Unintentional targets

THOMAS NILSEN

Persistent Organic Pollutants

The evidence that persistent organic pollutants affect Arctic wildlife is accumulating. On Svalbard, recent results indicate that polar bears with high levels of PCBs suffer from impaired defense against infections. High PCB levels may also be affecting cub survival. Effects of persistent organic pollutants have been documented in other Arctic species as well, including the northern fur seal, glaucous gull, peregrine falcon, and dogwhelk.

PCBs and a number of other organic pollutants have been regulated for several decades in Arctic countries. Recently they have also been regulated under a global convention. The levels in the environment are mostly a legacy of past emissions, and given enough time they will decline. However, some of the already-regulated persistent pesticides appear to have been used recently, and PCBs from old uses and equipment are still spreading in the environment. Moreover, additional persistent pollutants have started to arrive in the Arctic, and some of these are currently being produced in large quantities.

This chapter highlights sources of old and new persistent organic pollutants in the Arctic environment, their pathways, and their levels. It also discusses possible effects on wildlife. Effects on human health are treated in the *Human Health* chapter of this report.

Intentional use

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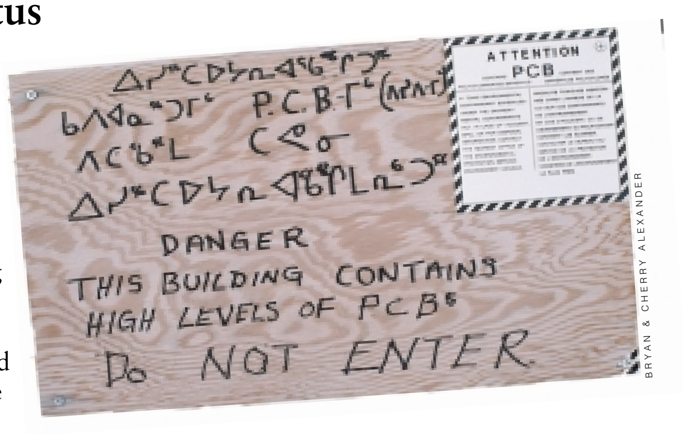
Sources and regulatory status

The class of persistent organic pollutants, or POPs for short, covers a large number of chemicals with some common characteristics that make them potential problems in the environment. By definition, POPs are persistent, which means that they break down slowly in the environment. Persistent chemicals are more likely to travel over long distances and reach remote regions such as the Arctic. Once in the Arctic, some compounds may last even longer in the cold and dark environment than they would in more temperate climates.



A warning sign for high levels of PCBs at an old DEW line station. Melville Peninsula, Nunavut, Canada. PCBs were used at many military radar stations.

Many POPs are taken up by organisms, either directly from their surroundings or via food. If the chemicals cannot be broken down or excreted as fast as they are taken up, they will accumulate in the organisms' tissues. Most POPs are poorly soluble in water but readily soluble in fat and therefore become concentrated in the fat of animals. At high enough levels, many POPs can have adverse effects on wildlife and on human health, including effects on reproduction, development, and resistance to disease.

The previous AMAP assessment showed that a number of POPs are present throughout the Arctic, including in regions where they have never been used. In addition to these 'legacy' POPs, most of which have been regulated, there are a number of persistent organic chemicals that are still in use. This section briefly describes the sources and regulatory status of most POPs covered in the updated 2002 AMAP scientific assessment.

PCBs are ubiquitous in the Arctic

PCBs, or polychlorinated biphenyls, are a group of heat-resistant and very stable chemicals that have been used in a number of industrial applications. The manufacture and use of PCBs have been banned, but they are still present in some existing products, such as sealants, paints in older buildings, and old electrical equipment. Most of the historical use of PCBs has occurred in the northern hemisphere.

PCBs have undoubtedly reached the Arctic via long-range transport, but there are a number of local sources as well. In several Arctic regions, mineral exploration, coal mining, and heavy industry account for the highest input. At Svalbard, Norwegian and Russian settlements are both sources to the local environment.

Harbors are newly identified sources, and high levels of PCBs have been found in the sediment of harbors in northern Norway and

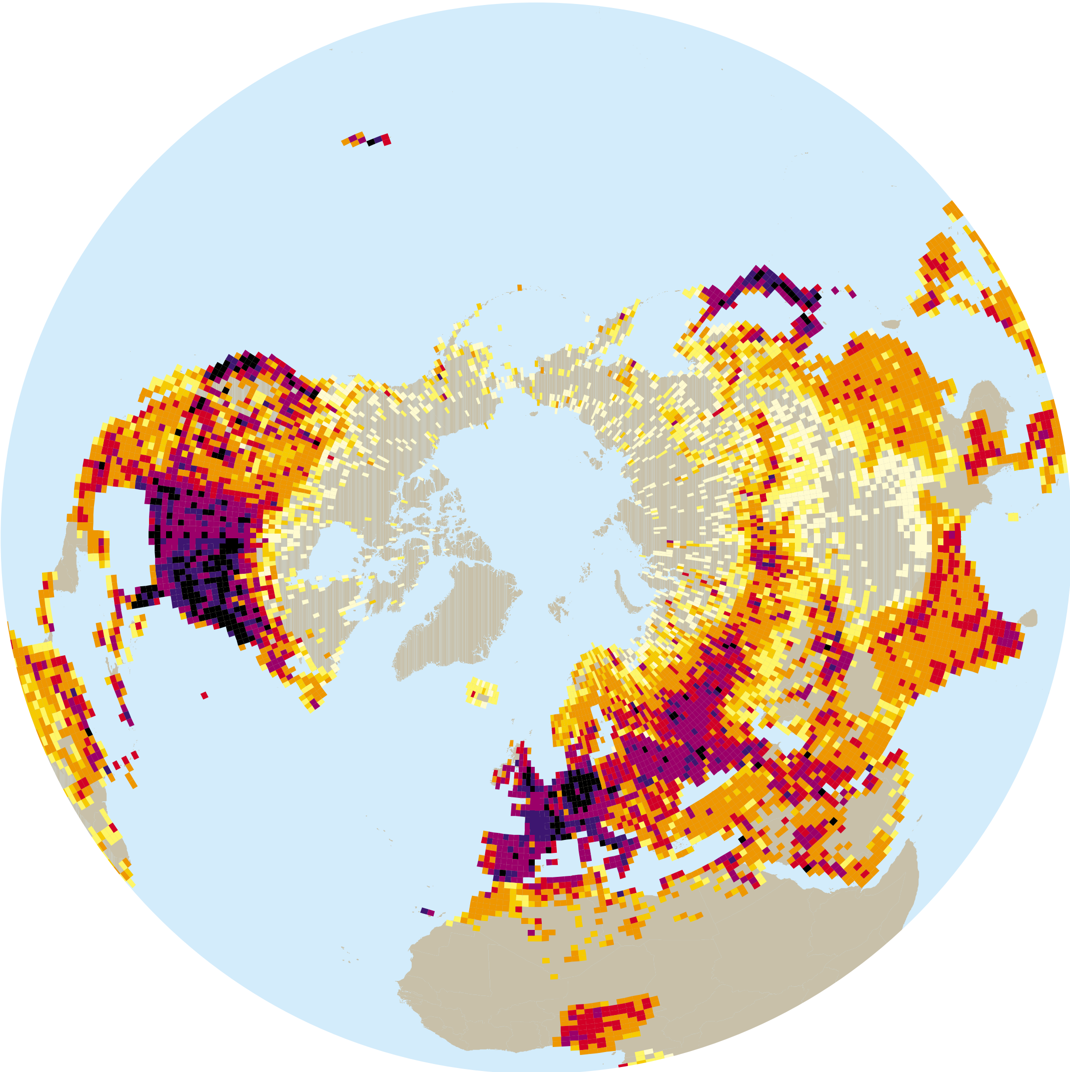
Conventions regulate some POPs

At a national level, the use and emissions of many POPs have been restricted since the 1970s. In 1998, the United Nations Economic Commission for Europe (UN ECE) negotiated a regional protocol on POPs under the Convention on Long-range Transboundary Air Pollution, the Aarhus POPs Protocol, which covers Europe, all states of the former Soviet Union, and North America. All AMAP countries except Russia are signatories to this convention. As of August 1, 2002, the following AMAP countries had ratified the POPs Protocol: Canada, Denmark, Norway, and Sweden.

The regional UN ECE agreement paved the way for global negotiations on banning POPs under the auspices of the United Nations Environment Programme. The Stockholm Convention on Persistent Organic Pollutants was opened for signature in May 2001. All AMAP countries have signed the Stockholm Convention. As of July, 2002, Canada, Iceland, Norway, and Sweden had ratified it.

Both agreements identify a number of specific POPs to be banned or whose use or emissions are to be restricted. They include industrial chemicals and by-products, such as PCBs, dioxins, furans, and hexachlorobenzene. Also included are a number of organochlorine pesticides: aldrin, chlordane, dieldrin, DDT, endrin, heptachlor, mirex, and toxaphene. Together, these are often called the 'dirty dozen'. Some POPs, most notably the pesticide hexachlorocyclohexane (HCH), are covered in the UN ECE Protocol but not the Stockholm Convention. For several of the listed substances, some limited use is allowed, for example DDT for fighting malaria.

The conventions also define criteria for including new chemicals based on their persistence, bioaccumulation, potential for long-range transport, and adverse effects. The Arctic is well suited as an indicator region for long-range transport. Monitoring data that provide information about the fate of chemicals in the Arctic will therefore be critical in identifying new POPs to be considered under the agreements.



Estimated cumulative global usage of PCBs (1930-2000). Most of the use was in the northern temperate region.

Russia. Because of much higher concentrations relative to non-harbor areas, harbors probably constitute a source for PCBs in the Arctic marine environment.

Other sources within the Arctic include abandoned military sites, specifically parts of the radar network established under NATO and built in the 1950s to detect missiles heading toward North America (e.g. DEW Line sites). In recent years, high levels of PCBs in soil have been found at two additional former military locations, Saglek Bay in northern Labrador and Resolution Island at the southeastern tip of Baffin Island. In Alaska, a large number of sites have been identified as known or potential sources of contaminants, not only of PCBs, but also of pesticides and polycyclic aromatic hydrocarbons (PAHs). Thule Air Base in Greenland is a local source of PCBs. On Jan Mayen, north of Iceland, old, dumped PCBs contaminate the local environment. Signs of contamination pointing to local PCB sources have recently been detected near small settlements in southern Greenland. Remedial action is underway for several of the sources mentioned above.

A recent inventory of PCB use in Russia shows that PCBs remain in many electrical installations, which slowly release this pollutant into the environment. The Arctic Council Action Plan to Eliminate Pollution of the Arctic (ACAP) has initiated a cooperative project to assist Russia in phasing out PCB use and in handling PCB-contaminated waste.

Svea Mine, Svalbard. Mining activities are a local source of PCBs.

BIRGER AMUNDSEN

Declining use of other chlorinated technical products

Chlorinated naphthalenes (PCNs) are chemically similar to PCBs and have many similar industrial applications. These include use in electrical equipment, lubricants, solvents, dyes, and sealants. They are also present as impurities in technical PCB and are formed during anthropogenic combustion processes.

One of the largest PCN producers ceased production voluntarily in the late 1970s. Otherwise, there is a general lack of information about production volumes and history. Use has declined in the past few decades, but in most countries PCNs are not prohibited. Air levels are highest in winter and the distribution pattern in the Arctic suggests a combustion source. PCNs have been detected in air and in marine mammals and birds.

Some PCNs have toxic properties similar to those of chlorinated dioxins, furans, and dioxin-like PCBs, and their proposed relative toxicities can be expressed as toxic equivalents (TEQs), see box below. A study of beluga from the Canadian Arctic showed that PCNs can account for a substantial portion of the TEQs.

Toxic equivalents (TEQs)
Dioxins, furans, and some PCBs and PCNs are thought to act via a similar toxic mechanism. The levels of these substances are sometimes expressed relative to the most toxic dioxin congener, TCDD. Toxic equivalents (TEQs) are the sum of the concentrations or amounts of different dioxin-like substances multiplied by their relative toxicities.

Other technical products are short-chain chlorinated paraffins, which are added to fluids used in metal-working to keep the fluids functioning at extremely high temperatures. They are also used in paints and sealants and in the leather-working industry. They can travel over long distances and have been detected in Arctic sediment and biota. Because of concern about their toxicity, the use of these chemicals is declining in favor of alternative products.

Use of brominated flame retardants is on the rise

To prevent fabrics and equipment from burning, many materials are treated with chemicals that contain bromine. Examples are polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane, and tetrabromobisphenol-A (TBBPA). They are present in consumer products such as TV-sets, computers, building materials, foam cushioning, and textiles.

In some cases, brominated flame retardants can leach into the environment, where some of them are known to behave in a way that is similar to PCBs. PBDEs seem to travel over long distances in the atmosphere and some studies have shown that they can be toxic to the immune system and can affect neurobehavioral development. The environmental properties of other brominated flame retardants have not yet been very well investigated.

The use of brominated flame retardants has increased drastically in the past decade, and annual worldwide production is over 200 000 tonnes. Most of the use is in the industrial areas of the northern hemisphere that are potential source regions to the Arctic. The technical product penta-BDE is used primarily in North America but is being phased out in Europe, whereas other PBDE products are still widely used globally.

In areas outside the Arctic, PBDEs have shown up in human breast milk as well as in the tissues of several animal species. In North America levels are increasing. In Europe, levels in biota increased up until the mid-1980s and in humans until the late 1990s. In the Arctic, PBDEs have been detected in air and in biological samples from remote areas, although their levels are much lower than levels of some legacy POPs, such as PCBs. Recent results from southern Greenland also point to local PBDE contamination, possibly from consumer products used in the settlements.

POLFOTO / PREBEN KIRKHOLT

▶ Computers can be a source of brominated flame retardants.

Perfluorooctane sulfonates are extremely persistent

In regard to the environment, organic compounds with fluorine have until recently been discussed only in the context of ozone-depleting chemicals such as CFCs. However, the compound perfluorooctane sulfonate (PFOS) has come into focus because of its extreme persistence. It does not seem to break down under any circumstances. PFOS is mainly used as a stain repellent.

PFOS can leach from the materials in which it is used. Although not volatile itself, it seems to be capable of long-range transport by some as yet unknown mechanism. Little is known

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Waste incineration at Narsaq, Greenland. Uncontrolled incineration is an important local source of dioxins.

about its potential to bioaccumulate or whether animals can break it down, but it has been detected in polar bears and seals in the North American Arctic and Svalbard.

The annual US production of PFOS was 2943 tonnes in 2000. The sole US producer plans to phase out production completely by 2003. Production in other parts of the world is not well documented.

Products that are chemically similar to PFOS are still in production. Their environmental fate is being investigated, but they have been detected in the air in regions outside the Arctic.

Industrial by-products are still not under control

Some POPs are produced as unintentional by-products in industrial processes. They include dioxins (PCDDs) and furans (PCDFs). Important sources are waste incineration without efficient temperature control and flue-gas cleaning, wood-burning stoves, metallurgical industries, and chlorine bleaching in pulp and paper production.

A UNEP review of global emission inventories for dioxin and furan emissions from northern Europe, Canada, the United States, and Japan points to the United States and Japan as the most important global source regions. Their releases amount to several kilograms of TEQs annually, whereas Canadian emissions are estimated at only a few hundred grams. Sweden, the only Nordic country in the survey, had emissions of only 22 grams.

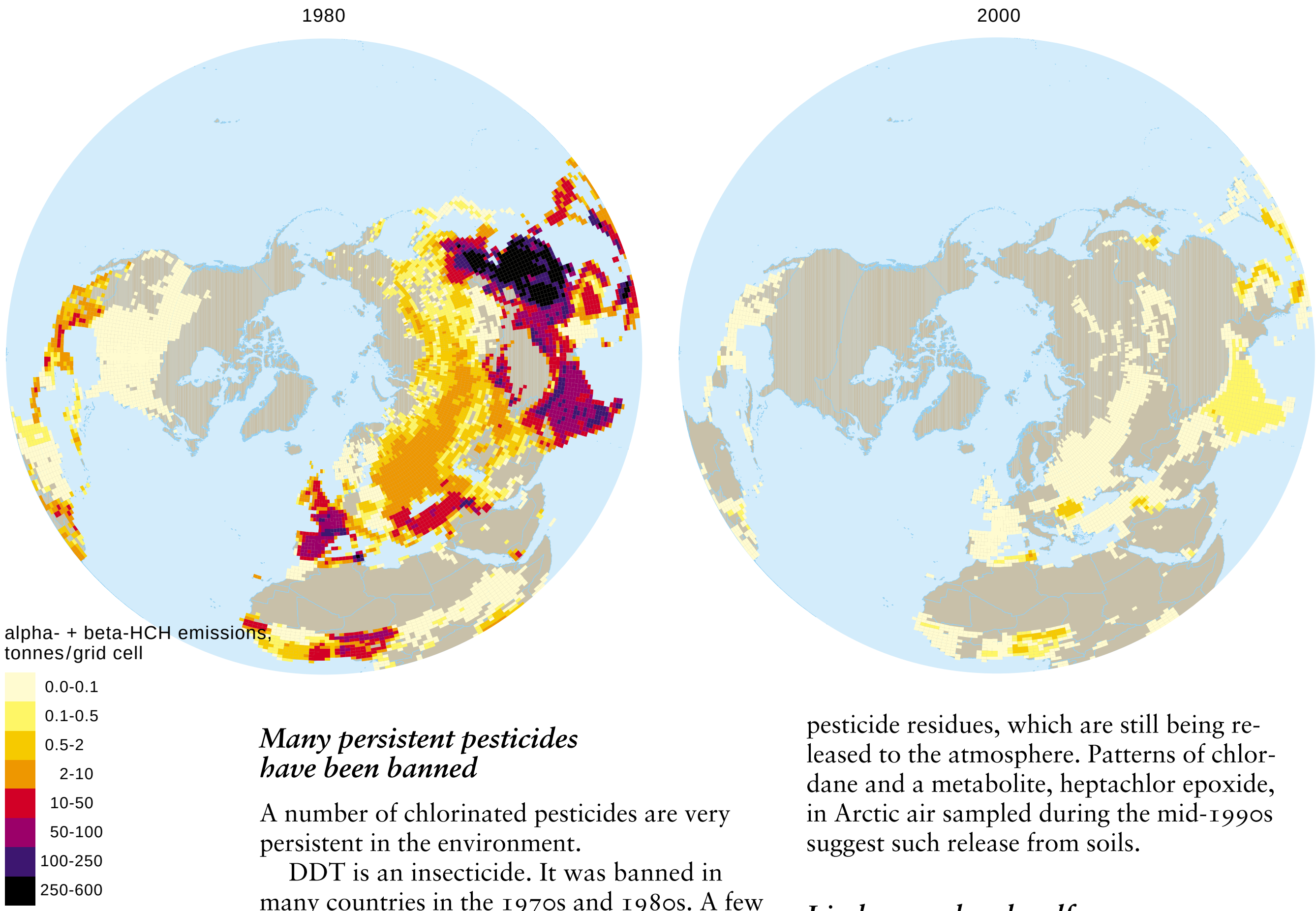
A model using information on sources and pathways shows the close relationship between source regions and the geographical distribution of deposition for dioxins and furans. Generally, air concentrations are low. The predicted deposition in eight communities in Nunavut, Canada, is highest in the south and east of Nunavut because of the preponderance of dioxin sources in the eastern United States and Canada. Russian and northern European sources are regarded as insignificant for Nunavut in comparison with those in the United States, Ontario, and Quebec.

