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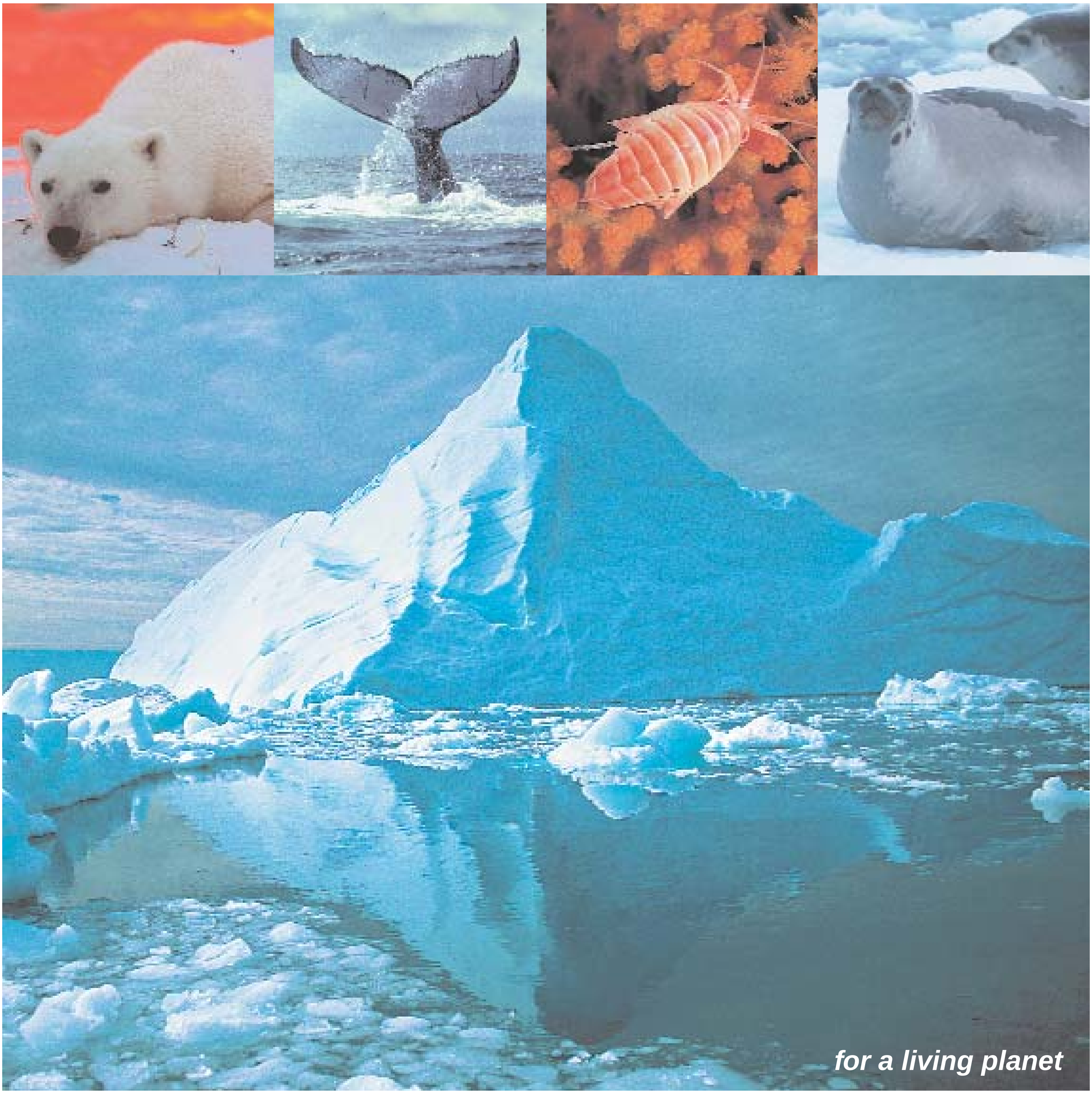
DETOX
CAMPAIGN

The tip of the iceberg:
Chemical contamination in the Arctic

WWF International Arctic Programme



for a living planet

The tip of the iceberg:

Chemical contamination in the Arctic

> "Progress and catastrophe are the opposite faces of the same coin"
>
> Hanna Arendt, German political philosopher (1968)

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I. Executive summary

The Arctic is the largest un-fragmented, yet inhabited, wilderness area remaining on Earth. However, it is under increasing threat from toxic contaminants. Like the small portion of an iceberg that can be seen from above the water, chemicals that scientists now know to be contaminating the animals of the Arctic may be a warning of a larger problem that, for now, remains hidden.

