the climate and the weather in other parts of the world, and vice versa. The Arctic is frequently referred to as the 'canary in the coal mine' ... the idea being that changes happening now in the Arctic are a tangible warning of what other areas could expect to experience later.**

Environmentally persistent contaminants can be transported to the Arctic from distant sources by rivers and ocean currents and via the atmosphere. Atmospheric pathways are generally faster, but some contaminants arrive following a series of 'hops' involving deposition to surfaces and re-volatilization to the air.

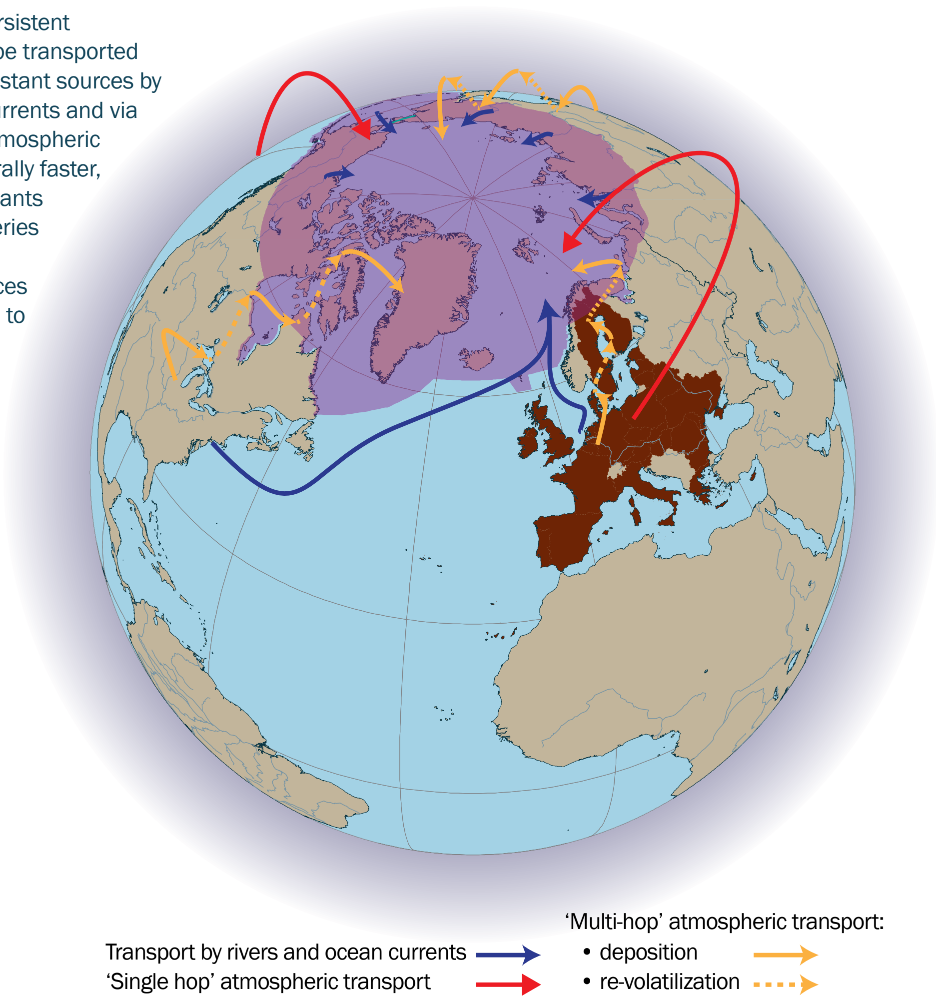



Photo: Pernilla Carlsson

Arctic populations include small, isolated communities, some of which rely heavily on local natural resources for their food supply. Subsistence life-styles are also an important component of their cultural integrity and well-being. Unique circumstances associated with some subsistence diets can result in high exposures to environmental contaminants, including a number of contaminants that originate outside the Arctic and are therefore entering the Arctic diet as a result of long-range transport from emissions and releases in high-use areas, such as industrial and agricultural areas of Europe. However, local sources are implicated in exposure to certain contaminants in some Arctic communities.