Several other industrial POPs are found in the Arctic. Hexachlorobenzene (HCB) is a by-product in the production of chlorine gas and chlorinated compounds, including several pesticides. It is also a by-product of the metallurgical industry. It has been used as a fungicide. Known emissions cannot account for the levels of HCB in the atmosphere, so there may be sources that have not yet been identified. An alternative explanation is that previously deposited HCB is being revolatilized into the air.

A compound related to HCB is pentachlorobenzene, which has been used in dielectric fluids in PCB-containing transformers. Older PCB-containing devices are thus a potential source of this contaminant.

Breakdown products of octachlorostyrene have recently been detected in the Arctic. Emissions of this compound probably peaked in the 1960s. Historically important sources are magnesium production and chlorine production using a method that was abandoned in the 1970s.

Polycyclic aromatic hydrocarbons (PAHs) are a large group of compounds that are present in unburned petroleum and are produced when organic matter burns. Sources are ubiquitous and include the burning and coking of coal, production of aluminum, internal combustion engines, cooking on fire or hot coals, cigarette smoking, and forest fires.



Estimated emissions of alpha- plus beta-HCH in 1980 and 2000, showing a drastic decrease over this period.

Many persistent pesticides have been banned

A number of chlorinated pesticides are very persistent in the environment.

DDT is an insecticide. It was banned in many countries in the 1970s and 1980s. A few countries, such as China and India, still produce DDT for use in controlling malaria and other insect-borne diseases. The previous AMAP scientific assessment suggested some continuing use of DDT in Russia.

Toxaphene is another insecticide. It was primarily used in the cotton belt of the United States, but was banned in the United States in 1986. In Nicaragua, production continued until the early 1990s. The former Soviet Union and former East Germany were also major producers of this type of pesticide, but compared with the United States, use in Europe was limited.

Chlordane, heptachlor, dieldrin, endrin, aldrin, and mirex are other chlorinated pesticides covered by the Stockholm Convention. Chlordane has been used extensively in the United States for agriculture, home lawns and gardens, and termite control, and to a lesser extent in Western Europe, the former Soviet Union, and tropical Asian countries. In 1997, the sole US manufacturer voluntarily ceased production in all its national and international facilities. There is still some production in Singapore and China. World sales of aldrin and dieldrin ceased in 1991, while endrin production ceased in the mid-1980s. However, old stocks of these chemicals, particularly dieldrin, were donated to African countries from the mid-1980s to the 1990s for insect control. Releases to the environment have therefore continued.

Because chlorinated pesticides were deliberately applied to control insects, many agricultural and some non-agricultural soils contain pesticide residues, which are still being released to the atmosphere. Patterns of chlordane and a metabolite, heptachlor epoxide, in Arctic air sampled during the mid-1990s suggest such release from soils.

Lindane and endosulfan are still in widespread use

The use of technical hexachlorocyclohexane (HCH) began in 1943, and global consumption during the period 1948-1997 has been estimated at a total of 10 million tonnes. Technical HCH is a mixture of mainly alpha-, beta-, and gamma-HCH, which differ in their chemical structures. Gamma-HCH is an insecticide, whereas alpha- and beta-HCH are by-products from the production of gamma-HCH and present in the technical product.

Technical HCH was banned in most western countries in the 1970s and in the Soviet Union in the late 1980s. China has been a major user but switched to lindane, which is pure gamma-HCH, in 1984. Lindane is also used in North America, Europe, and Asia, for seed treatment and other applications.

Endosulfan, a widely used insecticide, is also used in some Arctic countries. It is very toxic but less persistent than some other organochlorine pesticides.

Butyltin compounds are only partially regulated

Tributyltin (TBT) is a broad-spectrum pesticide used against algae, mites, fungi, and insects. TBT has been most widely used as a marine antifoulant on small boats, ships, and marine structures such as aquaculture pens, offshore oil rigs, and underwater pipelines. It may also enter the sea in runoff from agricultural areas, from boat repair yards, and from municipal wastewater and sewage sludge.

Mono- and dibutyltins are used primarily as heat and light stabilizers in the production of PVC plastic. The organotins have been shown to leach from PVC and other materials leading to contamination of food, drinking water, municipal water, and sewage sludge. Mono- and dibutyltins are also breakdown products of TBT in higher organisms.

TBT breaks down fairly quickly in water but can remain for a long time in sediments, especially in cold climates. Contaminated sediments are therefore potential environmental reservoirs for TBT, and may continue to be a source long after the industrial use of TBT has been curtailed.

Because it is extremely toxic to some marine invertebrates, many developed countries have restricted the use of TBT. Regulations vary, but generally, only controlled release formulations are permitted and TBT-based antifoulants are prohibited for boats smaller than 25 meters. The United Nations International Maritime Organization has agreed to a global ban, beginning in 2003, on the new use of TBT on ship hulls. After 2008, TBT-based antifouling paints must be removed from ship hulls or sequestered with an impermeable paint so that no leakage to the environment can occur.

Pathways to the Arctic

Even if there are local sources of POPs within the Arctic, they cannot explain current environmental levels. In many cases, the main sources are in mid-latitude industrial and agricultural areas, and the contaminants travel to the Arctic with air and water currents. Migrating animals also carry POPs to the Arctic. Long-range transport and subsequent biomagnification in Arctic food webs account for most of the concern regarding contamination of the Arctic by these substances.

Pathways can change with shifts in climate regime or long-term climate change. This is discussed further in the chapter *Changing Pathways*, including some specific changes that have occurred during the 1990s.

The atmosphere provides a fast transport route

Air is the most important transport route for volatile and semi-volatile pollutants. Under favorable weather conditions, air masses can transport contaminants from mid-latitudes to the Arctic within a few days or weeks.

Most POPs are semi-volatile and their transport is complex. In temperate and tropical regions, they are picked up by the winds as gases. When temperatures drop, they condense onto atmospheric particles and other surfaces, reaching the ground via rain, snow, or direct deposition onto land and water. However, they can revolatilize when weather conditions change, re-entering the atmosphere for further transport. Higher temperatures, storms, snowmelt, or icemelt in spring can also encourage revolatilization of POPs. Soils contaminated with PCBs in the past via atmospheric deposition are now releasing them back into the air to begin the transport process anew.

The role of atmospheric transport varies with the seasons. Generally, atmospheric long-range transport to the Arctic from source areas in North America and Eurasia is much higher in winter and early spring than in summer.

Ocean transport is slow but important

The role of ocean currents in transport is probably more important for contaminant levels in the Arctic than was previously thought. Water-soluble chemicals that are efficiently removed from the air by precipitation or air-to-sea gas exchange may reach the Arctic primarily via ocean currents. Beta-HCH is an important example.

Ocean transport is relatively slow and it can take many decades before POPs released in other parts of the world show up as pollution in the Arctic. This can create a time lag between emissions and increasing levels and possible effects in the Arctic and, conversely, between emissions reductions and decreasing levels in the Arctic environment. It also raises questions about how modern pesticides, which normally degrade fairly rapidly, behave in cold Arctic waters.

The precise importance of ocean transport for each compound depends on that substance's physical properties (see box below).

Water-solubility determines importance of ocean transport

Alpha- and beta-HCH were significant contaminants in technical HCH and were released to the environment with this pesticide. They differ in one important physical property: the solubility of the gaseous compound in water. The greater solubility of beta-HCH profoundly influences the relative importance of different pathways to the Arctic. Specifically, alpha-HCH is transported efficiently both by the atmosphere and ocean currents. Initially, when emissions were still substantial, air transport was most important. The solubility of gaseous HCH in water is greater at lower temperatures and the cold waters of the Arctic Ocean and the marginal seas became a sink. Alpha-HCH levels in air declined during the mid-1980s and 1990s because of a drop in technical HCH emissions, and ocean currents took over as the major transport route. Today, the Arctic Ocean has reached equilibrium with the atmospheric alpha-HCH concentrations, and in some areas is releasing it back to the atmosphere. In the central Arctic Ocean, the ice cap prevents this outgassing.

Due to its greater water solubility, beta-HCH is more efficiently scavenged by rain and snow than alpha-HCH. Most of its emissions have therefore been deposited closer to the source regions in high precipitation areas in the northern North Pacific, from where the Alaska coastal current can transport beta-HCH farther north into the Bering Sea. Thus, even during the years of high technical HCH emission, beta-HCH was most likely carried to the High Arctic mainly via ocean currents. With ocean transport being relatively slow, it will likely take longer for environmental levels of beta-HCH than alpha-HCH to reach equilibrium with emissions.

Rivers and sea ice can carry contaminated sediment

A route for contaminants that has been increasingly recognized in the past few years is sea ice that carries sediment from large rivers. Several great rivers flowing through industrial and algricultural regions drain into the Arctic Ocean. When their sediments reach the coast, some are incorporated into coastal ice.

The general movement of sea ice north of Eurasia is from the coast of the Kara Sea northward to the Siberian branch of the transpolar drift between the Franz Josef Land and Severnaya Zemlya archipelagos. Ice-bound particles possibly laden with contaminants may thus be carried out of the area and released when the ice melts. The main melting areas are east of Svalbard and in the Fram Strait. The importance of sea ice for contaminant transport remains an open question.

Levels and geographical patterns

Levels in the environment can be used to piece together a picture of how pathways distribute POPs throughout the Arctic from their sources.

The emerging picture suggests that differences in biological pathways may be much more important than was previously realized. Specifically, the fact that the same species may have different diets in different parts of the Arctic seems to be important in explaining different contaminant burdens in some populations. There is also new evidence that animals can carry contaminants between areas and environmental compartments, creating a biological pathway of as yet undetermined significance.

Another picture, which is consistent with the previous AMAP assessment, is that levels in the environment are influenced by proximity to known or suspected source regions. Generally, levels of HCHs are higher in the western North American Arctic than farther east, reflecting emissions in eastern Asia. By contrast, PCB levels are higher in the Eurasian part of the Arctic, especially around eastern Greenland, Svalbard, and the Kara Sea. Evidence from seabirds and several marine mammals points to releases of PCBs in Russia.

In the previous AMAP assessment, there was little information on toxaphene. New data show that this pesticide occurs throughout the Arctic, in some cases at rather high levels. Moreover, there are data that suggest current releases of regulated pesticides, specifically DDT and toxaphene, mostly in the Russian Arctic.

New contaminants are also showing up in the Arctic. These include brominated flame retardants in Canada, Greenland, the Faroe Islands, Norway including Svalbard, and Sweden, as well as PFOS in North America and Svalbard. TBT-related compounds have been detected in several species.

The following sections provide details about levels in different animals and compartments of the environment.

Air and precipitation data indicate fresh DDT use

New data on POPs in air are available from several land-based stations. The results for HCHs, chlordanes, and DDTs suggest rather uniform, low concentrations in Arctic air during the mid-to-late 1990s. DDT levels at Stórhöfdi, Iceland, suggest a fresh source. At Tagish, Canada, there is some inflow of DDTs that is linked to trans-Pacific transport. The DDT pattern at Amderma, Russia, differed from most other sites, suggesting recent use.

Concentrations of PCBs and HCB at Zeppelin (Ny-Ålesund), Svalbard, are higher than at the Canadian sites. The results suggest that the European Arctic continues to receive elevated PCBs compared to the North American Arctic. The data also indicate long-range transport of PAHs from Eurasian sources, with a signature typical of coal and oil combustion.

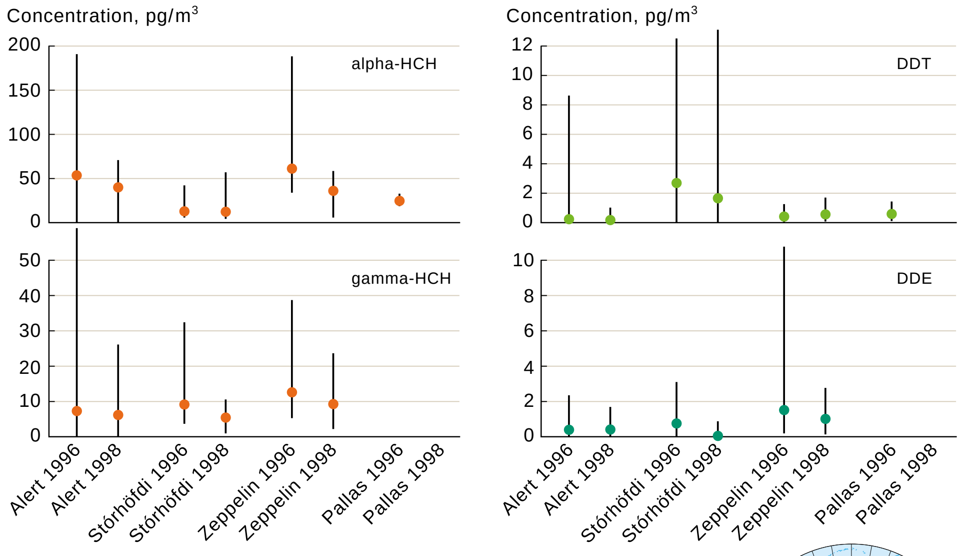
Many new contaminants have been detected in Arctic air. They include several current-use pesticides (endosulfan, methoxychlor, trifluralin, and pentachloroanisole), industrial by-products (trichloroveratrole, tetrachloroveratrole, and

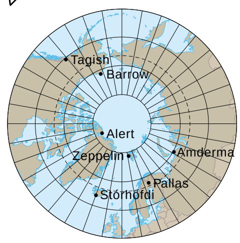
Zeppelin station at Ny-Ålesund, Svalbard, is part of AMAP's air monitoring network.

TORUNN BERG

octachlorostyrene), chlorinated naphthalenes, PBDEs, and short-chain chlorinated paraffins.

Snow accumulating on top of glaciers has been used to look at deposition of POPs. There are data from the summit of the Greenland ice cap and from Lomonosovfonna on Svalbard. The high flux of DDTs at Lomonosovfonna, nearly nine times greater than that at Summit, suggests a possible local source. HCHs, dieldrin, and endosulfan fluxes were also higher at Svalbard. The highest input of PCBs was at Summit.





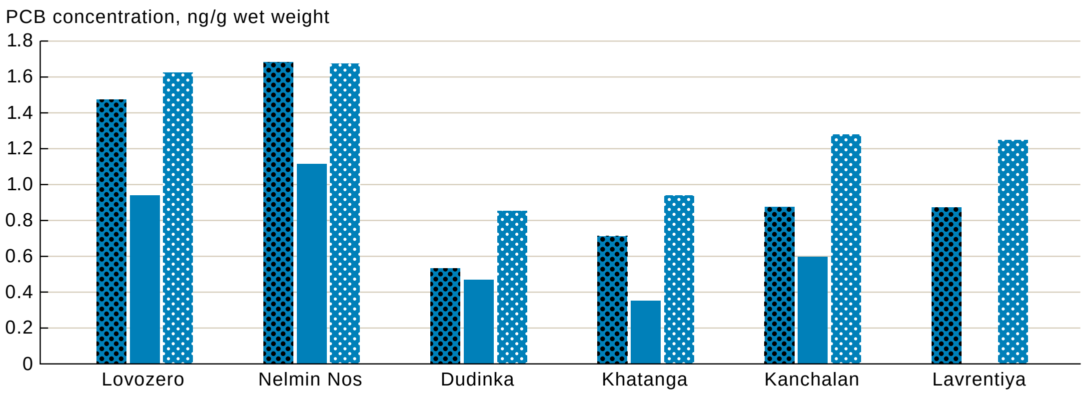
Average annual concentration of HCHs and DDTs in air. Bars indicate range in values. The map shows the monitoring station network for POPs in the Arctic.

Predatory birds and some Russian reindeer stand out in the terrestrial environment

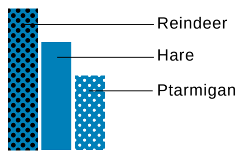
With the exception of predatory birds and organisms impacted by local sources, the Arctic terrestrial environment is among the least POPs-contaminated ecosystems in the world. Predatory birds that feed on migratory waterfowl have high levels of many legacy POPs, such as DDTs. New data from peregrine falcons in northern Norway and Sweden and from several other birds of prey in northern Norway show that brominated flame retardants are now also present.