Pollutants that were never produced or used in the Arctic are now showing up in this remote region of the world, sometimes in higher concentrations than in the countries where they were made and used. Air, river, and ocean currents, drifting sea ice, and migrating wildlife species carry industrial and agricultural chemicals from distant sites of production and use to the polar environment. In many cases, transport of chemicals to the Arctic from sources in Europe, Asia, or North America can occur in just a matter of days.

This report reviews and synthesizes the current status of literature and knowledge of selected toxic substances, with an emphasis on hazardous chemicals not monitored for in arctic and sub-arctic wildlife until recently. The remote and sensitive Arctic serves as an indicator of how our use of chemicals will impact life everywhere on Earth, what is happening in the Arctic is an early warning providing us with the opportunity to protect our planet from further harm.

Some of the chemicals covered in this report are in current-use while others have already been widely restricted or phased out – yet they still show up in the Arctic years later. Everywhere arctic scientists look and whichever chemicals they choose to monitor for – what they are discovering is that these chemicals have made their way to the Arctic and contaminated species covering the whole range of the food web. (See Table 1 in the Appendix.)

The chemicals covered in the report are or were previously used in a variety of commercial and industrial manufacturing processes and in agriculture. Releases of these chemicals to the environment may occur near the site of original manufacture, later on during production of common-use items such as cosmetics, plastics, and furniture cushions, from pesticide treatments to control insects or other pest species, and from waste incineration and disposal of chemicals or chemical-containing products.

This report shows widespread contamination with a range of toxic substances is evident – with a build up of these chemicals in arctic air, sediments, and many of the arctic animals that are at or near the top of the food chain. Overall, chemical levels in arctic marine mammals and bird species are exponentially increasing and are expected to continue to increase. For example, without restriction of brominated flame-retardant (BFR) use and if current trends continue, levels in the Arctic may reach the same levels as polychlorinated biphenyls (PCBs) within 10–20 years.

Although further research is needed, we already know enough about the harmful health effects of contaminants – particularly on immune, reproductive, and hormone function – to justify the need for precautionary action and protective chemical legislation. The lingering toxic legacy from chemicals widely used in the past and once thought to be safe, such as PCBs[1] and DDT,[2] should serve as a warning against continued use of chemicals that have not been adequately assessed for safety. PCBs, introduced in the 1920s for use in electrical equipment, and DDT, introduced in the 1930s as a successful insecticide, still persist in the environment and accumulate in our bodies many years after their phase-outs. The very quality that made these chemicals so useful in the past – their persistence – is now what enables them to remain in the environment decades after their use was discontinued in most parts of the world.

Despite the lessons of the past and our increasing awareness of the risks posed by chemical exposures, chemicals remain on the market with the status "safe until proven otherwise." Existing chemical regulation is inadequate and out-dated, illustrated by the fact that basic safety information is not required for more than 90% of chemicals currently on the market. While some hazardous chemicals, including PCBs and DDT (with the exception of limited, controlled use to prevent malaria), were banned in 2004 under the Stockholm Convention[3] due to their toxicity or persistence, there are many other un-restricted chemicals in current use for which indications of their hazardous properties are rapidly accumulating.

Chemical contamination does not only threaten the remote Arctic. We are all exposed to chemicals from our air, food, water, everyday household and workplace items, and personal products. We should have the right to know which chemicals are in the products we purchase and we need protective legislation that will reverse the current alarming situation where blood, breast milk, tears, and raindrops worldwide are full of chemicals. For these reasons, there is a growing movement, exemplified by the REACH chemical legislation[4] currently being debated within the European Union, demanding additional and improved chemical safety data and access to this information, and control or eventual phase-outs of the most hazardous chemicals.

International agreements and safe, precautionary chemical legislation (such as REACH) have the potential to reduce further global contamination and to protect the unique arctic ecosystem and its species. While the older class of toxic chemicals has already widely contaminated humans and wildlife, we still have a chance to prevent further pollution from toxic chemicals in current use. As mixtures of many chemicals build up in our bodies and wildlife with largely unknown long-term consequences, it is more urgent today than ever before to revise and improve the current system. Only then will the many benefits chemicals can offer us outweigh the risks. REACH provides an opportunity to set a new global standard, putting chemical production and use on a safe and sustainable path.