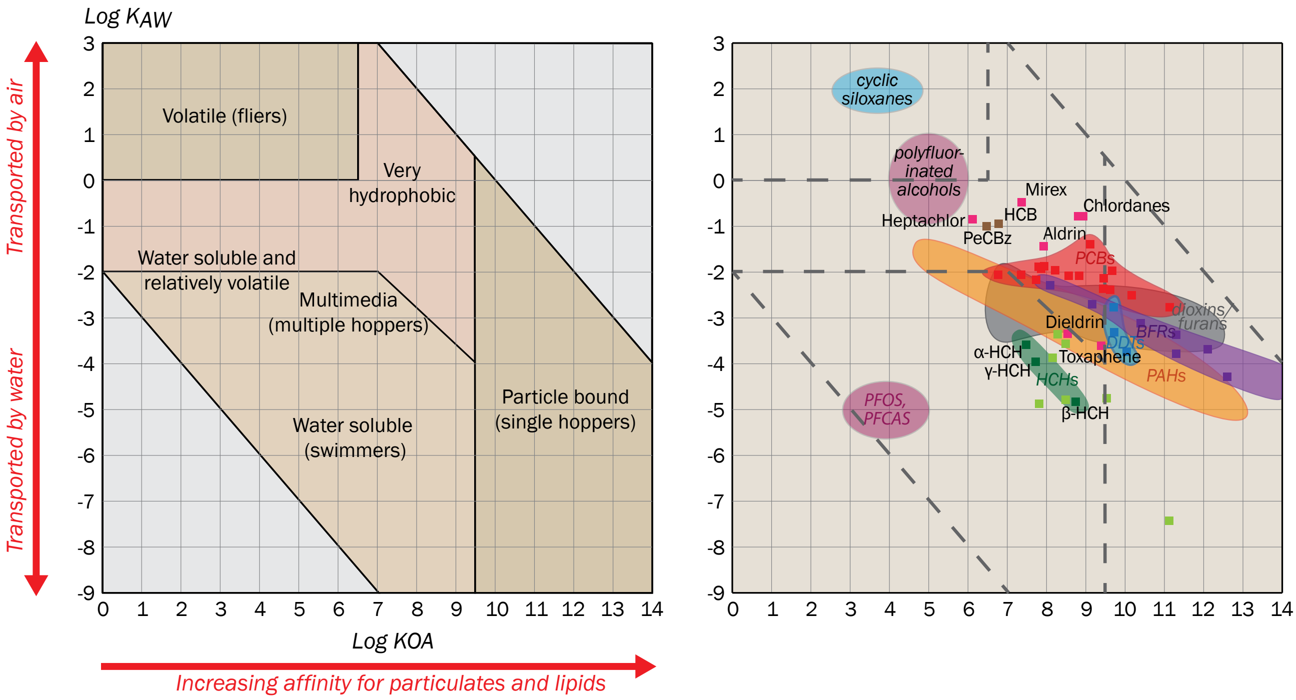
Health studies looking into relationships between contaminants and potential health effects are complex and rely on detailed and well-defined knowledge about the routes of exposure and many other factors that influence human health. Arctic communities, that are both isolated and include some highly exposed population groups, provide a situation with fewer complicating factors that need to be taken into account when studying health outcomes. Nevertheless, Arctic studies must be considered in a wider context in order to provide a sufficiently large study group.

WHAT ARE ENVIRONMENTAL CONTAMINANTS AND WHERE DO THEY COME FROM?

Environmental contaminants are chemicals that enter the environment as a result of intentional use (such as pesticides or herbicides) or unintentional releases (such as dioxins released during incomplete combustion of wastes). Although many of these chemicals serve a useful purpose in their original uses, their subsequent dispersion and accumulation in the environment is highly undesirable, and has the potential to negatively affect the health of humans and ecosystems. Some of these substances have natural sources (such as heavy metals), while others are produced extensively by humans (mainly organic chemicals).

Following their release, environmental contaminants persist in the environment – either in their original form or as breakdown products; they degrade to harmless chemical forms only very slowly. Concern is greatest for chemicals that as well as being environmentally persistent also find their way into food chains (i.e., they bioaccumulate) and are toxic. These characteristics give rise to abbreviations that are commonly applied to groups of these chemicals: PTS (persistent toxic substances) and POPs (persistent organic pollutants).

Owing to their persistence, many of these chemicals are widely dispersed around the globe by winds and ocean currents. The chemicals used in high volumes are found almost everywhere, but as the properties of individual compounds differ so does their 'partitioning'. This means whether the chemicals in the environment associate with air, soil and sediments or water, and in animals whether they accumulate in particular tissues and organs (many POPs concentrate in fatty tissues).



The properties of chemicals can be used to predict their environmental behaviour – whether they will be transported by winds or with ocean currents; or whether they are more likely to remain dissolved or associate with particles or lipids. Contaminants like PCBs consist of a variety of individual compounds that have a range of properties.

Health effects of chemicals released during accidents or resulting from high-dose occupational exposures are often well-documented. Environmental contaminants, however, tend to occur in low concentrations, and so their associated health effects for the general population are difficult to identify; these health effects tend to be associated with low-dose, chronic (long-term) exposure through, for example, diet or inhalation.

The properties of individual chemicals can be used to infer their persistence, bioaccumulation potential and toxicity, and this approach was used in ArcRisk to select substances for investigation. These substances include 'legacy' POPs (substances that have mostly been banned or phased out and where their presence in the environment is a result of past uses) and current-use chemicals, some of which have been used for decades and others that are only now beginning to appear on the market, often as replacements for banned substances. The table (below) shows examples of some of these groups of chemicals.

	Industrial sources/uses	Agricultural/pest control uses (including disease control uses)	Consumer product/ household use sources
Legacy	Polychlorinated biphenyls (PCBs) Hexachlorobenzene (HCB) Pentachlorobenzene (PeCBz) Chlorinated naphthalenes	Organochlorine (OC) pesticides including: • DDT (and its metabolite DDE) • Hexachlorocyclohexanes (α-, β-, and γ-HCH) • Toxaphene • Chlordecone • HCB Chlorinated naphthalenes	DDT Chlordane
Current/ established use (including unintentional emissions from combustion sources)	Brominated flame retardants (BFRs) including: • Polybrominated diphenylethers (PBDEs) • Hexabromocyclododecane (HBCD) Polychlorinated dibenzo-*p*-dioxins and -furans (PCDDs/PCDFs) Perfluorinated compounds e.g. perfluorinated alcohols and perfluorooctane sulfonic acid (PFOS) Mercury Cadmium Lead	Endosulfan	Lindane (γ-HCH) Perfluorinated compounds e.g. perfluorooctane sulfonic acid (PFOS) Brominated flame retardants (PBDEs/ HBCD) Mercury
Newly emerging in the Arctic	Short-chain chlorinated paraffins (SCCPs)		Chemicals used in pharmaceuticals, skin care products, etc., including: • Siloxanes

Colours indicate contaminants included for elimination (red) and restriction (green) under the Stockholm Convention.

ArcRisk KEY FINDINGS

Model simulations conducted under ArcRisk suggest that climate change will affect contaminant pathways and levels in the Arctic and elsewhere; however, most results project only modest changes in levels in air, soils and water as a result of climate change.