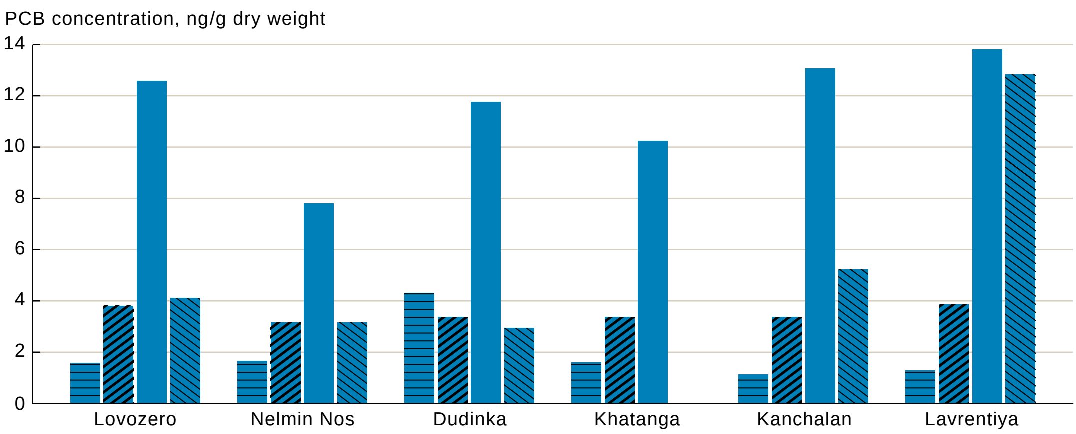
Concentrations of POPs in terrestrial biota other than predatory birds are generally orders of magnitude lower than in the freshwater and marine environments of the Arctic. New data for several terrestrial species from West Greenland confirm that POP levels in herbivores are very low. In soil, plants, and herbivores, the most prevalent POPs are HCB, HCHs, and lower-chlorinated PCBs. In predators, higher-chlorinated PCBs, chlordanes, and DDTs are more pronounced.

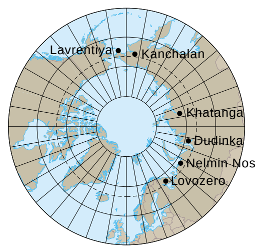
Since the previous AMAP assessment, some plant and soil data from four regions of Russia have become available. Levels are generally low but an order of magnitude higher than lichen in the Canadian Arctic. There were no strong spatial trends within Russia. However, some recent data on Russian reindeer and mountain hare indicate elevated dioxin and furan levels on the Kola Peninsula, probably connected to local emissions from smelters.

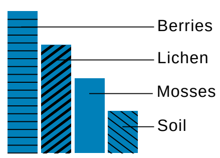


Concentrations of PCBs in terrestrial animals (liver tissue), berries, lichens, mosses, and soils from regions within Russia sampled in 2000-2001.









GUTTORM N. CHRISTENSEN

Bjørnøya (right) and Ellasjøen (below).

GUTTORM N. CHRISTENSEN

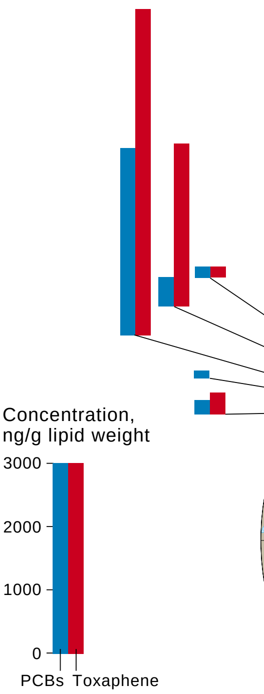
Birds connect marine and freshwater environments

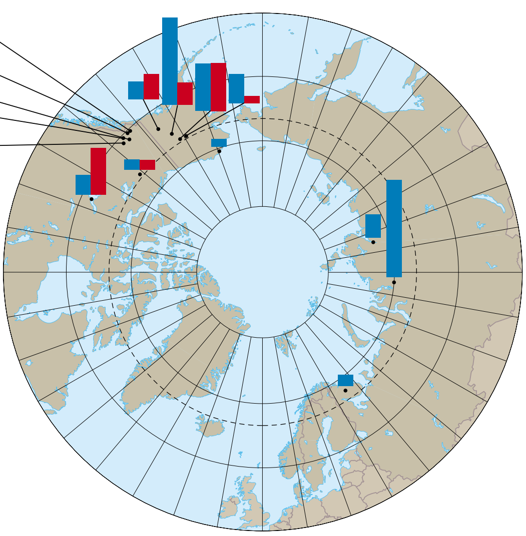
In 1994, it became clear that fish in the lake Ellasjøen on Bjørnøya had exceptionally high levels of POPs. In 1999, Norwegian researchers initiated a study to investigate why. One question was the role of long-range transport, as there were no local sources on the island. Levels of POPs in air samples seem to be very similar to the levels measured in air samples from Svalbard, and levels of POPs in snow and rainwater samples from Bjørnøya are comparable with levels found in other Arctic areas. However, levels in fog are relatively high, leading to a suggestion that a relatively high precipitation rate and a high frequency of fog in this part of Bjørnøya could lead to a high deposition of the air-borne contaminants.

Another explanation for the high levels found in Ellasjøen could be the thousands of seabirds that breed close to the lake or use it as a resting area. Their guano contains elevated levels of POPs, especially PCBs, and they deposit it directly into the lake or in the catchment area of the lake. In another lake on Bjørnøya, with no nearby seabird colonies, levels of POPs are several times lower than in Ellasjøen.

One conclusion from this study is that seabirds can serve as a biological pathway carrying contaminants from the marine to terrestrial and freshwater environments. Data from a lake on Jan Mayen, an island north of Iceland, show that this pathway is not unique to Bjørnøya.

There are also some additional Russian and Alaskan data from soil and plants from the early 1990s. The levels are generally as low in Russia and Alaska as in the rest of the Arctic, and several POPs could not be detected. The levels of higher-chlorinated PCBs and several pesticides were higher in samples from the Kola and Ural sites than in the Alaska and Taymir sites, which probably can be explained by proximity to urban areas and industrial activities.





Spatial trends for PCBs and toxaphene in burbot in the Canadian, Russian, and Alaskan Arctic.

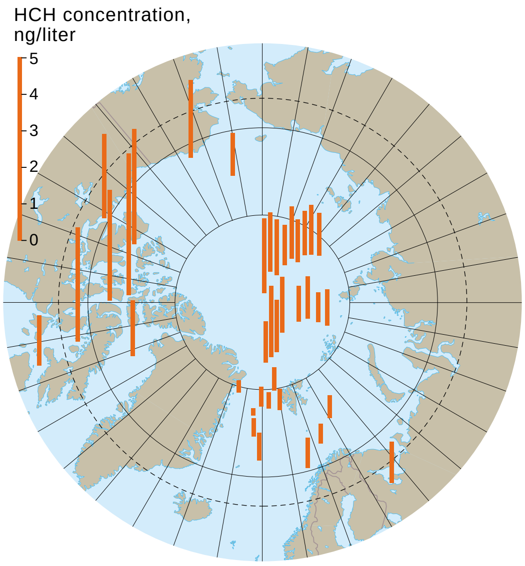
Local pollution is a problem in some freshwater environments

Freshwater biota in the Arctic generally have low levels of POPs compared with marine birds and mammals. The exceptions are fish in lakes and rivers that are contaminated via other routes than through the atmosphere. One example is in the lake Ellasjøen on Bjørnøya, south of Svalbard, where seabirds have been shown to transport contaminants from the marine environment (see box above). Another example is higher DDT and PCB levels in burbot from a lake near Fairbanks than in other lakes in interior Alaska, reflecting historical use of these compounds in the city of Fairbanks. Burbot from the Taymir-Dudinka area in Russia had similarly high levels. In other freshwater fish from Russia, POP levels, except for dioxins, are comparable to other parts of the Arctic. Dioxin levels in the Kola freshwater fish are elevated, similar to those in reindeer. Across the Arctic, toxaphene and PCBs are the contaminants that predominate in freshwater animals.

In the abiotic environment, new data from Russia confirm elevated POP levels in freshwater compared with levels observed in Canada and Norway. PCBs were the dominant POP in both water and sediment, followed by DDTs and chlorobenzenes. At one site, Nelmin Nos, DDT concentrations in sediment were 70 times higher than elsewhere. The high levels suggest fresh input into the environment in this region. With this exception, POP concentrations in sediment were similar to those previously reported for other areas of the Arctic.

HCHs, PCBs, and toxaphene dominate in seawater

Several scientific cruises have gathered data on seawater since the previous AMAP assessment. HCH levels are higher north of North America than north of Eurasia. This geographical pattern is best explained by proximity to source regions in Asia.



Concentrations of sum-HCHs in seawater 1996-2000.

For PCBs, there are too few measurements to assess spatial trends. There are some other interesting observations, however. PCB concentrations are lower under the permanent pack ice than in open nearshore surface waters. This suggests that levels are related to air-sea exchange and possibly to biological activity. The highest PCB concentrations were found in the nearshore waters of the Canadian Arctic archipelago, southern Beaufort Sea, and northern Baffin Bay. Measurements from the Surface Heat Budget of the Arctic Ocean (SHEBA) Project show that PCBs seem to be delivered to the Bering Sea via runoff and spills, whereas the interior Arctic Ocean owes a significant portion of its PCB content to condensation and air-sea exchange.

Toxaphene data suggest a fresher, less degraded input to the White Sea than the other places where toxaphene has been measured.

DDTs, chlordanes, dieldrin, and HCB are present at much lower levels than toxaphene, PCBs and HCHs. Sea-air exchange and melting snow and ice are important sources for DDTs and chlordanes to the marine environment.

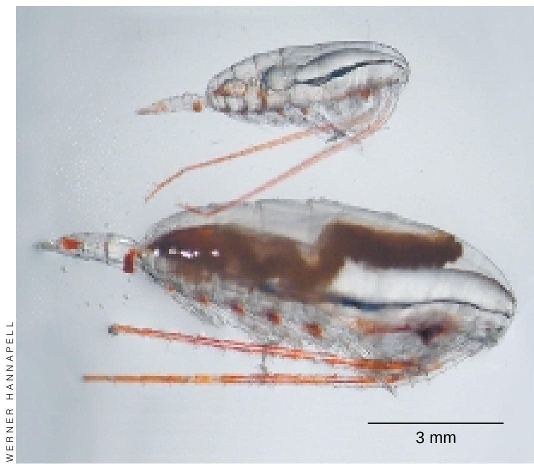
The SHEBA research lab barely afloat. During the SHEBA project an icebreaker was frozen into the pack ice and left to drift for a year.

Levels in marine invertebrates reflect food habits

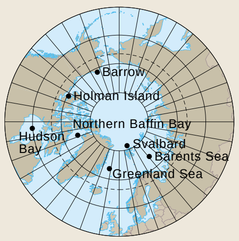
Marine invertebrates provide a link from phytoplankton to fish, seabirds, and mammals in the Arctic marine food web. They carry not only nutrients, but also POPs. Understanding the dynamics of POPs in marine invertebrates is therefore a key to understanding POP trends in the marine ecosystem.

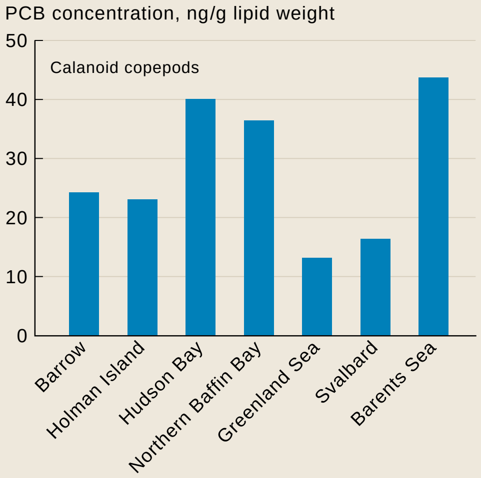
In general, marine invertebrates have low POP levels, consistent with their place low in the food web and their short life span. However, longer-lived bottom-dwelling invertebrates that scavenge the remains of fish and mammals have higher contaminant loads. One group of organisms that has been extensively sampled since the previous AMAP assessment is the calanoid copepods, a zooplankton group that dominates in open water in the high-latitude marine environment.

Copepods feed on phytoplankton. The most common POPs in these animals were relatively water-soluble compounds such as HCHs and some PCBs, followed by less water-soluble compounds such as DDTs, chlordanes, and HCB. The concentrations of DDTs and chlordanes were higher in the copepods than in the surrounding water, indicating some bioconcentration.



Two species of calanoid copepods, *Calanus finmarchicus* (above) and *Calanus hyperboreus* (below).



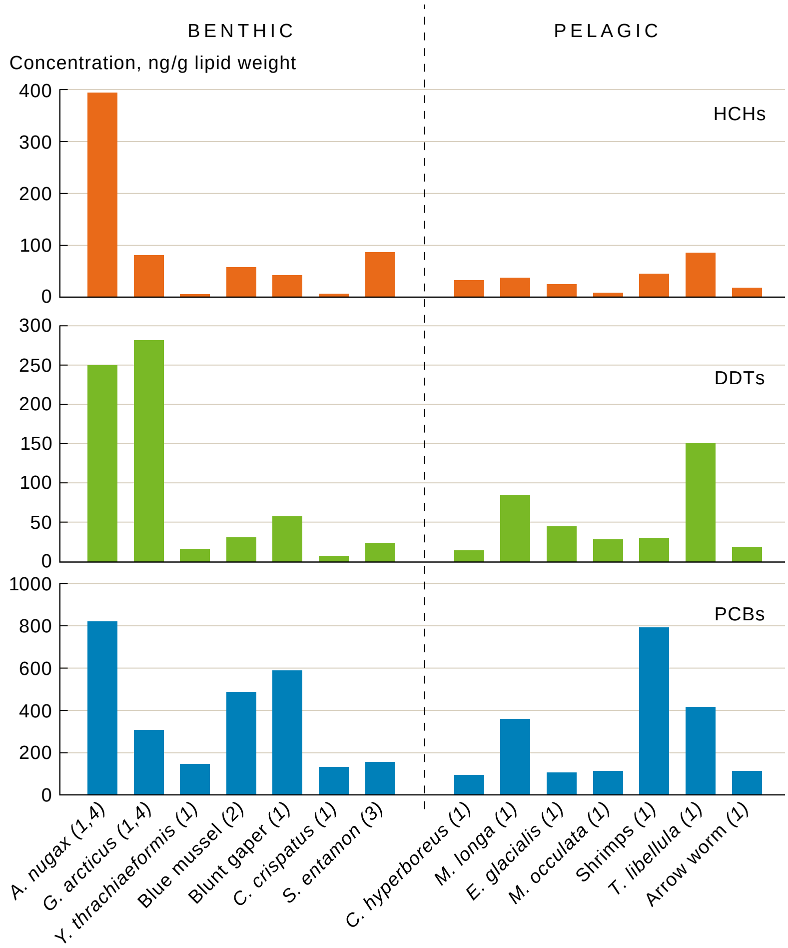


Barents Sea POP levels remain unexplained

Seabirds and marine mammals from the Barents Sea, Svalbard, and East Greenland have higher PCB and DDT levels than animals from Canada and Alaska. There are many ideas about the cause of this difference, including transport by contaminated ice from Russian rivers, but as yet no clear-cut answers have been found. The in-depth study of zooplankton and ice-associated amphipods does not show any clear geographical pattern that could provide an explanation. For example, PCB levels are higher in these organisms in the North American Arctic than in the Greenland Sea and north of Svalbard. Food web structure may be part of the explanation. More research is thus needed to understand the dynamics of contaminant transport around the Barents Sea, Svalbard, and East Greenland.

The geographical pattern for POPs in zooplankton shows higher levels of HCB and HCHs in Alaskan and western Canadian waters compared with other parts of the Arctic. This probably reflects the proximity to recent sources in Asia. Toxaphene levels were lower at Alaskan sites than those in the eastern Canadian Arctic, reflecting proximity to North American sources.

Averaged concentrations of HCHs, DDTs and PCBs in benthic and pelagic invertebrates from northern Baffin Bay (1), northern Quebec (2), northern Alaska (3), and Cumberland Sound (4).



The levels for ice-associated invertebrates were as low as those for the zooplankton. No clear geographical trend was apparent for PCBs, DDTs, and toxaphene. The only geographical difference was higher alpha-HCH levels in Fram Strait compared with the area north of Svalbard.

The study of ice-dwelling amphipods has increased understanding of their ecology and its relation to contaminant burden. The differing levels of fat-soluble POPs in these creatures indicate that diet may play an important role in the bioaccumulation of POPs. For example, the highest POP levels were found in a long-lived species that, as it grows larger, switches from eating phytoplankton to eating other zooplankton.

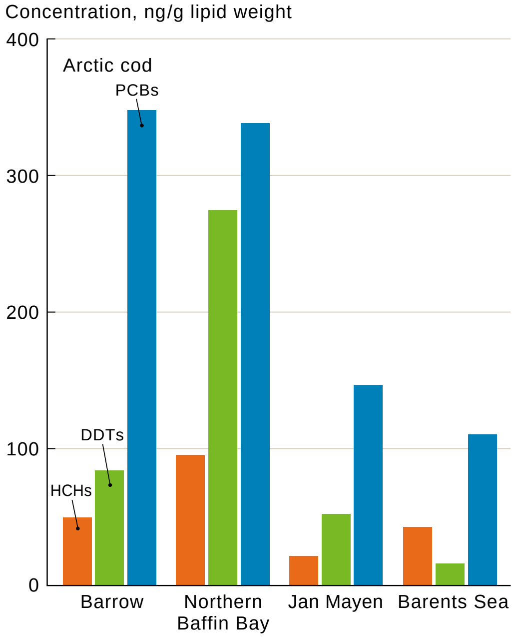
Bottom-dwelling, or benthic, invertebrates have a larger range of sizes and feeding ecologies than those living in the water column. Since the previous AMAP assessment, a number of new benthic invertebrates have been analyzed for POPs. Those that feed on animal carcasses can have very high POP concentrations. For example, the amphipod *Anonyx nugax* has concentrations in the same range as Arctic cod and the dovekie, a seabird. PCBs are the contaminant of greatest concern, but chlordane and DDT levels were also high in some species.