Currently, at the individual level, for many of us our only options to minimize personal chemical exposures are to modify our habits and purchases (i.e. eat organically, wash fruits and vegetables to reduce pesticide residues, use naturally scented and colored cleaning and personal products). However, even these measures are not all universally available or practical and, at best, only allow us to reduce our exposures and not prevent them. So while we cannot escape much of the current risk posed by the numerous chemicals already present in our environment; we can regulate existing and future chemical production and use to prevent further contamination with hazardous chemicals for generations to come.

The European Union's REACH chemical legislation and why it is needed

Europe produces more chemicals than any other region of the world, accounting for about 35% of sales worldwide. The countries of the European Union, led by Germany, account for the majority of European chemical production. It is now known that many agricultural and industrial chemicals are accumulating in our bodies and in wildlife, even in remote regions of the world far from sources of chemical production and use. Only a fraction of all chemicals (usually those suspected of being the most hazardous) are actually monitored for in the environment. The current system of chemical regulation does not adequately assess chemicals for toxicity or protect humans and wildlife from chemical exposures. The European Union's new proposed REACH (Registration, Evaluation, and Authorization of CHemicals) legislation will, if passed in a strong form, lead to increased chemical safety.

Globally, there are an estimated 30 to 70 thousand chemicals now being produced. Current chemical regulation makes a distinction between "new" chemicals (about 3000 chemicals that came on the market after September 1981) and "existing" chemicals (the many thousands of chemicals that were on the market and registered by 1981). While all post-1981 "new" chemicals are required to undergo basic safety testing, the same is not required for the "existing" chemicals, which make up the majority of chemicals in current use. As a result thousands of chemicals, more than 90% of those on the market today, have not been evaluated for basic safety. In addition, the current system discourages industry innovation and development of new, safer alternative chemicals since the testing requirements are stricter to bring a chemical to the market today compared to continued use of a pre-1981 chemical, for which safety testing is not required.

The new REACH legislation would shift the burden of proof onto industry to show the chemicals they are producing are safe (rather than the current "safe until proven otherwise" system), make chemical safety information available to the public, and remove the arbitrary distinction between "new" and "existing" chemicals – requiring safety information in increasing levels based on chemicals' inherent properties and production volumes. Removing the distinction between "new" and "existing" chemicals would level the playing field and promote industry innovation and development of safer alternatives.

Benefits of the REACH legislation will include public availability of chemical safety information, development of safer chemical alternatives, production and use of safer chemicals both within and outside the European Union, and numerous benefits to environmental, human, and wildlife health. Specific benefits to industry from REACH will include new markets for safer products, easier introduction of new chemicals onto the market, easier long-term planning due to a more predictable regulatory system, fewer liability lawsuits, increased trust among consumers and a more positive business environment, and improved transparency and communication through the supply chain and to downstream users.

The REACH debate has been exaggerated and distorted by inaccurate industry impact studies.

What does WWF want?

Through the DetoX campaign, WWF is working to raise greater awareness and understanding about the failures of the current chemical regulation system and the need for improved chemical legislation. WWF welcomes and supports the REACH proposal but is calling for several specific areas of the legislation to be strengthened:

- A method to identify the worst chemicals of highest concern and to substitute them whenever safer alternatives are available is essential.
- The regulatory system must be made more transparent and open, maximizing information flow to all parties.

- More detailed information is available on WWF's DetoX website at: http://www.panda.org/detox

II. Chemical Threat in the Arctic

Chemical contamination is a serious global threat and the Arctic is uniquely vulnerable to this threat. When air masses carrying contaminants reach the Arctic, the "cold-condensation effect" occurs – this is when air contaminants move from the gas or vapour phase into a liquid phase, and are carried to the ground in rain or snow. Once pollutants reach the Arctic, the cold temperatures and long, dark winters slow the chemical break down process. Polar ice can trap contaminants that are gradually released into the environment during melting periods, even years after their arrival in the Arctic. As a result, the Arctic acts as a final "sink" where pollutants from around the world accumulate and become trapped.

The wildlife of the Arctic is especially at risk from chemical pollution. Many arctic animals – such as polar bears, seals, and whales – have thick layers of body fat to help them stay warm and, in the case of polar bears, to allow them to live off their fat reserves during their winter hibernation. While these traits make the unique animals of the Arctic perfectly adapted to their cold, harsh environment, the chemical characteristics of many toxic substances cause them to preferentially accumulate in fat. As a result, the fat that is so essential to keeping arctic animals warm and providing them with sufficient energy throughout the year also acts as a magnet for storing these substances, potentially leading to the build up of very high chemical levels.