ArcRisk modelling results project both decreases and increases in future environmental concentrations of organic chemicals. Model runs with climate change typically project concentrations by 2100 that are half to double those in runs with no climate change.

Climate variability is also important; annual to decadal fluctuations in climate conditions can affect the global distribution of some chemicals, and variability in ocean circulation plays a strong role in the marine dispersion of soluble pollutants affecting regional exposure, residence time and spatial distribution.

Climate change (in particular rising temperatures) will alter the distribution of contaminants between environmental compartments. In general, concentrations in air will rise whereas concentrations in surface soils and water will fall, increasing the potential for long-range atmospheric transport. However, extreme events (which are projected to increase in frequency) may be a more important factor in influencing levels of some contaminants in the Arctic.

The decline in the amount of sea ice that lasts over several seasons is expected to enhance the transfer of contaminants deposited onto sea ice to underlying sea waters. For mercury, where deposition in the Arctic is enhanced in areas close to the sea-ice margin, loss of Arctic sea ice is projected to significantly change the atmospheric deposition pattern.

For the POPs considered in ArcRisk, increases in environmental contamination due to climate change will be offset by increased rates of environmental breakdown in soils and water and, for regulated substances, declines in fresh emissions from use areas.

Phase-out or restrictions on the use of specific chemicals in recent and coming decades are expected to result in declines in primary emissions that will dominate projected changes in environmental concentrations driven by climate change-related effects. This is confirmed by ArcRisk studies of temporal trends in previously regulated POPs such as PCBs, DDTs, and HCHs. These studies of past temporal trends in levels of legacy POPs in air did not find any evidence that global climate change had an influence on observed (mostly downward) trends. For mercury, there is higher uncertainty in projections due to the possibility that climate change may remobilize mercury that has accumulated in the global oceans.

Models examining the influence of climate change in the absence of changes in emission patterns, project higher HCH concentrations in Arctic air under future climate scenarios, with total accumulation in all Arctic media slightly higher for β- and γ-HCH and slightly lower for α-HCH. Levels of PCB congeners in air under the future climate scenario are projected to be higher for lighter congeners (PCB56 and below) but not for heavier congeners; the mass accumulated in all Arctic media was lower under the future climate scenario for all PCB congeners with the largest decline for the lightest congeners. These changes are small compared to the 100- to 1000-fold declines projected for a number of POPs covered by the Stockholm Convention as a result of their global phase-out.

Current- and future-use agricultural and industrial chemicals have a wide range of properties and potential use patterns. For certain chemicals, projected concentrations in Arctic air and seawater in model scenarios that take into account the possible changes in the amounts and location of emissions are up to four-fold higher than projections in scenarios that include climate change only.

Photo: Olivier Bertrand

Models are useful and continue to be improved, but further improvements are needed.

ArcRisk activities have led to improvements and further development of a number of models used to investigate contaminant transport in the atmosphere and oceans and transfer between air, water, soils and plants. In particular, the modelling of sea-ice characteristics and the role of sea ice in influencing contaminant pathways has been advanced in ArcRisk.

Model simulations have large uncertainties and even state-of-the-art models were shown to be unsuitable for predicting levels of several organic contaminants under the effects of climate change on a Baltic regional scale.

However, future projections of the environmental fate of chemicals conducted in ArcRisk under different possible global climate change and chemical emission scenarios can differentiate between alternative pathways for the future time-course of chemical contamination levels in the environment that may result from different policy decisions.

Models employed in ArcRisk focus mainly on the physical environment, with emphasis on the direct effects of climate change (i.e., changes in temperature, ice and snow cover, precipitation, wind speed and ocean currents). The ArcRisk project demonstrates that direct effects are expected to have only a small influence on environmental levels of chemical contaminants relative to changes in primary emissions and potentially important indirect changes. Understanding of processes related to indirect effects – such as changes in the occurrence and distribution of species, carbon cycling, catchment hydrology, land use patterns and vegetation cover – is, however, limited and associated with large uncertainties, making it far more challenging to assess how these processes may be affected.

Food-web models have been developed to examine the transfer of contaminants into and through food chains, and potentially the influence of climate change on this process. However, an incomplete understanding of the underlying processes means that such models are currently unable to produce reliable projections of future developments.

A food-web model developed to simulate the bioaccumulation of PCBs in a Svalbard marine food web was evaluated with PCB monitoring data collected under ArcRisk. The model was shown to largely under-predict PCB concentrations within the food web. This inability to estimate bioaccumulation in Arctic marine food webs under existing climate conditions, even using state-of-the-art modelling tools, needs to be addressed before such tools can be used to predict food-web transfer under changing climatic conditions. This includes a need for an understanding of the potential impact of both climate change and ocean acidification on ecosystem structure (e.g., primary production, species' distributions and trophic interactions).

Both legacy and more recently introduced organic chemicals can be found in Arctic marine foodstuffs (generally at very low concentrations, but at high concentrations in some marine mammals). Much of the contamination is due to long-range transport; however, Arctic towns and settlements may be important sources of contaminants to local coastal fisheries.

Analyses of Arctic marine foods (fish, shrimps, marine mammals) reveal a range of concentrations of legacy contaminants (e.g., those already banned from production and use) as well as chemicals that have been used in industry, agriculture or household products more recently. Levels of legacy contaminants in traditional Greenlandic food items were lower than or similar to previously reported results and below guideline or limit values for human food consumption. Shrimp and halibut from coastal fjords (near Tromsø, Norway) had concentrations of most legacy contaminants at levels comparable to those reported for shrimp and Arctic cod from other locations in the High Arctic. Concentrations of PFOS in shrimp were around ten-fold higher than those measured in shrimp in the Canadian Arctic, and indicative of local sources.