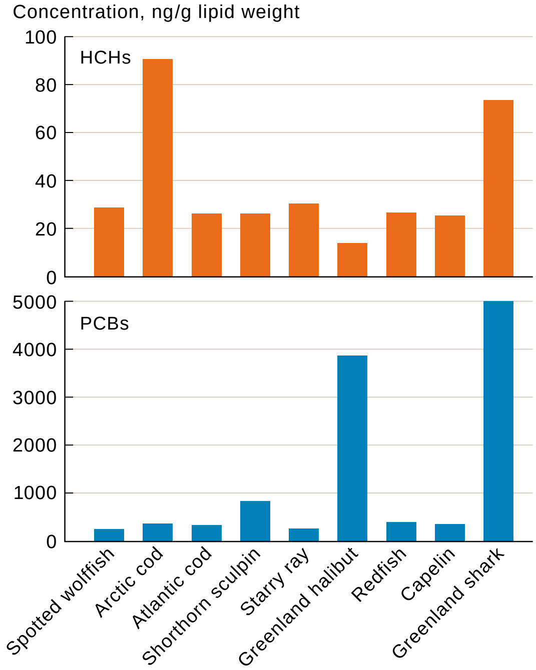
POP levels in the filter-feeding blue mussel are available for several locations. With one exception, the levels are low. PCBs are the most prominent contaminant, probably because they adhere to the sediments that the mussels filter to gather food. The one area with high contaminant levels was Kuujjauq in northern Quebec. This can probably be explained by a local PCB source. High TBT levels have been reported in blue mussel in harbors in northern Norway.

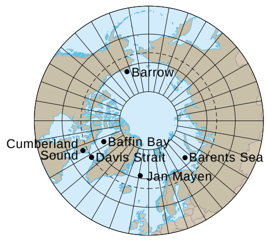
The Greenland shark stands out among marine fish

Arctic cod is an important link from invertebrates to marine mammals and seabirds. It is included in AMAP's monitoring program because of its circumpolar distribution. The geographical pattern indicates higher DDT levels in northern Baffin Bay than elsewhere in the Arctic. PCB levels were somewhat higher in North American Arctic cod, consistent with zooplankton but not with what has been seen in seabirds and marine mammals (see graph left on opposite page).

For some long-lived predatory fish, POP levels are high. The previous assessment mentioned high toxaphene levels in Greenland halibut from eastern Canada. Recent data from West Greenland confirm high POP levels in this species. New data on Greenland shark caught in Davis Strait and Cumberland Sound show levels in the same range as in other top Arctic predators, such as polar bear and glaucous gulls (see graph right on opposite page). DDT levels







◄ Concentrations of HCHs, DDTs and PCBs in Arctic cod.

Concentrations of HCHs and PCBs in Arctic marine fish from Davis Strait and Baffin Bay, and Greenland shark from Cumberland Sound.

were among the highest ever measured in Canadian Arctic animals. The explanation is probably a combination of slow metabolism, long life span, and a high position in the food web.

Scavenging seabirds can have very high loads of POPs

There are about fifty species of Arctic seabirds. Their levels of contamination depend to a large extent on their different feeding habits. Some birds migrate to southern areas and their contaminant load also reflects what they eat during their migrations. For example, Greenland and Canadian kittiwakes, which overwinter in European waters and off the North American east coast, have high POP levels, as do kittiwakes from several sites in the Barents Sea.

In the Arctic, POP levels are highest in the glaucous gull, the great skua, and the great black-backed gull, which are all birds that scavenge and prey on other seabirds and occasionally on carcasses of marine mammals. The glaucous gull migrates to the northern Atlantic region in winter, and the other two migrate as far south as southern Europe. Levels are also high in the ivory gull and northern fulmar, both of which scavenge.

The most prevalent contaminants are PCBs, DDTs, and chlordanes, but relative levels of these and other POPs vary by species. New data show that toxaphene is present in Canadian, Greenland, and northern Norwegian seabirds, with levels as high as those of PCBs. For some dioxins, furans, and dioxin-like PCBs, the levels in Arctic seabirds exceed levels in marine mammals by several orders of magnitude and are comparable to levels in seabirds from temperate North America and Europe. The levels are especially high in glaucous gulls from Bjørnøya. Some new chemicals have also been detected, most notably PBDEs. The levels of this chemical in Norwegian and Canadian Arctic birds are higher than in marine mammals in Canada but lower than in birds from the polluted Baltic Sea. Some individual glaucous gulls from Bjørnøya have PBDE levels as high as those of seabirds in the Baltic Sea.

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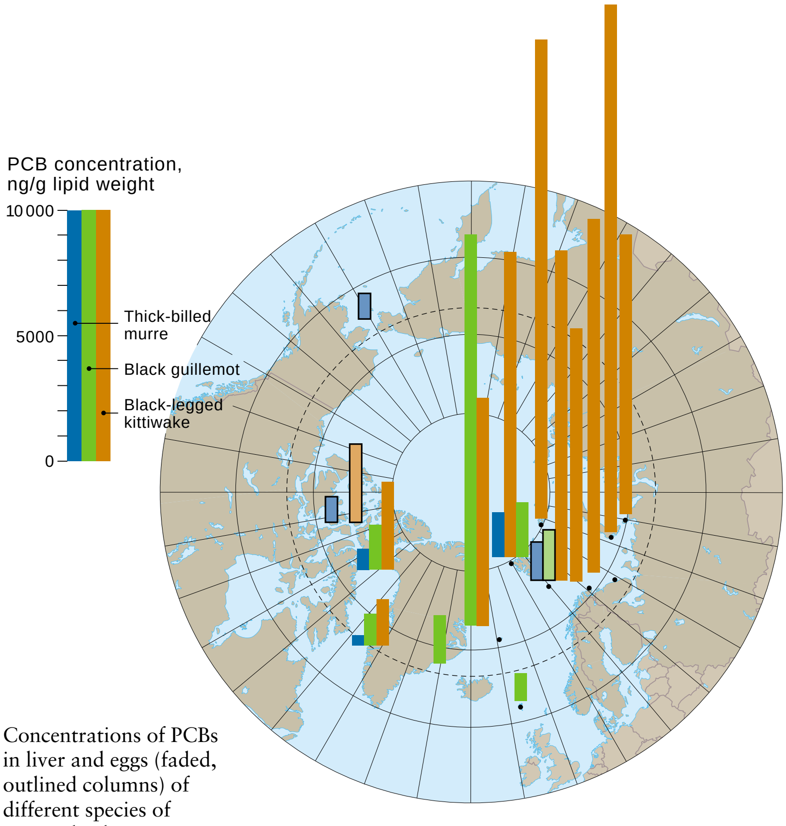
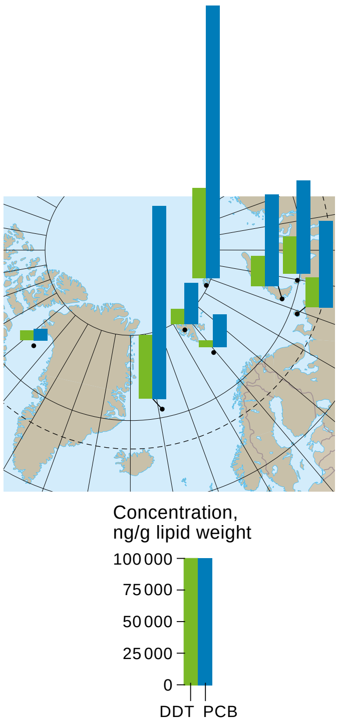
The Greenland shark is the largest fish and the only shark known to inhabit Arctic waters. Very little is known about its ecology, but there is some evidence that this shark can live more than 100 years. They eat seal pups and beluga whales, and thus live high in the food web.



Concentrations of PCBs in liver and eggs (faded, outlined columns) of different species of marine birds.

Mono-, di-, and tributyltins have also been found in these glaucous gulls. Polychlorinated naphthalenes (PCNs) have been detected in herring gulls and black-backed gulls in northern Norway.

POP levels in seabirds that do not migrate and have a circumpolar distribution, such as black guillemot, can be used to look at spatial trends. New data are available from Alaska, the Bering Sea, Baffin Bay, Greenland, Iceland, the Faroe Islands, Jan Mayen, and Svalbard. HCH levels were highest in the Baffin Bay birds, reflecting the generally higher levels of this contaminant in the Canadian Arctic and more recent use in Asia. PCB levels were highest at Jan Mayen, Norway. Glaucous gulls only migrate within very limited areas. The spatial trend for glaucous gulls shows the highest PCB levels at Franz Josef Land, Russia.

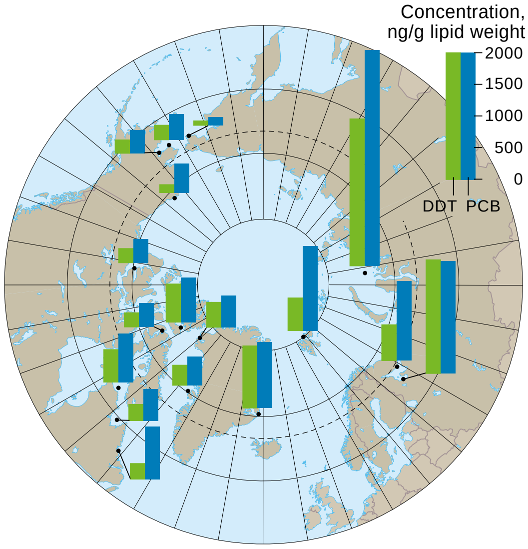


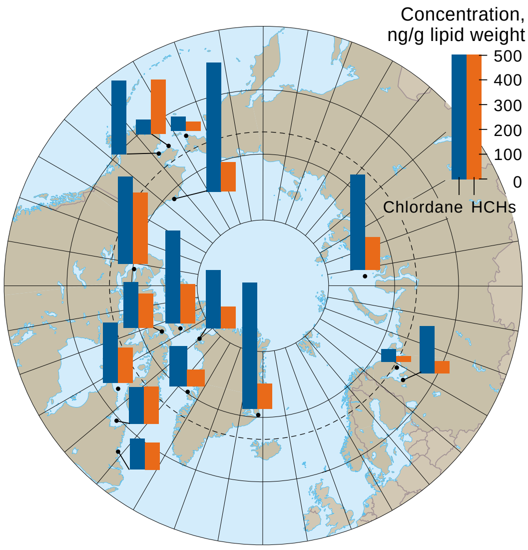
Concentrations of DDTs and PCBs in glaucous gull liver.

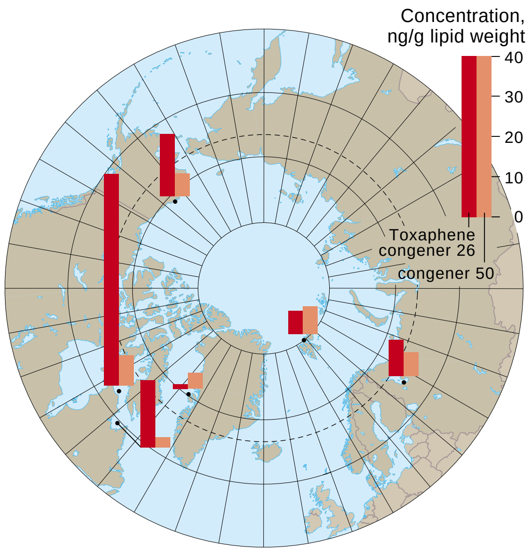
Seal data reveal high POP load in parts of the Arctic

The most abundant and widely distributed seal in the Arctic is the ringed seal. It feeds on fish and crustaceans. The most prominent contaminants in ringed seals are PCBs, chlordanes, and DDTs. Old and new data give a similar geographical picture of the contaminant load. Levels of PCBs and DDTs increase from west to east, with the lowest levels in Alaska and eastern Russia (Chukotka), moderate levels in the eastern Canadian Arctic and West Greenland, and higher levels in East Greenland and around Svalbard. The Svalbard seals have PCB levels four times higher than seals from the western Canadian Arctic and Alaska. In the Russian White Sea and the more easterly Kara Sea, levels were even higher than in the seals from Svalbard.

A number of studies have measured toxaphene in ringed seals, and the data show that this pesticide is an important contaminant throughout the Arctic. In some cases the levels are higher than for PCBs. The levels in ringed seals are highest in the Canadian Arctic, probably reflecting the extensive past use of toxaphene in North America. Harp seals on the ice edge east of Svalbard have surprisingly high toxaphene levels. This suggests that they are







Concentrations of DDTs and PCBs (upper), chlordanes and HCHs (middle), and toxaphene (lower) in ringed seal blubber.

continuously exposed to fresh toxaphenes and may indicate the use and production of these compounds in spite of bans.

Low but detectable levels of mono- and dibutyltins have been found in Svalbard ringed seals and in Alaskan Steller's sea lions, in which tributyltins were also found.

migrations. The bowheads are exposed to a variety of contaminants via their prey, which is mostly plankton, but contaminant levels are generally low. The pattern of different POPs in bowheads matches the contaminant load in the surface waters of the Bering and Beaufort Seas.

Baleen whales have low loads of POPs

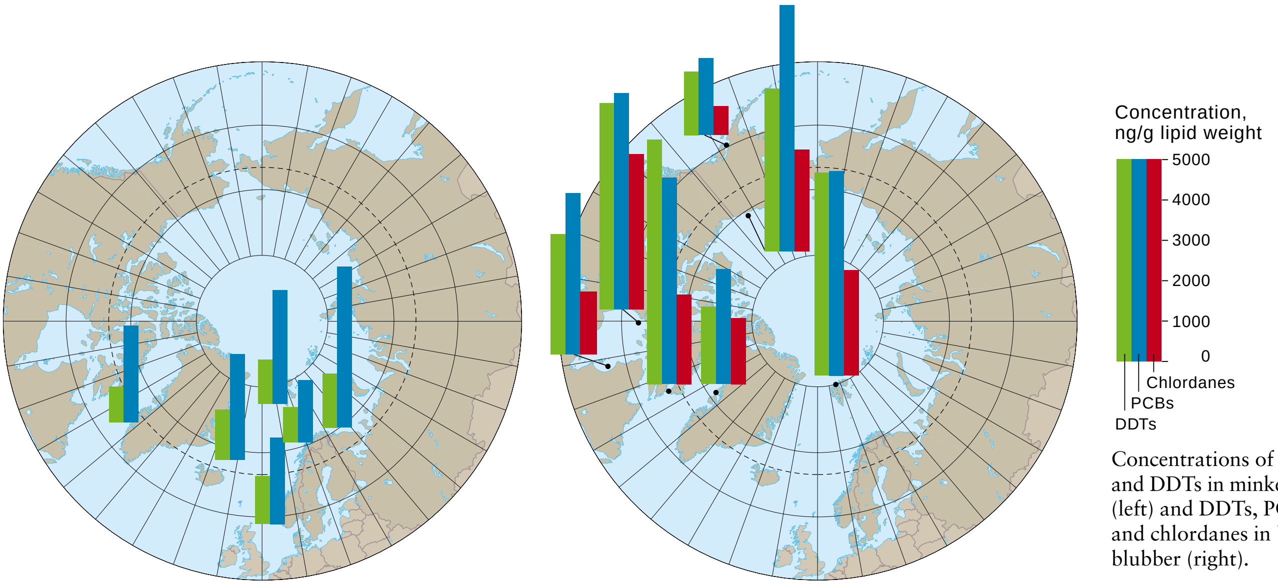
The North Atlantic minke whale is found across the Atlantic in both polar and northern temperate waters. It feeds mostly on fish and krill. PCB and DDT levels generally increase from west to east with the highest levels in the North and Barents Seas. The levels in recent measurements from the northeast Atlantic are two-to three-fold lower than those made in the early 1990s. The decline in POPs in these minke whales may reflect a change in feeding habits to almost exclusively krill after a collapse of the capelin stocks. The geographical differences in levels may reflect proximity to sources as well as differences in migration patterns and food habits, which are not well studied.

Gray whales make an annual round-trip migration between their breeding grounds in Baja California and the southern Gulf of California and their major feeding area in the northern Pacific Ocean. Gray whales mostly eat bottom-dwelling prey and thereby also ingest sediment and other bottom material. The only data on contaminants are from 17 whales sampled in Russian waters of the Bering Sea in 1994 and in one gray whale from Chukotka in 2000. DDT and PCB levels were comparable to other baleen whale species in other parts of the Arctic.

The bowhead whale lives in Arctic waters. The largest stock migrates between summer grounds in the eastern Beaufort Sea and Amundsen Gulf and winter habitat in the Chukchi and northern Bering Seas. The traditional native harvest occurs during the spring and fall

Toothed whales can be very contaminated

The beluga or white whale is a small toothed whale feeding near the top of the marine food web. It is relatively long-lived. Belugas are found throughout the Arctic. The major POPs in beluga are PCBs, DDTs, chlordanes, and toxaphene. Levels are generally lower in southern Alaska and higher in the eastern Canadian Arctic and around Svalbard. Samples from Nunavut have also been analyzed for chlorinated naphthalenes, which accounted for about one tenth of the TEQs in those beluga. PBDEs are another new contaminant group present in measurable quantities in beluga.



Concentrations of PCBs and DDTs in minke whale (left) and DDTs, PCBs, and chlordanes in beluga blubber (right).

In Alaska, free-ranging transient killer whales, which feed on marine mammals, have high POP levels compared with resident killer whales in Prince William Sound, which stay in one area and prey mostly on fish. The difference in contaminant burdens is probably caused by the different diets. The levels in the transient killer whales are similar to the populations in the Strait of Georgia/Puget Sound area at the border between Canada and the United States.

PCB and DDT levels in harbor porpoises off the west coast of Norway are comparable to those in porpoises from the polluted Baltic Sea and the Kattegat-Skagerrak passage between the Baltic and North Seas. Some of the porpoises from western Norway may have been exposed to local PCB sources. Levels in harbor porpoises from Greenland are much lower.

Norwegian and West Greenland harbor porpoises and Dall's porpoises from the Aleutian Islands have detectable levels of mono-, di-, and tributyltins.

PCB levels in pilot whales from the Faroe Islands are higher than for most other whales. Levels of several other POPs are also comparatively high. PBDE concentrations are an order of magnitude higher than in other Arctic marine mammals examined to date.

Narwhal from West Greenland and the Canadian Arctic have similar POP levels, whereas levels of PCBs, DDTs, and chlordanes were considerably higher in narwhal from Svalbard. Levels of HCHs, HCB, and toxaphene were quite consistent across the sites sampled.