Chemical exposures, even at low levels, may lead to serious health effects, especially when exposure occurs during the critical fetal and development periods. Newborn mammals – such as polar bear cubs and seal pups – are extremely vulnerable to toxic substances because they feed on their mother's fatty and contaminant-laden milk during the especially critical development period. In addition, many arctic animals – such as whales – have long life spans, leading to many decades of chemical exposure and the potential to build-up high and dangerous levels of toxic substances in their bodies. The Arctic is mainly a marine ecosystem, placing it at higher risk of contamination than terrestrial ecosystems because pollutants that enter seawater are easily absorbed by plankton and thereafter make their way all the way up the food chain. Thus, the combination of global chemical transport to the Arctic and the special characteristics of the ecoregion and its wildlife places arctic species at high risk of suffering harmful effects caused by pollution.

Contaminant exposure has the potential to affect wildlife growth and survival, at both the individual and population levels, and thus represents a major obstacle to preserving the Arctic as a region where wildlife can flourish – now and in the future. Exposure to chemicals was a key factor in the mass deaths of European harbor seals due to infection by morbilliviruses,[5] is thought to play a role in the continued decline of the Alaskan Stellar sea lion populations,[6] and may have affected age distribution and reproductive potential of the Svalbard, Norway polar bear population.[7,8] Strong scientific indications for the association between long-term contaminant exposure and negative health and reproductive impacts in key arctic species became available with the second AMAP report[9] and CACAR II report.[10] Svalbard polar bears have immune suppression, lowered Vitamin A levels, and lowered testosterone hormone levels; beluga whales from the St. Lawrence Estuary in Canada have increased cancer occurrences; Northern fur seals exhibit lowered Vitamin A levels, depressed thyroid hormone function, and immune suppression; the egg shells of peregrine falcons are thinning; and the survival rate of some Canadian glaucous gull populations is lowered, their eggs do not develop successfully, and their breeding behavior is altered. Although all of these health effects may not be exclusively caused by chemical exposures, scientific studies indicate that these health effects are associated with the levels of various chemicals in the bodies of the animals.

Similar properties and health effects are likely shared between the older generation of persistent contaminants and many of those in current use today. More importantly, the concurrent presence in wildlife of current-use as well as older legacy contaminants could result in even more harmful cumulative effects due to chemical mixtures and interactions.[11] The addition of new contaminants to the existing contamination from older chemicals may intensify eminent immune suppression, reproductive decline, and behavioral alterations already present in important arctic species such as polar bears, seals, whales, birds of prey, and seabirds.

Chemicals that are toxic,[12] persistent,[13] able to bioaccumulate[14] or build up in the bodies of animals, and capable of being transported long distances are especially hazardous and pose a high risk to the diverse and sensitive arctic ecosystem. How harmful a chemical exposure will be depends on the specific chemical and wildlife species it is found in, the level or dose of the chemical exposure, which other chemicals are also present and in what dose, and the animal's age, gender, physical condition including amount of body fat, nutritional status, and metabolizing ability to break down and excrete toxic substances.[15]

Unlike humans, who can be assessed for neurologic function or studied to determine if chemical exposures are associated with diseases that occur many years later (i.e. cancers and reproductive problems), studying wild animal populations poses a special challenge. Measurable and easy to assess markers are needed to quickly determine how chemicals are impacting the health of wildlife. Different "biological markers"[16] or indicators have been developed and are used to document more immediate changes to the animal's nervous system, immune system, and hormones that control stress responses, sexual behavior, and reproductive function. These indicators are then compared to the levels of chemicals in the animal's body to determine if the chemical exposure is associated with measurable changes. In the past few years, several studies have added to the accumulating indications that changes in the immune and hormone systems of arctic species, most notably polar bears, are associated with their exposure to hazardous chemicals. (See boxed text on pages 10-11.)

Many contaminants of concern have harmful impacts on immune, reproductive, hormone, and neurologic function; and on behavior and development. Notable reproductive effects associated with contaminant exposures include diminished fertility and reduced sperm production, altered hormone levels, decline in offspring numbers and their survival, an increase in deformities and offspring deaths,[17,18,19] and possibly pseudo-hermaphrodism.[20] Behavioral modifications affecting movement, feeding, predator avoidance, learning and memory, and social interactions have been linked to alterations in thyroid hormone[21] levels and neurotransmitter release and function.[22,23,24,25,26,27] Lowered resistance to common bacterial and viral diseases is a prominent sign of immune suppression associated with delayed or absent immune responses and altered Vitamin A equilibrium.[28,29,30,31,32,33,34,35,36,37,38] Finally, increases in the occurrences of cancers in exposed populations may reflect exposure to certain toxic substances.[39,40]

Harmful Effects Linked to Contaminant Exposures in Polar Bears

Photo: WWF-Peter Prokosch

As the top predator within the Arctic, the polar bear is of special importance to the ecoregion, is at high risk from chemical contamination, and is a research priority.