Arctic towns and settlements may be an important source of contaminants to coastal fisheries. Exploratory research undertaken through ArcRisk using advanced chemical analytical tools has helped understanding of metabolic processing of pollutant residues in fish and other species. This type of metabolic chemical fingerprinting provides insight into chemical sources, especially remobilization of contaminants from melting ice, food-chain uptake and bioaccumulation as well as biologically driven contaminant degradation processes.

Photo: B & C Alexander/Arctic Photo

Climate change will affect pathways and mobility of contaminants in Arctic snow and ice.

Some contaminants deposited from the atmosphere accumulate in ice and snow. Land ice and sea ice therefore represent chemical 'storage' sites, and when ice melts these contaminants can be released.

Sea-ice accumulation and melting provide a mechanism for regulating the exposure of marine food webs to environmental contaminants. Contaminant accumulation appears most pronounced in single-season ice; this type of sea ice is becoming the predominant form in a warmer Arctic where increased summer sea-ice melting inhibits the formation of multi-year ice.

The seasonal snowpack is also a significant reservoir of organic contaminants deposited from the atmosphere. Snowfall events occurring at slightly higher temperatures in the late winter season were found to deposit higher quantities of perfluoroalkylated substances (one of the newer groups of contaminants now being found in the Arctic) compared to snowfall at lower temperatures. This suggests a complex process by which these chemicals are scavenged or formed on wet snow surfaces. Unlike some legacy chemicals, perfluoroalkylated chemicals do not revolatilize back into the atmosphere as snow ages. This allows them to accumulate in the snowpack with implications for their entry into catchment waters during snowmelt.

Organic contaminants are released from melting snow and ice at different times, depending on their specific chemical and physical properties, resulting in a staggered release of contaminants from the seasonal snowpack during spring melt. The release of contaminants stored in the snowpack is also greatly affected by rapid thaw events associated with winter warming anomalies – an increasing feature of a warming Arctic.

Interactions between falling snow and contaminants in air are complicated, but following polar sunrise some of the newer contaminants may be created on snow surfaces due to photo-oxidation of precursor chemicals present in the air. Other contaminants may be partially degraded in the sunlit snowpack.

Melting snow and glaciers have also been shown to release legacy organochlorine pesticides to the Arctic Ocean. These observations suggest that a warmer climate, which results in, for example, predominance of first-year ice and enhanced melting of snowpacks and glaciers, can lead to increased transfer of contaminants accumulated in snow and ice to Arctic ecosystems. The effect will, however, differ for different contaminants.

Effects of a changing climate on contaminant levels in Arctic ecosystems will depend on how climate change exerts its greatest effect, for example, on atmospheric transport patterns, erosion and riverine transport or ocean currents.

Atmospheric and oceanic transport are the primary mechanisms for, respectively, fast and slow long-range transport of contaminants to the Arctic from source regions at lower latitudes. Measurements performed in ArcRisk studies have shown that the large Arctic rivers are also important sources of PCBs to Arctic Ocean ecosystems. Differences in PCB composition (mixtures of different component chemicals) in different parts of the Arctic Ocean indicate different origins of the contamination, with some areas affected more by riverine input and others mainly by atmospheric deposition or oceanic transport.

Climate change can affect riverine transport, for example, by altering amounts and timing of river discharge, especially in rivers strongly influenced by ice-melt runoff, and by altering erosion and sediment transportation. Changes in atmospheric circulation patterns and precipitation will also influence contaminant deposition in river catchments.

Climate change effects on contaminant levels in Arctic ecosystems thus depend on when, where and in what way climate change exerts its greatest effect.

Fish and marine mammals are major contributors to dietary exposure to contaminants in the Arctic. In other areas of Europe, fish and shellfish consumption is an important route of exposure. However, these foods are also rich sources of important nutrients.

ArcRisk studies confirm that contaminant exposure in the general population is mainly related to the consumption of fish and shellfish. In areas such as the Mediterranean, fish and shellfish are the main sources of dietary contaminants including methylmercury. In the Arctic, people (indigenous peoples in particular) also eat marine mammals such as seals and small whales that accumulate mercury in their muscle and potentially large concentrations of organic contaminants in their fatty tissues and liver.

Different species accumulate different amounts of contaminants depending on the degree of environmental contamination and their feeding habits, with predatory fish and mammals accumulating the highest amounts. Human intake of both contaminants and nutrients depends on what parts of these animals are eaten.