Polar bear PCB levels point to possible regional sources

Polar bears are top predators in the marine food web. They are distributed throughout the Arctic and range over large areas in search of food. They follow their main prey, ringed seals and bearded seals, as the edge of the sea ice moves south in fall and winter and north in spring and summer. Often, polar bears eat only the blubber from the seal, and are thus exposed to higher loads of POPs because the blubber carries more fat-soluble pollutants than other tissues.

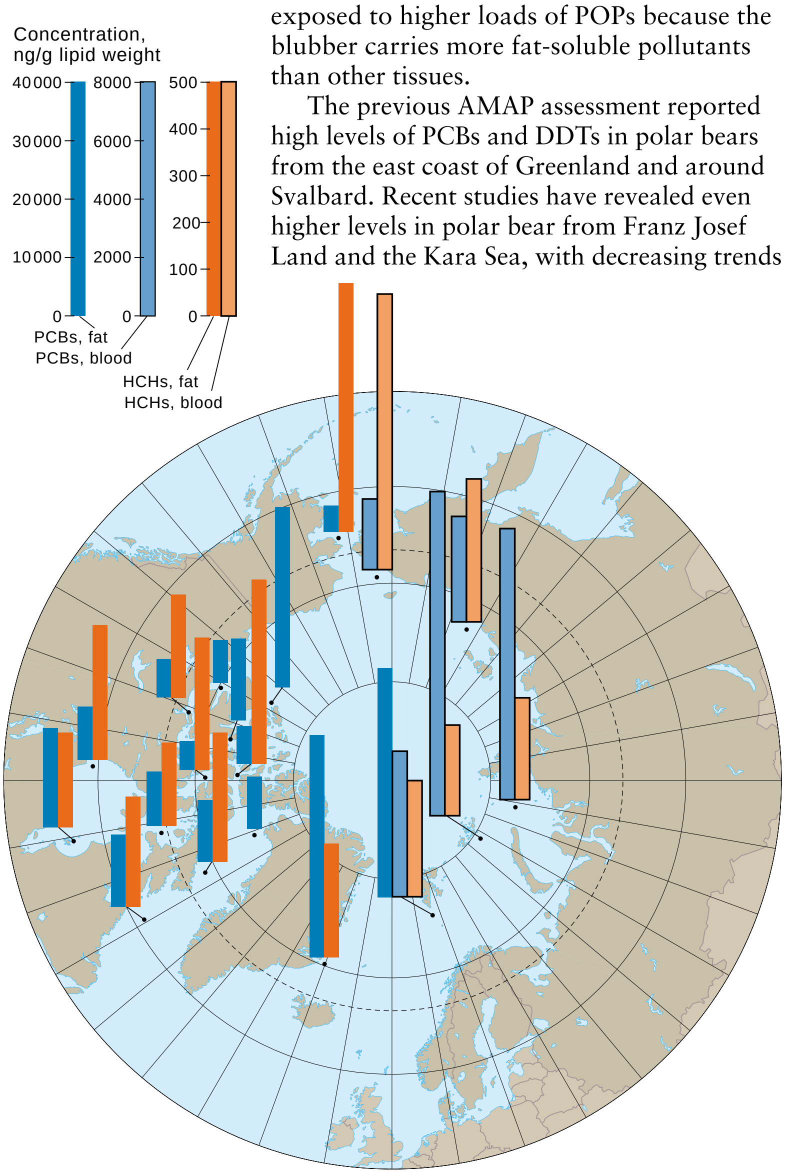
The previous AMAP assessment reported high levels of PCBs and DDTs in polar bears from the east coast of Greenland and around Svalbard. Recent studies have revealed even higher levels in polar bear from Franz Josef Land and the Kara Sea, with decreasing trends eastwards and westwards from this region. This may imply a significant source of PCB pollution in Russia. The contaminant load in these polar bears also indicates that there may be significant sources of DDT and chlordane in this part of Russia.

There are also new polar bear data from Alaska, where PCB levels are lower than in polar bears from Hudson Bay, Canada, and Svalbard. In Alaska, the highest levels were in bears from the southern Beaufort Sea. The Alaska bears had higher HCH levels than polar bears elsewhere in the Arctic.

There have been several suggestions to explain why some polar bear populations have much higher PCB levels than others. These include proximity to sources and contaminant transport by ice from source regions. New information about what polar bears eat might shed more light on the issue. Most polar bears feed on ringed seal, especially the blubber. However, east of Svalbard, an unusually high number of bears feed on harp seals. These seals migrate from the Russian White Sea and may serve as a biological pathway from Russia to Svalbard. Moreover, blubber from adult harp seals has higher POPs concentrations during the molting season in June, compared with ringed seals sampled at the same time. The results suggest that the season, availability, and biological condition of polar bear prey may play an important role in biomagnification of POPs in the marine food web.

Though PCBs have been the major contaminant of concern in polar bears, other POPs are present as well. Most notable is PFOS. Levels in some polar bear liver samples from northern Alaska are high enough to make this one of the most prominent POPs. PFOS has also been detected in blood of ringed seals in eastern Canada and in Svalbard and in Alaskan northern fur seals.

Recent measurements show the presence of toxaphene in Svalbard bears. Their fat also contains PBDEs, along with several unidentified brominated compounds.



Concentrations of PCBs and HCHs in adult female polar bears. Data from AMAP phase I (fat) and recent studies (blood). At Svalbard, PCB levels measured in fat are approximately five times higher than in blood from the same animals. If this relationship is the same in other areas, high fat PCB concentrations can be expected in bears in the Russian Arctic.

Arctic fox

Arctic foxes are very opportunistic in their food habits and can be part of both the marine and terrestrial food webs. On land, the foxes feed on lemmings, birds, bird eggs, and caribou carcasses, whereas coastal foxes may also eat marine invertebrates and fish in summer. During the winter and spring they scavenge on the remains of seals killed by polar bears and on seal placentas. Arctic fox also prey on newborn seal pups. Their feeding habits influence both their position in the food web and their contaminant load. Foxes in Canada, inland Iceland, and Alaska generally have lower POP levels than do foxes along Iceland's coast and on Svalbard. Iceland's coastal foxes have PCB levels higher than Svalbard polar bears.

Time trends

Comparing previous and current levels of contaminants can give an indication of new sources as well as information about the effects of bans or other political actions to limit emissions. Interpretation of time trends must also take into account possible changes in pathways, as is discussed in the chapter *Changing Pathways*. This is especially true for trends comparing the 1990s with previous decades, because of a shift in climate regime that has affected wind patterns, precipitation, and ocean currents.

In general, the levels of several banned persistent organic pesticides have declined or otherwise mirror historical usage. However, there are some notable increases in air during the 1990s for DDTs, dieldrin, and endosulfan. Increases for endosulfan have also been seen in beluga

Some HCHs have not declined as much as expected based on decreased use. In fact, levels of beta-HCH have increased in some areas, probably because old emissions are only now reaching parts of the Arctic via ocean transport. The time trend for toxaphene is also complex, with both increases and declines reported.

For PCBs, levels have generally decreased, but with varying rates in different parts of the Arctic. In polar bears and belugas, the decline has leveled off since the mid-1990s.

Not all contaminants are decreasing. Data from seabirds, belugas, and seals indicate that levels of the brominated flame retardant PBDE are increasing. This product is still in use.

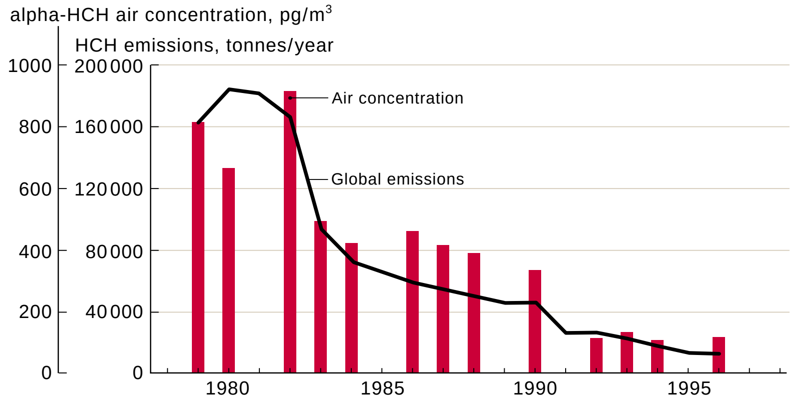
The following sections give more detailed information about the different time series.

Air samples show trends in atmospheric concentrations

Air sample data mirror atmospheric transport of contaminants. The most reliable time trend data are from Alert, Canada. At Alert, DDT concentrations increased significantly over the period 1993 to 1998, and the chemical signature implies a continued source of technical DDT entering the Arctic atmosphere. HCHs declined during the same period, as did chlordane levels. Dieldrin concentrations increased significantly. The concentrations of alpha-endosulfan also increased significantly at Alert, which can probably be explained by continued use in North America.

For PCBs there was a definite reduction in air concentration at Alert from 1992 to 1998, whereas other stations showed no clear downward trend. Also, for PAHs, there was no consistent trend.

Longer time-trend data for HCHs clearly show how reduced use has an impact on air transport to the Arctic, decreasing the load to the environment.



Emissions of technical HCH and concentrations of alpha-HCH in Arctic air.

Ice cores show declining input

Snow collected in glaciers and transformed into ice can give a historical record of POPs deposition. In the spring of 2000, a core of ice was collected at the Lomonosovfonna Ice Cap on Svalbard that represents a historical record of the past 70-80 years. It gives the first detailed picture of deposition in the European Arctic. For all the measured contaminants, the maximum concentration occurred below the snow surface, indicating that inputs have declined in recent years.

The results indicate that DDT levels probably peaked before the 1970s in most of the areas that are sources to Svalbard. The levels were unusually high compared with some other pesticides, which may reflect past DDT use in nearby communities. An unexpected result was that the concentration of HCHs in the ice core was higher than for the other POPs. The highest concentrations were similar to 1993 levels in water from the Yenisey River, the most contaminated of the large Russian rivers. HCHs, being volatile, would normally evaporate and the levels may thus have been even higher when the snow fell. The snow near the surface, reflecting recent input, had levels that were similar to current levels in lake and river water. The recent downward trend in HCHs is consistent with what has been seen in air and water samples.

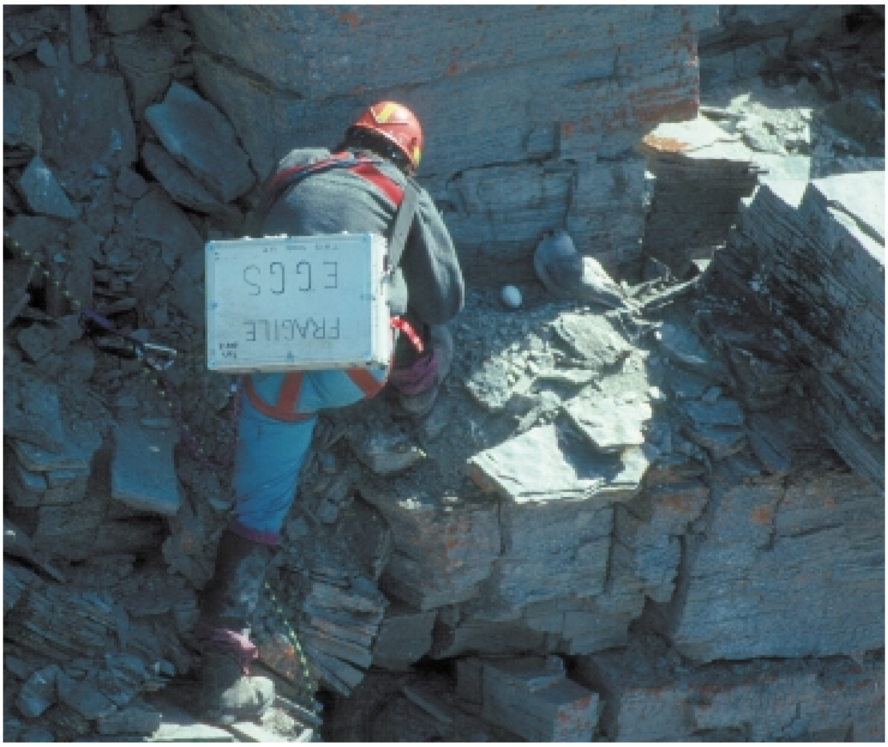
Falcon eggs and freshwater fish show declining POP levels

Eggs from Alaskan peregrine falcons have been analyzed to look at time trends for the terrestrial environment. From 1979 to 1995, the levels of dieldrin, DDTs, chlordanes, and PCBs declined. The trend was weaker for PCBs than for the other contaminants.

In the North American Arctic, some time trend conclusions can be drawn by comparing burbot liver samples collected in Fort Good Hope in the years 1986, 1988, 1994, and 1999. Slow declines in all major organochlorines and toxaphene were observed, although the rate of change varied with the chemical and the year. Russian burbot data from 1988 and 1994 indicate declines in HCHs and DDTs.

Seabird eggs provide wealth of time trend data

One way to look at time trends is to analyze archived samples. One such study has been carried out on seabird eggs collected between 1975 and 1998 from Prince Leopold Island in the Canadian High Arctic. During egg formation, POPs are transferred to the egg via lipids.


BIRGIT BRAUNE

Climber on cliff with northern fulmar and egg. Bird eggs collected on Prince Leopold Island in the Canadian Arctic provide important information about temporal trends of POP levels.

The contaminant burden in the egg reflects residues assimilated by the female over a long period. In migratory birds, eggs also integrate the exposure from a number of different locations.

Levels of PCBs, DDTs, and HCB decreased in all the bird species studied during this period. The most dramatic declines were in kittiwake eggs. These birds migrate to industrial areas, and the declines are similar to what has been seen in birds from polluted areas such as the Baltic Sea. Chlordane, dieldrin, and mirex levels decreased in kittiwake eggs, but not in the eggs of other birds.

The story about HCHs in the North American Arctic is mixed and provides a lesson about the role of biomagnification in temporal trends. For total HCHs, the levels in bird eggs increased, driven by beta-HCH. Alpha-, beta-, and gamma-HCH all continue to be delivered to the Arctic by seawater flowing through the Bering Strait. Moreover, the Arctic Ocean may work as a major reservoir of these contaminants. However, only beta-HCH biomagnifies, and this component drives the temporal trends for total HCHs in higher-trophic-level organisms. In other words, the decline in total HCHs that would be expected based on reduced global use is delayed partly because beta-HCH biomagnifies. Another reason for the delay is that ocean currents are still delivering beta-HCH into the Arctic Ocean from the Bering Sea.

Some measurements in bird livers from Prince Leopold Island provide data on dioxins, furans, and dioxin-like PCBs in kittiwakes, fulmars, and murres. Reported as TEQs, levels were lower in 1993 than in 1975. Within this general picture of declining levels, however, there was an increase in dioxins and furans in murre livers and an increase of dioxin-like PCBs in fulmar livers.

The Canadian data also suggest that levels of toxaphene and PBDEs have increased from 1975 to 1993.

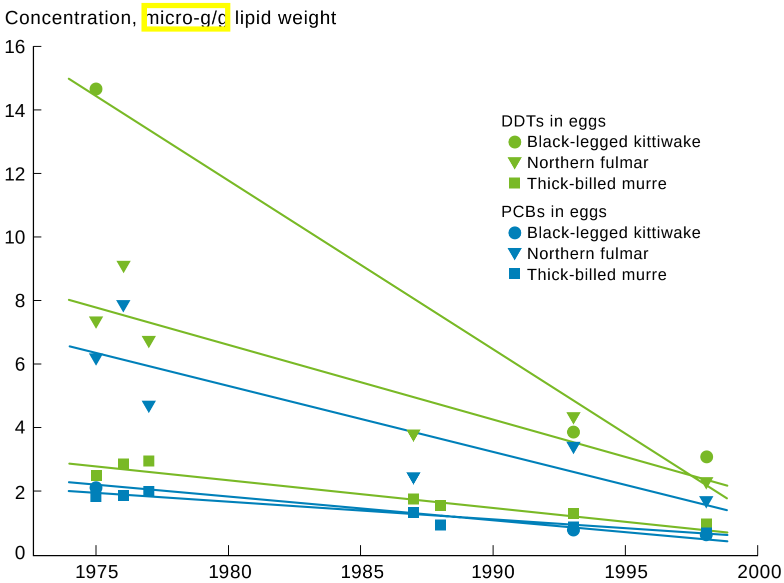
Another time trend in several seabird species was carried out in northern Norway, looking at eggs from 1973, 1983, and 1993. There was a significant decline in PCBs and DDTs.

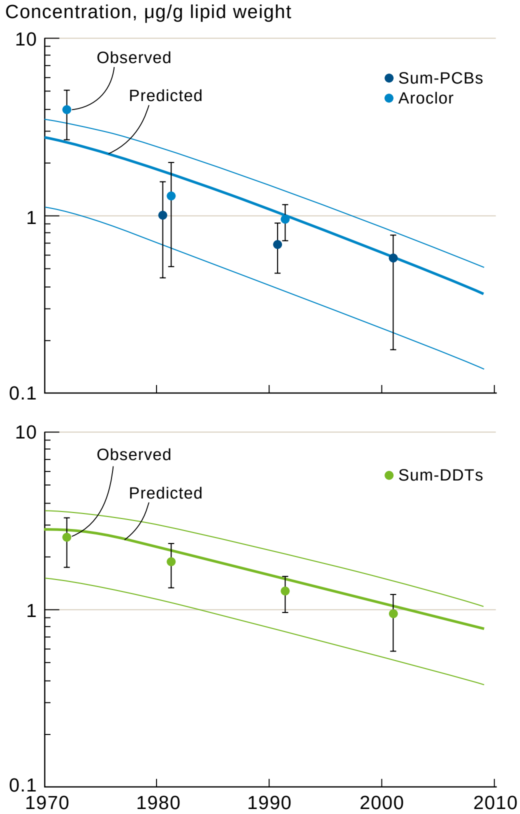
Model based on seals predicts future DDT and PCB declines

Ringed seals collected by hunters in the three Canadian communities of Ausuittuq and Ikajutit in Nunavut and Holman in the Northwest Territories have been used to compare current contaminant levels to those in the 1970s. The most striking declines are for DDTs and PCBs. HCH concentrations showed no significant change, but the proportion of beta-HCH increased over this time period. A similar increase in beta-HCH has been reported for seawater during the 1980s and 1990s. Chlordane levels increased in Holman and Ausuittuq, in contrast to falling PCB and DDT concentrations. The concentration of dioxins, furans, and dioxin-like PCBs remained constant between 1981 and 2000.

What will happen to ringed seal contaminant levels in the future? By modeling the historical input to the environment along with biological factors that affect the levels in the animals, it has been possible to make some predictions. Contaminant levels in ringed seals do not seem to lag behind inputs, probably because the seals can excrete the contaminants

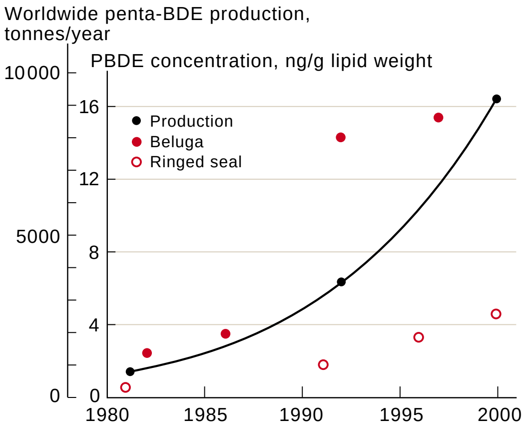
Concentrations of DDTs and PCBs in seabird eggs collected between 1975 and 1998 on Prince Leopold Island.





Observed and predicted trends for PCBs and DDTs in ringed seal from Holman Island, Northwest Territories.

and because of population turnover. Therefore, PCB and DDT levels are predicted to decline substantially over the coming decade. The predicted rapid decline should not be extrapolated to other species as lifespan and position in the food web have a major influence. For example, levels in polar bears and belugas do not decline as fast. Neither should the expected decline be extrapolated over longer time frames or to other contaminants.



Comparison of temporal trends of PBDEs in ringed seal and beluga in the Canadian Arctic with estimated global production of penta-BDE over the same period.

PBDEs are on the rise

Not all contaminants are decreasing. Studies of beluga blubber from southeastern Baffin Island, Canada, show that the levels of PBDEs have increased from 1982 to 1996. The levels are low compared to PCBs in the same animals, but the levels doubled in only three years. The trend parallels PBDE increases in fish and in herring gull eggs from the Great Lakes in North America. A similar increase has also been seen in ringed seal from Holman Island, Canada, with a doubling of concentration in 4.5 years, and in seabirds from Prince Leopold Island, Canada. If nothing is done to reduce emissions and current trends continue, PBDEs may reach the same levels as PCBs in a few decades.

There are no temporal trends for PBDEs in the European Arctic, but data from the Baltic Sea indicate declines after a previous exponential increase in the 1980s. The penta-BDE product has been withdrawn in Europe and this shows the close relationship between discontinued production and use and decreased environmental concentration.

Declining concentrations in polar bear are leveling off

In the Canadian Arctic, the most striking time trend is a strong decrease in DDTs in polar bears from Hudson Bay from 1968 to 1999. The decline started from comparatively high DDT levels, probably connected to use in local communities and a military base to control insects during the 1950s and 1960s. After a ban on DDT and the closing of the military base in the mid-1970s, local DDT input into the environment decreased drastically. For other contaminants, trends could only be detected from 1991 to 1999. HCB, alpha-HCH, and PCBs decreased, whereas there were no significant changes in chlordanes, DDTs, dieldrin, beta-HCH, and total HCHs. In spite of the recent declines, PCB levels in Hudson Bay polar bears were almost as high in the late 1990s as they were in the late 1960s. This is in sharp contrast to the large declines in PCB contamination in the Great Lakes and in the North Atlantic.

In Svalbard polar bears, PCB levels decreased rapidly in the early 1990s, more so than in the bears from Hudson Bay. However, the decrease has now leveled off and PCBs in Svalbard polar bears have probably reached a steady state with the global distribution of PCBs. Current results indicate that further decreases in PCBs in the Arctic may be slow. In contrast to the bears from Hudson Bay, beta-HCH did decline in the Svalbard bears.

Biological effects

POPs have a range of potential effects on animals. A sensitive target is the immune system, where new information reveals that effects are apparent among some Arctic populations of polar bear, northern fur seals, and glaucous gulls. Current contaminant levels may also pose a threat to reproduction and brain development in wildlife. POPs interacting with hormones, especially during development in the womb or at a very young age, is probably a common link between many effects.

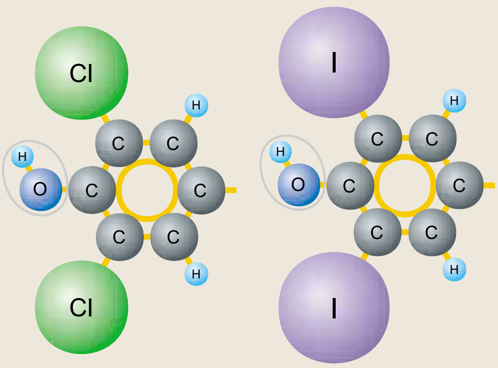
Hormone disruption may be a common link

New information on the mechanisms behind the toxic effects of POPs points to common underlying mechanisms involving disruption of the hormone system. Thyroid hormones have been a particular focus. These hormones control fetal brain development and behavior, as well as growth, metabolism, and reproduction throughout the life of the animal.

Some of the effects on the thyroid seem to be caused not by the contaminants themselves but by substances that the body has created in trying to detoxify the contaminants. Of special importance are metabolites that attach to the protein complex that normally transports thyroid hormone and vitamin A in the body. This leads to imbalances of thyroid hormones or vitamin A or both. Imbalance in vitamin A can cause a suppression of the immune system, increased susceptibility to cancer, and skin lesions, and can disrupt reproduction, growth, and development. Some POPs, especially dioxins and PCBs, are known to affect vitamin A balance in the body.

POPs can also influence the levels of thyroid hormones by increasing or decreasing the normal breakdown of this hormone in the body. The PCB metabolites hydroxy-PCBs can influence a regulatory pathway that is important in fetuses, and can thus affect fetal brain development. Additionally, exposure to POPs is known to lead to greater production of specific enzymes in the liver, which are involved in the breakdown of thyroid hormones.

Several POPs also affect sex hormones, for example by binding to the receptor for estrogen. Sometimes the result is an estrogen-like activity, sometimes the opposite. Slight changes in the levels of sex hormones can have dramatic effects on an animal.



The figure shows the similarity between a hydroxy metabolite of some PCBs (left) and the hormone thyroxin (right). This structural similarity allows hydroxy-PCB to fit into a hormone receptor, which in turn can lead to a range of effects.

Many sensitive targets

The toxic properties of POPs on wildlife have been recognized since the 1960s. The effects of POPs on reproduction are numerous. In birds, they include eggshell thinning, decreased egg production, dead or deformed chick embryos, and changes in mating and parental behavior. In mammals, POPs are known to alter hormone levels, reduce sperm production, and decrease the survival of offspring. In fish, documented effects of POPs include decreased survival of eggs and larvae, failure to mature sexually, and smaller-than-normal gonads.

Even more sensitive than the effects on reproduction may be the influence of POPs on the immune system. Several parts of the immune system are known to be vulnerable and the insidious result is to reduce an organism's defense against infections. The immune system is especially vulnerable during development before and just after birth. In mammals, the period after birth coincides with exposure via milk from the mother, which can contain high levels of POPs.

The brain is another sensitive target for POPs, especially during pregnancy and just after birth. During this period, a disruption that may result from relatively low levels of POPs can cause permanent damage to the brain in a way that similar low POP levels would not do in an adult.

An effect of POPs that has been documented since the publication of the previous AMAP assessment is on bone development. Dioxin-like substances appear to decrease bone density. Arctic studies on effects on bone have just started.

A common link between many effects may be disruption of the hormone system (see box on left).

Females transfer POPs to their young

Females transfer substantial amounts of POPs to the next generation. In birds and fish, this occurs via the eggs, and in mammals, directly to the fetus and via breast milk.

In marine mammals, mother's milk can have extremely high fat content to help the young animal grow rapidly during the short summer season. Because POPs dissolve in fat, they concentrate in the fat of mother's milk and thus transfer readily to the nursing young. In some species, such as harp seal, the transfer via milk is accentuated because the female does not eat during the nursing period and POPs are further concentrated in her diminishing fat stores, including her milk.

For many of the effects of POPs, including behavioral, immune, reproductive, and neurotoxic effects, there may be critical developmental windows, where effects in the young occur at lower exposure levels than in adults. Exposures in the womb and via breast milk are thus likely to be especially problematic.

ØISTEIN WIIG

Mother's milk is a major source of POPs for newborn marine mammals.

Starvation can lead to high POP levels

Most POPs dissolve in fat and accumulate in the fatty tissues of animals, such as the liver or parts of the body that specifically store fat. Some of the contaminants are in the blood or other organs. In the Arctic, many animals go through periods of fasting, when they use stored fat for energy. This leads to an increase in contaminant concentrations in the remaining fat, as well as in the blood and in other organs. This increases the risk that sensitive systems, such as the brain or reproductive organs, will be exposed to toxic levels.

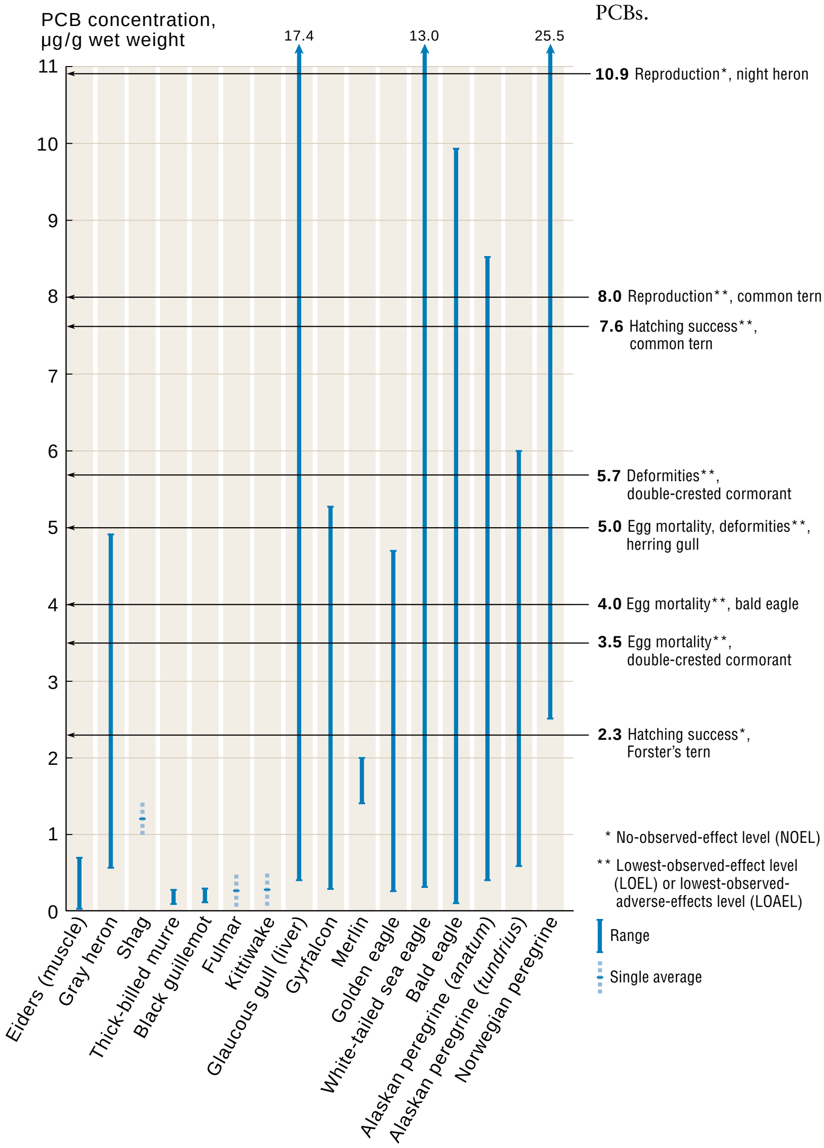
A study of Arctic char showed that females can lose about 80% of their fat during spawning and overwintering. Males lost a little more than 50%. Another study of Arctic char showed that this fat loss can have dramatic consequences for contaminant levels in sensitive organs. At the same time that the overall PCB concentration in the body dropped by 20%, PCB concentrations in the brain increased six-fold and concentrations in the liver doubled.

Experiments on Arctic char have also shown that the combination of high PCB levels and long-term fasting that is typical for high-latitude fish can compromise their response to stress and disease.

Birds of prey are still vulnerable

Birds of prey are known to be very sensitive to some persistent organic pollutants. Their health in relation to POP levels has been followed for many years. The previous AMAP assessment found that Canadian peregrine falcons still had high levels of many POPs. For PCBs and chlordanes, levels in the 1990s were even higher than in the 1980s. Eggshell quality had not improved and the conclusion was that this Canadian population might still be threatened.

New data from Alaska covering the period 1979 to 1995 complement this picture. In eggs from the American peregrine, which nests in the forested interior, a number of POPs were detected. Although concentrations declined over time, there was evidence for both cumulative and individual contaminant effects. Eggshells were still thinner than normal eggshell thickness in the pre-DDT era. Moreover, levels



Ranges of concentrations of PCBs in Arctic bird eggs (or otherwise indicated tissues) compared with thresholds for avian effects. The comparison should be used with caution because of problems with extrapolating data across species and differences in quantifying PCBs.

of dieldrin, oxychlordane, and PCBs were higher in unsuccessful nests (nests without chicks) than in nests that produced at least one young. The PCB levels exceed those known to cause reproductive problems in other wild bird species. Eggs from unsuccessful nests also had higher mercury concentrations, which may also have affected reproduction, see chapter *Heavy Metals*.

New data on bald eagles from the Aleutian Islands indicate that the population on Kiska, one of four studied islands, had reduced reproduction that was associated with high levels of DDE.

Several waterfowl species in Canada also had POP levels high enough to cause concern about reproductive effects according to the previous AMAP assessment.

For European birds of prey, the previous AMAP assessment concluded that Fennoscandian merlin and white-tailed sea eagles in Norway, Sweden, and Russia had contaminant levels that could affect their reproduction, even if the Norwegian and Swedish populations seemed to be recovering from previous declines caused by pollution. New data on organochlorines in Norwegian birds of prey show similar contaminant levels today. PBDEs are present in Norwegian white-tailed sea eagle and peregrine falcons in Norway and Sweden at fairly high levels, but there are no effects thresholds for PBDE with which the levels can be compared.

Mixed picture for terrestrial mammals

The previous AMAP assessment concluded that mink in northern Quebec and otters in northern Sweden, both of which feed mainly on fish, have PCB levels high enough to cause concern about effects on reproduction as well as on neurobehavioral development of the young. There is no new information about these species.

There is new information, however, about POP levels in Canadian wolverines and wolves, where the wolverines have PCB levels high enough to raise concern about subtle neurobehavioral effects.

For terrestrial herbivores (ptarmigan, hare, reindeer, sheep, and muskox), new data from West Greenland, the Faroe Islands, and Russia generally show very low POP levels that are nowhere near known effect levels. However, dioxin levels in some reindeer and mountain hare from the Kola Peninsula are rather high in relation to effects thresholds in other species, but potential effects are difficult to evaluate.

Local contamination may cause concern for freshwater fish

In most freshwater environments, POP levels are not high enough to cause concern for the health of the fish. But there are exceptions. One is Arctic char in the lake Ellasjøen on Bjørnøya, where high PCB levels affect liver enzymes.

The previous AMAP assessment noted that toxaphene levels in burbot in some Canadian lakes were high enough to potentially affect bone development. New Canadian data show a slow decline in toxaphene levels in Lake Laberge in the Yukon Territory and in the Mackenzie River in the Northwest Territories. Researchers looking for effects on bone development did not find any problems.

An Alaskan study of burbot has compared POP levels in 1999 with those in 1988. The data imply that most of the contaminants in the fish are from older releases into the environment. Moreover, the levels have for the most part decreased. The levels did not exceed known effect levels. However, PCBs in burbot from Fairbanks, Yukon Flats, and Lake Laberge were close to or exceeded the levels that are known to induce liver enzyme activity in other fish species (see map on page 16).