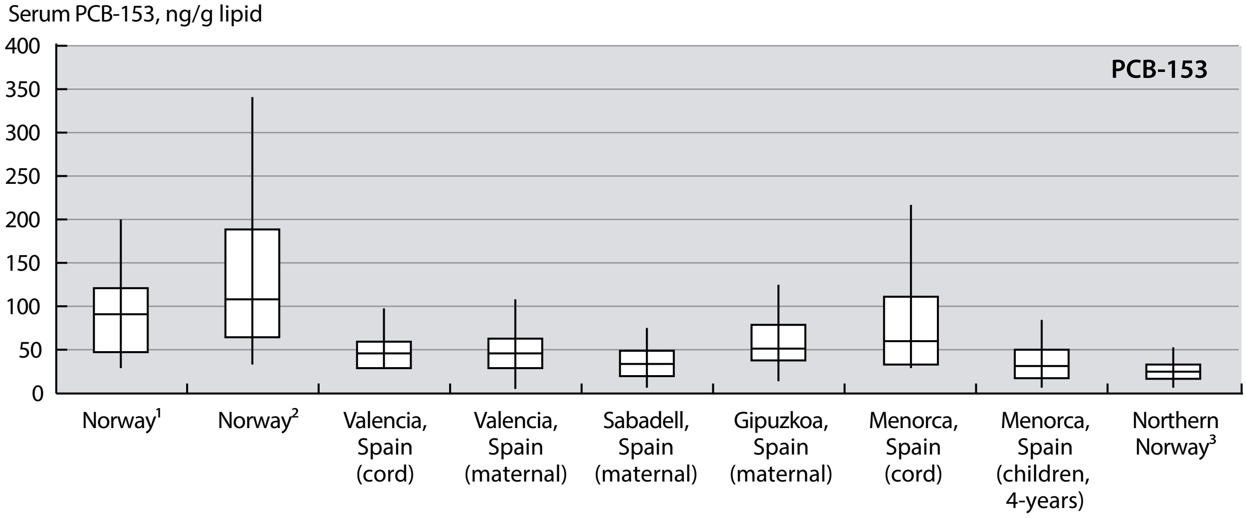
In an ArcRisk study in Norway, it was determined that oily fish, including salmon, trout, mackerel, halibut, herring, monkfish and catfish, contributed the most to the dietary intake of PCBs, dioxins, and the brominated flame retardants PBDEs and HBCD in the study population. This was based on concentrations of these contaminants measured in the food items and information about the amounts of these foods consumed, as well as concentrations measured in participants' blood. For several perfluorinated compounds, the combined intake of fish and shellfish was the largest contributor to the total intake. Seafood contributed on average 95% to the estimated dietary exposure to mercury.

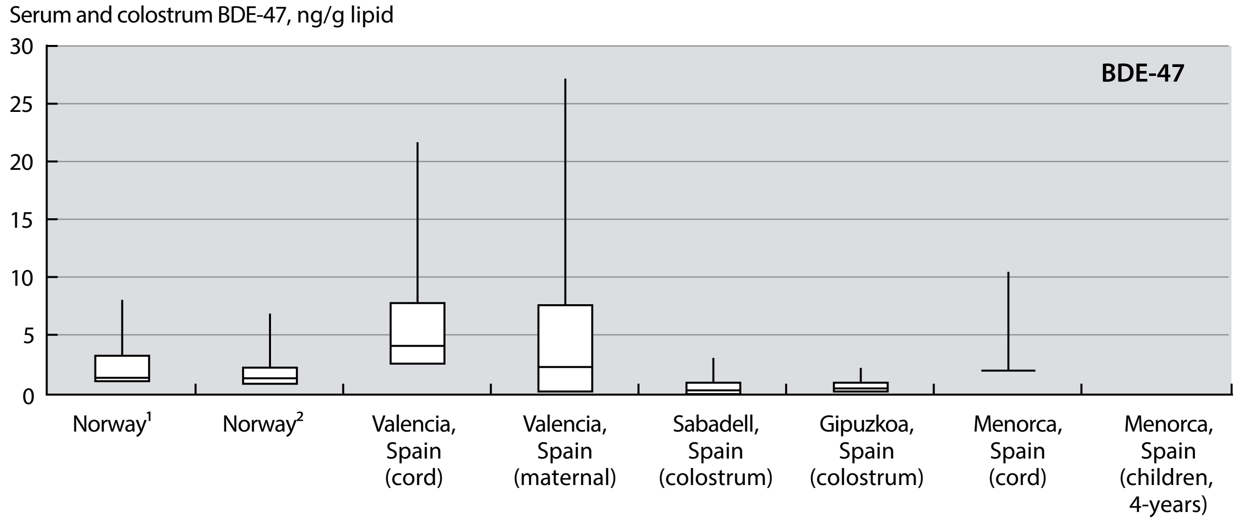
However, seafood is also a rich source of nutrients such as marine omega-3 fatty acids, vitamin D, iodine and selenium. Thus, the risks associated with contaminant intake and the benefits of nutrient intake must be balanced when developing dietary recommendations in relation to seafood consumption.

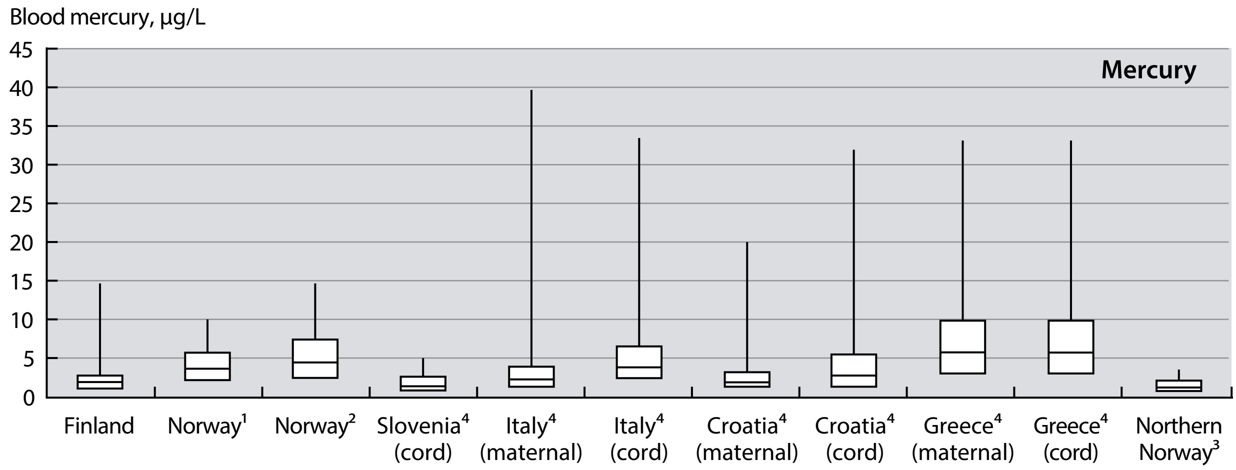
In general, levels of legacy POPs measured in humans in ArcRisk study populations have declined over the past 20-30 years. However, concentrations of some POPs remain relatively high, with PCB153 concentrations about 50 ng/g lipid weight in women living in Disko Bay and Nuuk (Greenland) and Nunavik (Quebec, Canada) where marine foods are important.

In comparison to other European studies, the Mediterranean populations exhibit higher median concentrations of HCB, β-HCH, and DDT and its metabolites, while concentrations of PCBs are lower in Mediterranean populations than in European populations in areas of intensive industrial activity. The Mediterranean populations studied also show higher concentrations of PBDEs than the European equivalents, but much lower than those observed in the USA.

The highest exposure levels to methylmercury occur in populations living near the sea and consuming more fish compared to inland populations.







[1]NFG: Norwegian fish and game study - representative group.
[2]NFG: Norwegian fish and game study - high consumers.
[3]MISA: Northern Norway mother and child contaminant cohort study.
[4]PHIME: Public health impact of long-term, low-level mixed element exposure in susceptible population strata study.

Photo: B & C Alexander/Arctic Photo

Health risks associated with contaminant exposure are greatest among certain vulnerable groups, especially the developing fetus and very young children. ArcRisk studies provide new insights into contaminant transfer during fetal development.

That pregnant women and young children constitute critical groups for contaminant exposure is well recognized. Contaminants can be passed from the mother to the fetus through the placenta and to young children during breastfeeding and affect critical stages of development. At the same time, breastfeeding is very beneficial to the health of newborns and in establishing the bond between mother and child.

In order to reach fetal circulation, foreign chemicals must cross the placenta, the main interface between mother and fetus. Based on analyses made from cord blood (i.e., fetal blood), it is known that the fetus is exposed to environmental contaminants present in the maternal circulation. Laboratory studies in ArcRisk looked at the transfer of several contaminants, mainly perfluorinated compounds, in newly delivered human placentas; the overall findings indicate that the fetus can be significantly exposed to perfluorinated compounds in the womb. These studies also suggest that environmental contaminants may interact with placental transporter proteins, which may affect fetal exposure to chemical contaminants. The clinical significance of these findings is still unclear.

Mother-and-child health studies in ArcRisk investigated the relationship between the diet of pregnant women and contaminant levels in their blood, finding that fish consumption was an important factor. A study of the maternal transfer of PBDEs showed that levels in the blood from umbilical cords of newborns were clearly associated with the levels in their mother's blood serum; this study indicated a broader range of exposure sources than fish, however, as neonates from rural areas had statistically significantly lower levels of contaminants in their blood than those from urban areas. A long-term study of the trends of PCBs and several organochlorine pesticides in breast milk from women in Central Europe has shown continually decreasing levels over the 15 years of the study.

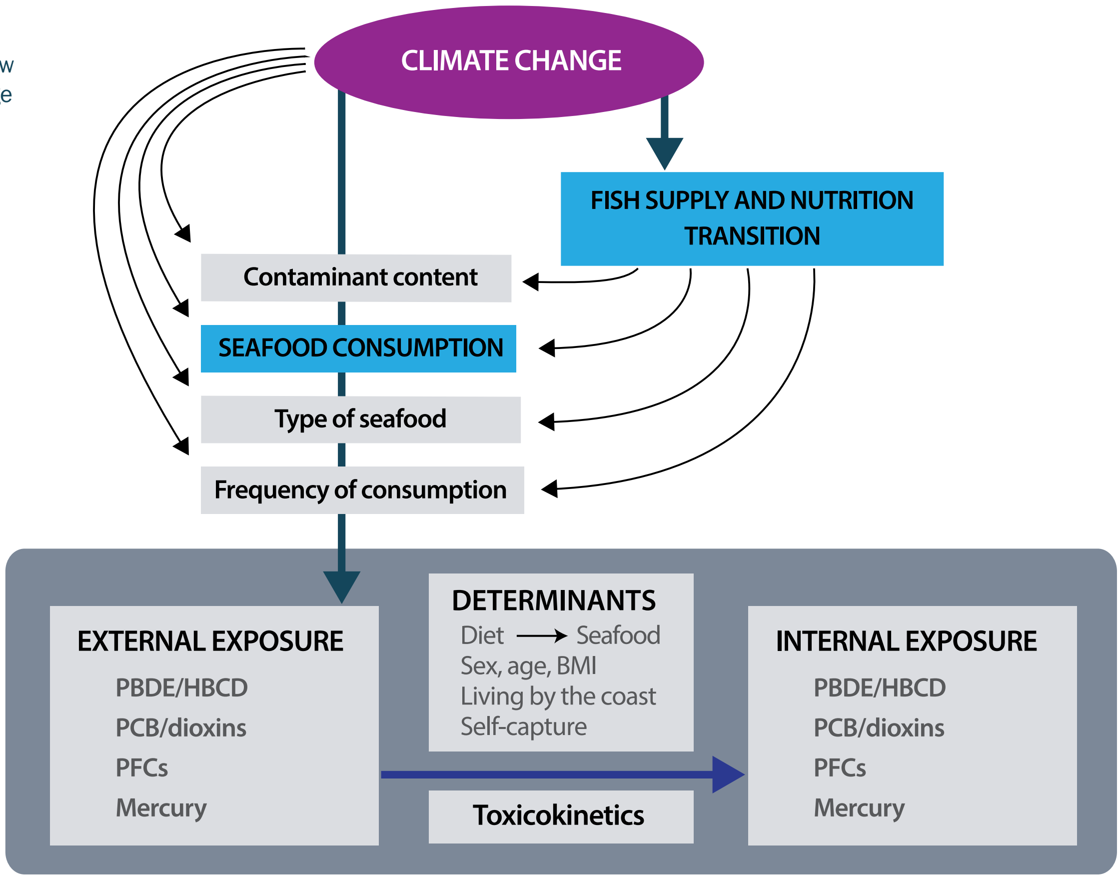
Several health effects have been identified as a consequence of the exposure to organohalogen pollutants in the Mediterranean populations studied. Significant decreases in birth weight have been associated with higher cord blood serum concentrations of DDTs and, marginally, HCB and β-HCH. Decreases in birth length have been related to high HCB concentrations and decreases in head circumference to increased DDT. Higher concentrations of β-HCH have also been significantly associated with higher levels of thyroid-stimulating hormone at birth. Health effects of low-level mercury exposure have demonstrated subtle neurobehavioral deficits in children prenatally exposed to methylmercury.