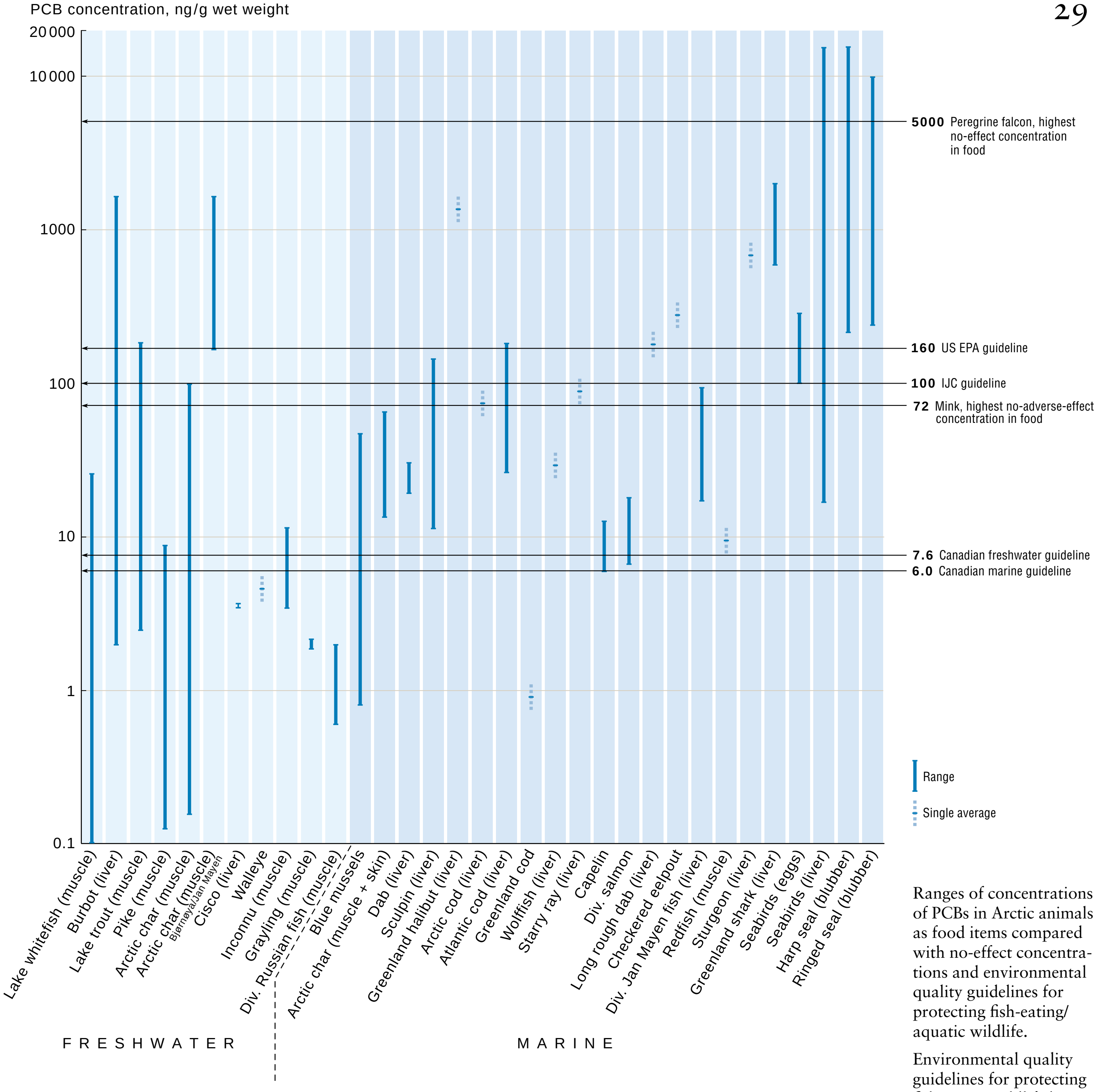
Imposex found in marine invertebrates

For most contaminants, levels in marine invertebrates are low enough not to cause any concern for biological effects. The exception is TBT, a compound that is toxic to some species at extremely low levels. In dogwhelk, a small mollusk, TBT causes the females to develop a penis and also makes them sterile. This condition is called imposex, and has been observed in harbors in West Greenland, Iceland, northern Norway, the Faroe Islands, and Svalbard.

A study of dogwhelk in harbors along the Norwegian coast has revealed that some degree of imposex occurred everywhere except for four of the study locations in northern Norway. In Iceland, the level of imposex decreased considerably from 1992-93 to 1998, after the use of TBT as an anti-fouling agent had been restricted in 1996. Imposex in Faroe Island dogwhelks is widespread and no change has occurred from 1996 to 2001. In West Greenland harbors, elevated TBT levels were found in blue mussel in 1999.

JORUNDUR SVAVARSSON

▶ The dogwhelk is a marine mollusk that is extremely sensitive to TBT.



Ranges of concentrations of PCBs in Arctic animals as food items compared with no-effect concentrations and environmental quality guidelines for protecting fish-eating/aquatic wildlife.

Environmental quality guidelines for protecting fish-eating wildlife have been established by several organizations and countries. They are based on contaminant levels in fish and known thresholds for effects in fish-eating wildlife. Biomagnification rates for different substances have then been used for back-calculating the fish concentrations that should not cause effects in fish-eating species.

PCBs disturb nesting behavior in some seabirds

At the time of the previous AMAP assessment, it was clear that contaminant levels among several seabirds were high enough to raise concerns about effects on reproduction. This assessment confirms this conclusion. Moreover, in some species, some contaminant effects on behavior and reproduction have been studied in more detail.

Even in the early 1970s, there were observations that glaucous gulls on Bjørnøya did not behave normally. Bjørnøya is a hot spot of PCBs (see box on page 16) and levels are higher than at most other studied sites in the Arctic. Recently, high PCB levels in Bjørnøya glaucous gulls have been correlated with increased time spent away from their nests. The results suggest that individuals with high PCB loads need more time to gather food than do birds with lower loads. The underlying cause could be that PCBs disrupt the birds' hormone systems or affect their nervous system. New results confirm hormone effects in this glaucous gull population. The end result is that the birds do not have sufficient energy to reproduce successfully.

Moreover, females with high PCB levels in their blood were more likely to have non-viable eggs in their nests than females with lower PCB levels. The chicks of females with high PCB levels were also in worse physical condition. Finally, high PCB levels decreased the probability of survival of adult birds. In long-lived birds, population growth rate is

Overview of toxic properties of various POPs. ▼= suppression or decrease, ▲ = induction or increase.

	Reproductive/ developmental effects	*Neurotoxic effects*	*Liver enzymes*	*Immune effects*	*Effects on thyroid and vitamin A*	*Cancer*	*Other*
Aldrin and dieldrin	▼ Reproduction		Induces liver enzymes	Suppresses immune system		Non-mutagenic. Increased liver tumors	
Chlordanes	▼ Reproduction		Induces liver enzymes	Suppresses immune system		Non-mutagenic tumor promoter	
DDT and metabolites	Egg-shell thinning in bird eggs. ▼ Reproduction		Induces liver enzymes	Suppresses immune system	▼ Thyroid weight		Overstimulation of adrenal cortex
HCB	Fetotoxic. Deformities. ▼ Reproduction		Induces liver enzymes	Suppresses immune system	▼ Thyroid hormones. ▲ Thyroid stimulation hormone. ▲ Thyroid weight	Non-mutagenic tumor promoter	▲ Porphyria (a blood disease causing skin and nerve damage)
alpha-HCH	No information		Induces liver enzymes			Non-mutagenic tumor promoter	
beta-HCH	Estrogenic		Induces liver enzymes	Suppresses immune system	▲ Thyroid weight	Non-mutagenic tumor promoter	
gamma-HCH (lindane)	Estrogenic and antiestrogenic. ▼ Reproduction		Induces liver enzymes			Non-mutagenic tumor promoter	
Mirex	▼ Reproduction		Induces liver enzymes	Suppresses immune system		Non-mutagenic. Induces tumors	
Toxaphenes	Fetotoxic. ▼ Reproduction		Induces liver enzymes	Suppresses immune system	▲ Thyroid-weight. ▲ Thyroid-stimulating hormone	Mutagenic, potent carci-nogen. Inhibits cell-to-cell commu-nication	▲ Bone brittleness in fish. Overstimulation of adrenal gland
Endosulfan	Fetotoxic. ▼ Reproduction		Induces liver enzymes	Suppresses immune system		Non-mutagenic	
Dioxin, furans, dioxin-like PCBs, and metabolites	Fetotoxic. Deformities. ▼ Reproduction	Permanent changes in learning, behavior, memory	Induces liver enzymes	Thymic atrophy. Suppresses immune system	▼ Thyroid hormones. ▼ Vitamin A	Non-mutagenic tumor pro-moters. Affects cell-to-cell communi-cation	▲ Porphyria
Other PCBs	Fetotoxic. Deformities. ▼ Reproduction	Permanent changes in learning, behavior, memory. Decreased dopamine (a neurotransmitter)	Induces liver enzymes	Suppresses immune system	▼ Thyroid hormones. ▼ Vitamin A	Non-mutagenic tumor pro-moters. Affects cell-to-cell commu-nication	▲ Porphyria Overstimulation of adrenal cortex
Short-chain chlorinated paraffins	Fetotoxic Deformities. ▼ Reproduction	▼ Motor perform-ance	Induces liver enzymes	No information	▼ Thyroid hormone. ▲ Thyroid-stimulating hormone	Non-mutagenic. ▲ Peroxisome proliferation. Inhibits cell-to-cell communication	
Poly-chlorinated naphthalenes	Embryotoxic. ▼ Reproduction		Induces liver enzymes				
PBDE (flame retardant)	Estrogenic and antiestrogenic	Permanent changes in learning, behavior, memory	Induces liver enzymes	Suppresses immune system	▼ Thyroid hormone. ▼ Vitamin A	Non-mutagenic	
PFOS/PFOA	▼ Reproduction					Non-mutagenic, tumor promoter . ▲ Peroxisome proliferation. Inhibits cell-to-cell communication	
TBT and metabolites	Imposex in invertebrates. Deformities. ▼ Reproduction		Inhibits liver enzymes	Suppresses immune system		May be carcinogenic	

very sensitive to adult survival rates. This suggests that high exposure to PCBs may have a considerable effect on the size of this glaucous gull population. Another study found signs of suppression of the immune system in these same gulls, indicating that they may suffer decreased resistance to infections.

Laboratory studies in which glaucous gulls chicks were fed Arctic cod and seabird eggs from the Barents Sea indicate effects on hereditary material (the chromosomes). The importance of POPs and other contaminants for these effects needs to be confirmed.

Black guillemots near a PCB-contaminated former military site at Saglek Bay, Canada, show multiple effects on the liver. This implies that PCBs affect the health of these birds.

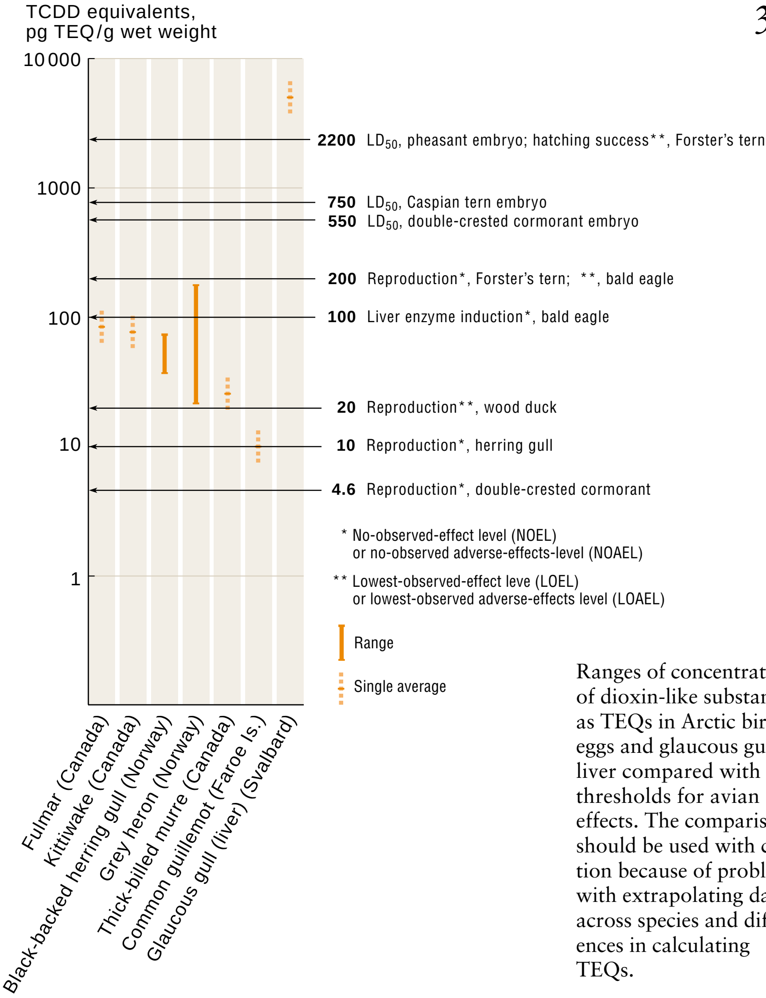
Effects of POPs have also been observed in shag from the central Norwegian coast. PCBs in eggs seem to affect the weight of the hatchling. There may also be a correlation with effects on vitamin A in the hatchling. The observed effect of PCBs on hatching success in shag is consistent with known effect levels in other birds.

For most bird species, there are no studies of effects, and the only way to judge the potential impact of POPs is to compare contaminant levels with levels that are demonstrated, through laboratory or field studies, to affect the health of other bird species (see diagram on page 27). Based on such comparisons, grey heron from the Norwegian west coast have PCB levels high enough to raise concern about hatching success. PCB levels in great skua, great black-backed gulls, and some glaucous gull populations (particularly from Bjørnøya) exceed most thresholds for reproductive effects in other bird species. Levels of POPs with dioxin-like activity may be approaching values high enough to cause concern about reproductive effects in Canadian thick-billed murres, kittiwakes, and fulmars, and in grey herons from the west coast of Norway. Dioxin-like PCBs in glaucous gulls from Svalbard are above all thresholds for reproductive effects as well as the threshold for effects on liver enzymes.

Eiders and alcids (guillemots, murres, and dovekies) feed lower in the food web. With the exceptions noted above, their contaminant levels are below known effect levels. However, an analysis of POP levels in their diet show that DDT and PCB levels in some of their potential prey exceed environmental quality guidelines for protecting fish-eating wildlife (see diagram on page 29).

PCB levels in toothed whales raise concern about toxic effects

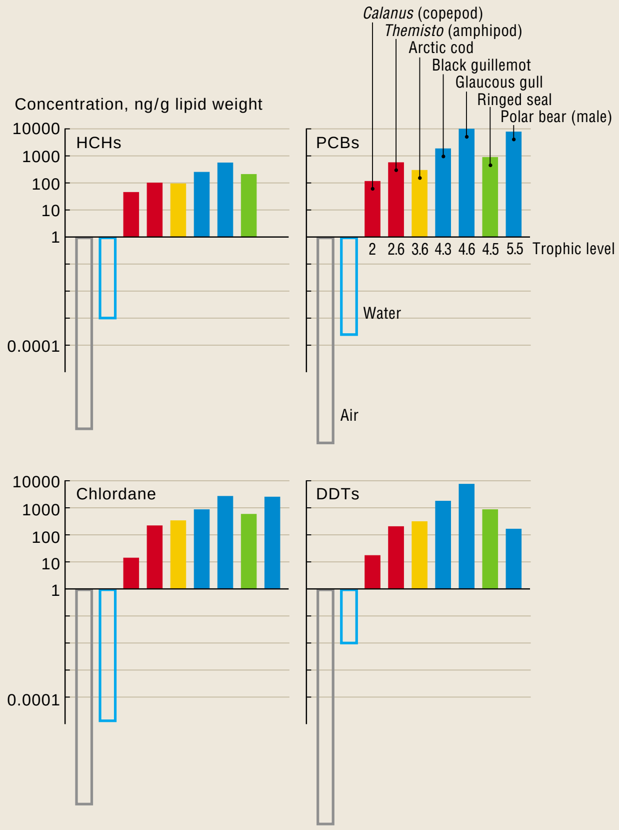
A comparison between observed levels in Arctic species and known-effect levels in other species raises concerns about effects in Arctic toothed whales. For most species (long-finned pilot whale, beluga, killer whale, narwhal, and harbor porpoise), the PCB levels reported in this AMAP assessment are high enough to cause concern about subtle neurobehavioral effects and effects on reproduction and on vitamin A metabolism. In cases such as harbor porpoises from northern Norway, some resident killer whales and all transient killer whales from Alaska, and some long-finned pilot whales from the Faroe Islands, there may also be concern about PCBs affecting the immune system and reproduction.

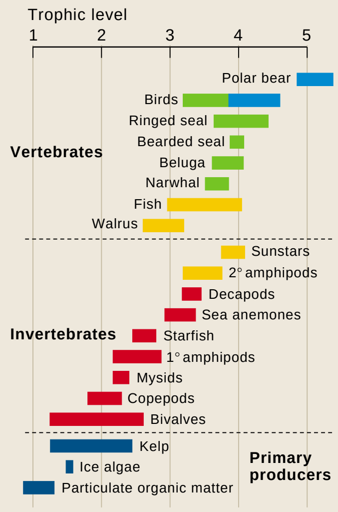


Ranges of concentrations of dioxin-like substances as TEQs in Arctic bird eggs and glaucous gull liver compared with thresholds for avian effects. The comparison should be used with caution because of problems with extrapolating data across species and differences in calculating TEQs.

POLAR PHOTOS / HENNING THING

Killer whale. One of the toothed whales where PCB levels are a source of concern.





The marine food web structure observed during the Northwater Project. Shown in the panels are average concentrations of selected compounds in air, water, and biota at various trophic levels.

Food web studies provide insight about biomagnification

Animals can eliminate some contaminants, whereas other contaminants accumulate in their bodies in higher concentrations than in the surrounding environment. When they fall prey to carnivores, the contaminants are passed up the food web. If the predator cannot get rid of the contaminants, the contaminant load will be higher in the predator than in the prey, reflecting the sum of all the contaminants it has ingested from all its prey. This is called biomagnification and is an important criterion when judging whether a chemical is a potential environmental problem. Contaminants with high biomagnification factors are more likely to reach toxic concentrations in top-level predators, including people, and are thus good candidates for regulatory action.

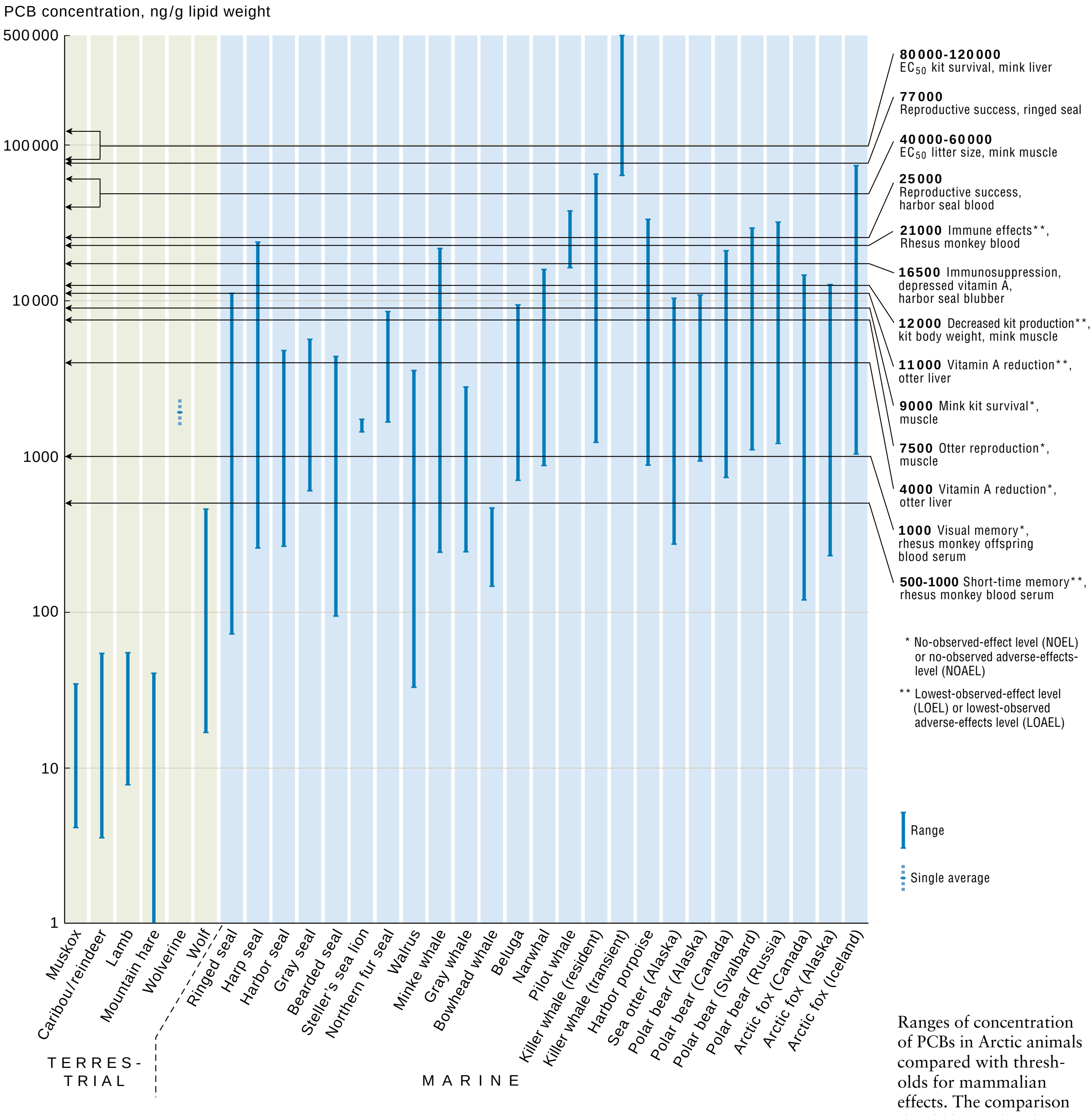
Two new food web studies provide insight into the fate of POPs in the marine environment. One is from the Barents Sea near Bjørnøya looking at copepods and euphausiids at the lowest trophic level, followed by predatory amphipods, fish, and avian predators. The concentrations of POPs were low in zooplankton and fish, but were biomagnified by 10-1000 times in seabirds, with the highest concentrations in glaucous gulls.

The other food web study was done in the Northwater Polynya in northern Baffin Bay. A polynya is an area of open water surrounded by sea ice that remains open throughout the winter. The contaminant levels were highest in seabirds and ringed seals and much lower in zooplankton at the lower trophic levels, which is consistent with previous food web studies in both Arctic and temperate waters.

As judged by the biomagnification factors obtained from these studies, significant biomagnification takes place when seabirds prey on fish and zooplankton. The seabirds have to eat large amounts of fish and zooplankton to get enough energy. Moreover, they have no way of returning the contaminants back to the water and are thus dependent on metabolizing and excreting them. Fish, on the other hand, can to a certain degree sustain equilibrium with the surrounding water via their gills.

Seabirds in the Barents Sea have higher contaminant levels than seabirds in the Northwater Polynya, despite levels in fish and zooplankton being fairly similar. The explanation is probably that the diets of Svalbard seabirds include a larger percentage of higher-trophic-level organisms. The extremely high biomagnification factor in glaucous gulls suggests that they scavenge as well, ingesting the tissues of other top-level predators.

The relative contribution of different POPs also changes between the different trophic levels. In fish and zooplankton in the study, HCHs, HCB, and chlordanes predominated. This is consistent with zooplankton and fish having a very limited ability to metabolize POPs. In seabirds and mammals, in contrast, DDTs, PCBs, and breakdown products of HCB and chlordane became more important, especially those breakdown products that are not readily excreted.



Ranges of concentration of PCBs in Arctic animals compared with thresholds for mammalian effects. The comparison should be used with caution because of problems with extrapolating data across species and differences in quantifying PCBs.

A look at the contaminant load in the diets of these animals shows that DDT and PCB levels exceed some or all environmental quality guidelines for protecting fish-eating wildlife.

Baleen whales generally have much lower POP levels than toothed whales. However, minke whales have high enough PCB levels to raise concern about subtle neurobehavioral effects and effects on reproduction and on vitamin A metabolism. Gray whales have levels that are high enough to raise the possibility of subtle neurobehavioral effects.

Seals, sea lions, and walrus: immune effects seen in northern fur seal

The previous AMAP assessment concluded that PCB levels in several seal species were high enough to raise concern about subtle neurobehavioral effects. At some sites, contaminant levels were also close to levels that could be associated with effects on the immune system. The species included in the assessment were harp, ringed, harbor, and grey seals. Based on comparisons with effects levels in other species, the new assessment confirms this picture. The mean PCB levels also raise concerns about effects on the levels of vitamin A and on reproduction.

The new assessment also includes some disconcerting information about the health of northern fur seals in relation to environmental contaminants. A large part of the world's population of northern fur seals has its breeding rookeries on the two largest Pribilof Islands, St. Paul and St. George, in the Bering Sea. The current stock is only half of its historical size and is listed as depleted under the US Marine Mammal

Protection Act definition. The St. George subpopulation underwent an unexplained decline of 4-6% per year for more than a decade prior to a study that started in 1997. Long-term monitoring has suggested that the population decline is, at least in part, due to pups dying at sea just after they have been weaned.

The Aleut population of the villages on St. George and St. Paul are dependent on an annual subsistence harvest of subadult male fur seals, both as part of their culture and as a major source of protein. Aleut concern over the population decline prompted a closer look into the cause and its possible connection to contaminants. The study revealed that fur seal pups with higher POP levels in their blood also had immune systems that were less able to respond to infections. Moreover, PCB levels were correlated with reduced levels of vitamin A and thyroid hormone, which can indirectly affect immune function. The high POP levels can probably be explained by fur seals' feeding on fish that are high in the food web. Perhaps more important is their extensive migrations as far south as California and Japan, where they feed on fish that are even more contaminated.

The role of POPs is also being investigated in the decline of the population of Steller sea lions in the eastern Aleutian Islands. Steller sea lions in the eastern Gulf of Alaska and southeastern Alaska are flourishing, whereas those in the western Gulf of Alaska and the Aleutian Islands are endangered. The Steller sea lions from the eastern Aleutian Islands excrete much higher levels of PCBs and DDTs in their feces than animals elsewhere. Recent data indicate correlations between POP levels and immune effects similar to those seen in northern fur seals. The high POP levels in the Steller sea lions are probably related to a local source or a strong influence from the Bering Sea.

In another part of the Arctic, the northwest Barents Sea, east of Svalbard, the focus has been on harp seals. These seals have elevated liver enzyme activity, a biomarker that can indicate a challenge by contaminants. Although no correlation was found between liver enzyme activity and PCB levels, there was a correlation between the activity of an enzyme controlling the male hormone testosterone and the contaminant toxaphene.

For walrus, there have been no studies of effects, and the assessment has to be based on comparisons between contaminant levels and effects thresholds in other species. Generally, contaminant levels are known to correlate with the diet of walrus. Individuals or populations that feed on other marine mammals have high levels, whereas walrus that eat mostly shellfish have much lower levels. In the previous assessment, concern was raised about PCBs being high enough to cause subtle neurobehavioral affects in walrus from eastern Baffin Island, eastern and northeastern Hudson Bay, and Svalbard. For eastern Hudson Bay and Svalbard, the levels were also high enough to raise concerns about reproduction, based on a comparison with effects in mink. New data show that walrus from East Greenland should be included in this group. For eastern Hudson Bay walrus, which had the highest contaminant load, there were also concerns about levels being high enough to suppress the immune system.

High PCB loads put the health of polar bears at risk

In polar bears, there have been strong suspicions that contaminants might affect their ability to fight infections as well as their ability to reproduce. New studies confirm these suspicions and the results indicate that the population status and health of polar bears from McClure Strait and eastern Hudson Bay in Canada, East Greenland, Svalbard, Franz Joseph Land, and the Kara Sea may be at risk.

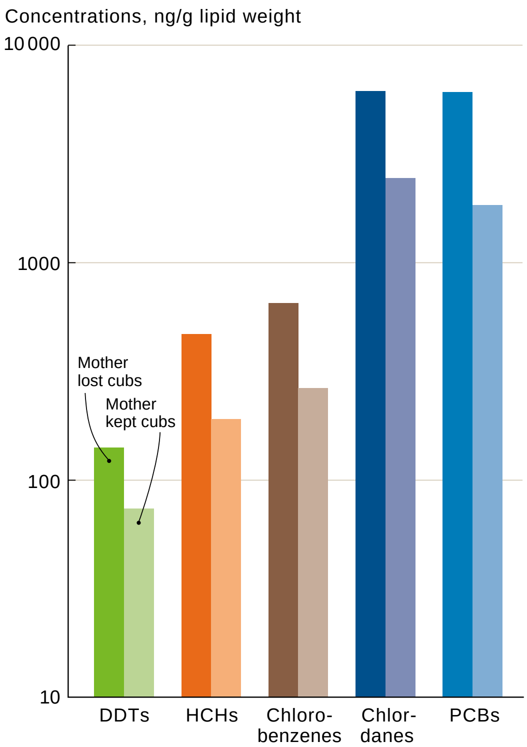
The contaminants that raise the most concern in polar bears are PCBs. Previous concerns about health effects were in part based on comparing PCB levels to contaminant loads that are known to affect the health of other species. Such comparisons have inherent weaknesses, particularly for polar bear. One reason is that the mix of contaminants in polar bears is different from other species, because polar bear are able to metabolize some PCBs better than others. Another reason is that polar bears have delayed implantation, which would allow a contaminant to act on a fertilized egg for some time before implantation. Many species with delayed implantation are known to be especially sensitive to reproductive effects of contaminants. A third reason is that polar bears go through periods of fasting, during which POP levels in the blood and sensitive organs may reach much higher levels than in an animal with consistent fat levels. Periods of fasting may also correspond with decreased disease resistance because of nutritional deficiency.

To better understand the biological effects of POPs on polar bears, researchers in Norway and Canada have looked for direct signs of health effects in the polar bears. The physiological parameters used in this study included a number of hormones and components of the immune system that contaminants are known to affect. Another sign of effects is how often a female reproduces and whether her cubs survive. In this study, the females could be followed via satellite transmitters. Because only pregnant polar bears den for the entire winter, the denning of a particular female indicated that the animal was reproducing.

The study compared Svalbard polar bears that had high PCB levels with Canadian bears that had lower levels. At Svalbard, an unusual number of cubs did not survive, and there were indications that the female's reproductive cycle was shorter than the normal three years. The fact that the females in Svalbard could breed sooner also suggests that cub survival may be impaired. One reason could be that the cubs receive a high load of PCBs from milk at a vulnerable period of growth and development. PCB levels were higher in cubs-of-the year than in their mothers. There are, however, other possible explanations for poor cub survival rates, such as high population density. It is therefore not yet possible to make a causal link with PCBs.

There are some other signs in the Svalbard polar bear populations that reproduction may be impaired. Specifically, there is lack of older females with cubs-of-the year compared with some other polar bear populations.

Other studies have also shown associations between contaminant loads and possible reproductive effects, but it is difficult to draw firm conclusions about how contaminants affect the health of the animals. In a Canadian study of polar bears from southwestern Hudson Bay, females who had lost their cubs had higher contaminant concentrations than females whose cubs survived. In another study, the levels of the male hormone testosterone were low in male bears with high loads of PCBs. This hormone plays a crucial role in sexual development. Vitamin A and thyroid hormones are also lower when the PCB load is high. However, it is unknown whether this affects the bears' health or ability to reproduce.



Concentrations of POPs in polar bear milk of females with cubs after emerging in March from dens in the Cape Churchill area, Hudson Bay. The data are grouped according to whether the female still had her cubs the following fall, or had lost them.

In the Norwegian-Canadian study, there was a correlation between contaminant levels and effects on the immune system. To follow this up, an experiment was conducted to see how the immune system responded to a challenge. The researchers gave the animals a vaccination containing a few common viruses and a bacterial toxin. Four to six weeks later the animals were recaptured to look for antibodies against these viruses and the toxin. The results from the vaccination experiments suggest that PCBs are indeed associated with decreased resistance to infections, and that the health of polar bears with high PCB loads may be at risk.

The previous AMAP assessment reported cubs with abnormal genitalia, so-called pseudohermaphrodites. The first two were found at Svalbard in 1996, and since then several more cases have been reported from Svalbard and from other parts of the Arctic. The frequency at Svalbard is 2-4% of the females, but the severity of the condition is variable. The females appear to reproduce normally. It is still unknown whether pseudohermaphrodism in polar bears has any connection to contaminants.

An assessment of contaminant levels in polar bears as they relate to known effect levels in other species complements the picture of a species under threat from pollution. PCB levels in polar bears are high enough to raise concern about subtle neurobehavioral effects and effects on vitamin A. At several sites in Alaska, Canada, East Greenland, Svalbard, and in Russia, levels are high enough to raise concerns about reproduction. At Franz Josef Land, the Kara Sea, and Svalbard, levels are high enough to cause concern about suppression of the immune system. The source of contaminants is the diet, with PCBs in blubber from ringed and harp seal exceeding all environmental guidelines for protecting aquatic wildlife.

PCB levels in Arctic fox raise concern about toxic effects

In the previous AMAP assessment, PCB levels in Arctic fox from Svalbard raised concern about subtle neurobehavioral effects as well as effects on reproduction, cub survival, and immune suppression. At the time, data for Arctic fox were only available from Svalbard. New data are available on contaminant levels in Arctic fox from Barrow and the Pribilof Islands, Alaska; Holman Island, Northwest Territories, Canada; and inland and coastal areas of Iceland. The PCB levels in the populations from Alaska, Canada and inland Iceland are considerably lower than those reported earlier for Svalbard foxes. Arctic fox from coastal Iceland have much higher PCB levels, which are more comparable to those seen previously on Svalbard. Compared with effects levels in other species, there is some concern about the potential for subtle neurobehavioral effects and effects on vitamin A levels. The Canadian foxes may also be at risk for reproductive effects and decreased cub survival. In addition, the coastal Iceland foxes are at risk for immunosuppression. Data on dioxin-like contaminants in Pribilof Arctic foxes also indicate a possible risk for immunosuppression.

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Polar bear sampling to study the effects of PCBs.

On individuals and populations

It is difficult to establish a causal link between contaminants and effects in wild animals. It is clear, however, that there is a correlation between high loads of contaminants in some animal populations in the Arctic and effects on their resistance to infection, reproduction, and behavior. Some of these effects are only apparent as subtle changes in the physiology of an animal, for example changes in the immune system or hormone levels. Nevertheless, AMAP considers the evidence strong enough to conclude that contaminants do have effects on some species of Arctic wildlife in that they can threaten the survival and reproductive success of individual animals.

The extent to which these effects can threaten local populations is another question. Here, there is no clear answer. If effects on individuals are sufficiently widespread, a population can become vulnerable, especially if it is exposed to other stresses, such as new disease-causing organisms or changes in access to prey. In such cases, the margin of safety for a population may no longer exist. The conclusion is thus that some contaminants, particularly PCBs, dioxin-like substances, DDTs, and TBT, may pose a population-level threat to some Arctic wildlife populations.

Summary

Persistent organic pollutants are present throughout the Arctic environment.

PCB levels in some areas are high enough to affect the health of individual animals, particularly their ability to fight infections. This is true for polar bears around Svalbard and probably also for polar bear populations closer to Russia, for northern fur seals in the Bering Sea, and for glaucous gulls on Bjørnøya, south of Svalbard. In the glaucous gull population, PCBs also affect nesting behavior and adult survival. In many animals, there is no documentation of effects, but based on knowledge from effects levels in other species, PCB levels are high enough to raise concerns about effects on resistance to disease, reproduction, and neurobehavioral development. PCBs are banned by both regional and global regulations. Local sources are indicated in the region of the White Sea, the Kara Sea, and the eastern Barents Sea. A recent inventory of uses in Russia shows that PCBs remain in many existing electrical installations. There are also examples of local PCB contamination in Alaska, Canada, Greenland, and Norway (including Jan Mayen and Svalbard), mostly from military sites, earlier uses, or dumped material. There is thus a need for more remedial actions for PCBs within the Arctic.

Levels of dioxin-like substances raise concern about reproductive effects in some Arctic seabirds and about effects on the immune system in Arctic fox, killer whales, and northern fur seals. Some sources, such as waste incineration and the metallurgical industry, have not yet been adequately addressed.

Many persistent organic pesticides have been banned and their levels in the environment are declining. However, there are several signs of fresh input of DDT in the Barents region and of toxaphene in the White Sea. This shows either that these pesticides are still used or that old stocks are leaking into the environment and thus need attention. DDTs are still a concern for the reproductive health of birds of prey. The pesticide lindane, or gamma-HCH, is still used in source regions to the Arctic. Its levels in the marine environment have not declined.

For persistent organic pollutants that are now regulated on a global and regional basis, the situation in the Arctic is likely to improve. This is not the case for other POPs, including brominated flame retardants (PBDEs). Levels of PBDEs are still low compared with PCBs, but are likely to rise unless there is a change in the expected increase in world production. In addition, the extremely persistent compound PFOS, used as a stain repellant and in other applications, is present at elevated levels in some Arctic animals. Very little is known about the behavior in the environment of chemicals of this kind and their potential effects.

Several important steps have already been taken to address the threats POPs pose to the Arctic environment, such as the Stockholm Convention and the UN ECE POPs Protocol. This AMAP assessment shows the continued need to bring Arctic concerns about POPs to the attention of these international policy fora to ensure continued emphasis on Arctic needs.