Studies of human health outcomes in relation to contaminants are seldom conclusive and it is difficult to link health effects to specific contaminants. If cohort studies addressing health effects of contaminants were conducted according to agreed protocols this would increase their suitability for meta-analyses.

Over the past few decades, many studies have been conducted that attempt to relate concentrations of contaminants such as mercury and organic chemicals in human blood and some other tissues to health effects. These studies, conducted in many countries for different purposes and using various methods, have yielded interesting results but rarely give a clear picture of health effect relationships.

In the ArcRisk project, special analyses termed meta-analyses were carried out on carefully selected published results of studies of contaminant levels and their effects in exposed populations. The meta-analysis on sex ratio vs. PCBs did not indicate that parental exposure to PCBs has any effect on sex ratio of their children, while the meta-analysis on birth weight vs. PCBs showed that a high maternal PCB concentration is probably related to low birth weight. However, a dose–response relationship with statistical significance could not be constructed based on this meta-analysis.

Several health effects have been associated with exposure to organohalogen contaminants in Mediterranean study populations. Assessment of the possible health effects of long-term exposure to low concentrations of these POPs requires their analysis in a large number of individuals. Newborns are more sensitive to contaminant exposure because their organs and metabolic functions are under development. In Mediterranean cohorts, exposure to organohalogens has been related to, for example, low birth size, low birth weight, low birth head circumference, poor social behavior, increases in the incidence of attention-deficit hyperactivity disorder (ADHD), decreases in cognitive skills, overweight, and alterations of porphyrin, thyroid and liver metabolism. Most of these effects have been observed in the early stages of life. These findings need to be confirmed by studies of cohorts from other geographic areas.



Simplified diagram of how climate change may influence contaminant exposure via seafood consumption.

Photo: Peter Prokosch (www.grida.no)

In Arctic populations that rely on traditional foods, the influence of climate change on contaminant levels in foodstuffs is expected to be small relative to future changes in dietary behavior.

Contamination by PCBs and other legacy POPs can be expected to decrease over time as a result of actions that have been taken to reduce their emissions. Climate change may, however, influence the rate at which these reductions translate into decreases in environmental contamination. For example, temperature-controlled degradation may accelerate the breakdown of POPs in the environment. Conversely, temperature-driven re-volatilization may enhance re-mobilization of contaminants from soils and waters in response to warming. These climate change effects can vary on a chemical-to-chemical basis. For mercury, climate change is also expected to alter some of the basic environmental transport and transformation processes.

ArcRisk model results indicate that the influence of climate change on the fate of PCBs (and other POPs) in the physical environment will be relatively small, and is unlikely to counteract the decreasing emissions. The implication is, that by 2100, environmental levels of these contaminants will be far below their present levels, and on this basis, human exposure to PCBs and legacy POPs should also be much lower. However, climate change is also likely to cause changes in ecosystem structures. At present it is not possible to predict how this may affect food-web bioaccumulation and biomagnification, or what the implications of this may be for contaminant levels in fish and other species traditionally consumed by some Arctic populations.

Future risks to people associated with dietary contaminant exposure in the Arctic will, however, depend to a large degree on changes in diet and food supply. The results from ArcRisk show that based on current predictors of contaminant exposure, the influence of climate change on future contaminant exposure will to a large degree depend on the consumption of fish and other seafood.

In the Arctic, future dietary exposure to contaminants may be influenced by climate change-related alterations in the distribution and availability of traditional foods, such as seals and fish, which cannot be predicted at this time. However, an even greater change will probably occur through the ongoing shift from traditional foods to a nutritionally poorer market-based diet.

Dietary guidance to indigenous populations in relation to chemical contaminants in traditional foods should be nuanced and sensitive to the fact that a diet based on a wise and balanced choice of traditional foods is nutritionally more complete and healthier than a market-based diet.

Food-based dietary guidelines from different countries contain broadly similar messages based on principles of nutrition science and recommendations that include eating more fish and seafood. However, the recommendations also include warnings about the intake of certain species known to have high concentrations of environmental pollutants. This is especially important for vulnerable groups including women of child-bearing age, pregnant women and young children.

The influence of climate change on fish supply is complex and unpredictable. It is a serious concern that climate change will cause changes that affect the supply of traditional food for people living in the Arctic.

Marine mammals and fish and terrestrial animals have been central to the survival of Arctic indigenous peoples and eating them has also helped to avoid many of the health risks associated with a more European lifestyle such as coronary heart disease and diabetes mellitus. However, population groups in Arctic areas that consumed large amounts of marine mammals could at the same time be exposed to high levels of contaminants. Advisories to reduce the consumption of specific food items to avoid contaminant exposures have been shown in some cases to result in a complete avoidance rather than reduced consumption of a particular food, thereby also reducing the benefits of these traditional food items.

Care needs to be taken that advice to limit consumption of fish and seafood does not inadvertently do more harm than good by reducing the consumption of foods with health benefits and increasing the consumption of alternative foods that have potential health risks. Separating the risk and benefits of seafood intake is very difficult, as illustrated below.

Healthy diets play a key role in the prevention of cardiovascular disease, cancer, diabetes and other non-communicable diseases. At present, the nutritional transition from traditional diets to 'western' diets including more processed, energy-dense, and unhealthy food is a larger threat to the health of Arctic populations than the potential increase in environmental contaminants following global warming.

A simplified relationship between diet and health, with diet as the source of both nutrients and contaminants.

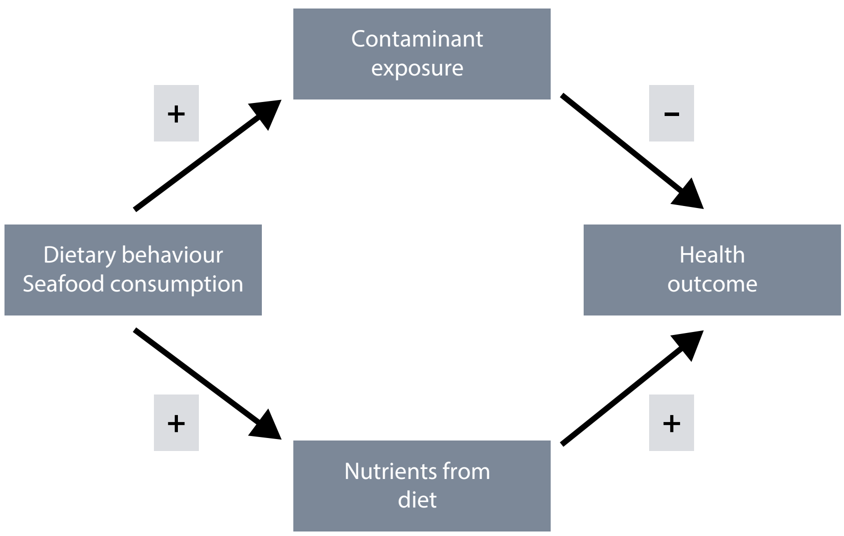


Photo: Rune Dietz

POLICY IMPLICATIONS

Avoiding future adverse effects on human health from exposure to contaminants requires an overall strategy that integrates policies and measures to reduce use and releases of contaminants, monitoring of environmental levels and human exposure, education and risk communication, and where necessary food consumption advice to critical groups.

ArcRisk objectives include providing input for the development of strategies on how best to adapt to and prevent adverse health effects related to climate-mediated changes in exposure to chemical contaminants in human populations in the Arctic and in Europe. The research performed in the project has illustrated the complexity of contaminant cycling and effects and also the limitations in our capability to predict how climate change may affect these processes. Policy advice related to reducing future exposure and effects cannot therefore be formulated in a single straightforward statement but rather comprises a series of recommended actions that need to be incorporated in an overarching plan (strategy) to meet this situation.

- **Policies, restrictions and technical measures to reduce emissions of contaminants.** Long-term, comprehensive reductions in human exposure to harmful environmental contaminants can only be achieved by minimizing their use and eliminating as far as possible releases to the environment. For some contaminants, climate change may increase exposure but climate change mitigation alone will not remove risks associated with chemical contaminants.
- **International collaboration.** Given the vast amount of chemicals used in society and the number of chemical compounds involved, the task of identifying those chemicals that pose the greatest risks for human and environmental health is enormous and requires international collaboration. In addition, risk reduction measures must be adapted to the specific use and emission patterns associated with different groups of chemicals. The potential for long-range transport of many harmful contaminants means that international agreements such as the Stockholm Convention, the Convention on Long-Range Transboundary Air Pollution, and the Minamata Convention have a key role to play. In addition, potential synergies between existing international policies and agreements concerned with monitoring, risk assessment, and mitigation measures should be exploited. For legacy substances that are already banned or restricted, additional measures to reduce environmental dispersion from remaining sources, contaminated sites, landfills, buildings, etc., may be warranted.
- **Access to information.** Information on emissions, use and life-cycle of environmental contaminants and potential contaminants is largely lacking and improved access to such data is necessary to allow risk assessment and prioritization of measures.
- **Monitoring and assessment.** Monitoring of contaminants in the environment, foodstuffs and humans provides essential information to follow-up the effectiveness of action taken, to identify new threats and to develop the basis for guidance aimed at reducing exposure. Monitoring in combination with modelling and assessment can also provide knowledge on contaminant pathways in the environment which can be used for predicting future changes and identifying measures to be taken. Monitoring aimed at environmental compartments that are expected to be affected by climate change (snow, ice, glaciers) and that may increase availability of contaminants for uptake in food webs is especially important.
- **Future use of human biomonitoring data.** Existing human biomonitoring data representing individual internal exposure provides an excellent opportunity in long-term follow-up studies to pursue potential association of blood levels of contaminants with health outcomes in these populations. Especially, cord and maternal blood levels give the possibility to link fetal exposure to later health effects according to the new concerns regarding developmental origin of adult onset diseases including cardiovascular diseases and cancers.
- **Advisories on human consumption of fish, seafood and mammals.** Many contaminants are persistent and continue to contaminate the environment for a long time after their sources have been reduced or eliminated. Food consumption guidelines and advisories can provide effective short-term solutions to minimize human exposure, in particular for critical groups. However, such advisories must be developed in close cooperation with local health professionals and the target groups themselves. They should be developed taking account of both risks and benefits of consumption of particular foods, including indirect benefits (such as cultural benefits). Risk communication is not a simple task. It will be necessary to update and complement existing food consumption guidance as knowledge about the effects of chemical contaminants and the associated impacts of climate change grows.

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SEVENTH FRAMEWORK PROGRAMME

ArcRisk