Since 2000, several scientific studies of polar bears in the Norwegian or Canadian Arctic have been published indicating that exposure to several "older" contaminants is associated with changes in reproductive and thyroid hormones and immune status. Reduced immunity and altered hormone levels have the potential to pose a serious threat to polar bears since impaired development, lowered reproductive ability, and changes in behavior may result.

Taken together, these recent studies provide the first compelling indications that contaminant levels in polar bears are already at levels where biological changes are occurring and likely contributing to harmful reproductive and immune function outcomes.

In polar bears from Svalbard, Norway[1] protective IgG antibodies[2] were found to decrease with increasing levels of PCBs,[3] indicating a possible immunotoxic effect. Decreased immune function in polar bears from Norway and Canada was associated with exposure to organochlorine chemicals and PCBs – indicating that high organochlorine exposure may reduce the bears' ability to produce antibodies and may leave them more susceptible to infections.

Studies are also beginning to show indications of contaminant-associated changes in both male and female reproductive hormones. In female polar bears from Svalbard,[4] PCB exposure was associated with increases in the hormone progesterone.[5] In male polar bears from Svalbard,[6] testosterone[7] hormonal changes were associated with pesticide and PCB exposure. These hormone changes may result in reproductive toxicity including reduced fertility.

In addition, a study[8] of male and female Svalbard polar bears found associations between altered levels of the hormone cortisol[9] and pesticide and PCB exposure. This finding indicates the potential for a wide range of negative health effects since cortisol regulates energy metabolism, growth and development, stress response, and reproductive and immune function. Thyroid hormone and retinol levels were associated with PCB and HCB[10] exposure in Norwegian polar bears.[11,12] Thyroid hormone imbalance may lead to negative impacts on learning ability, behavior, and reproductive function.

These recently published studies relied on blood and tissue samples taken from polar bears between the years 1991–1999. Since 1999, many new chemicals such as some of those discussed in this report have been added to the mixture of toxics that are now reaching the Arctic. It is highly likely that these new chemicals – on their own and as part of chemical mixtures – are also associated with similar biological effects.

The continued use of inadequately tested chemicals will allow further environmental contamination to occur at a time when we are just beginning to understand how many chemicals build up in our bodies and the ways they affect us. There is therefore an urgent need for safer chemical legislation, such as REACH, to protect our global environment, and key ecosystem species such as the polar bear, from further contamination and a range of potentially harmful effects.

References

[1] Lie E, Larsen HJ, Larsen S, Johansen GM, Derocher AE, Lunn NJ, Norstrom RJ, Wiig O, Skaare JU. *Does high organochlorine (OC) exposure impair the resistance to infection in polar bears (Ursus maritimus)? Part I: Effect of OCs on the humoral immunity.* J Toxicol Environ Health A. 2004 Apr 9;67(7):555–82.

[2] Antibodies are proteins produced to protect the body against foreign invaders such as bacteria or viruses. IgG antibodies are one of 5 classes of antibody found in vertebrate species.

[3] Polychlorinated biphenyls, or PCBs, are a group of chemicals developed in the 1930s and finally banned in the early 1980s due to recognition of their hazardous properties. PCBs were used primarily as coolants and lubricants in electrical equipment and can now still be found in the environment and in the bodies of humans and wildlife.

[4] Haave M, Ropstad E, Derocher AE, Lie E, Dahl E, Wiig O, Skaare JU, Jenssen BM. *Polychlorinated biphenyls and reproductive hormones in female polar bears at Svalbard*. Environ Health Perspect. 2003 Apr;111(4):431–6.

[5] Progesterone is a female steroid hormone that results in the uterus being suitable for implantation of a fertilized egg and maintains the uterus throughout pregnancy.

[6] Oskam IC, Ropstad E, Dahl E, Lie E, Derocher AE, Wiig O, Larsen S, Wiger R, Skaare JU. *Organochlorines affect the major androgenic hormone, testosterone, in male polar bears (Ursus maritimus) at Svalbard*. J Toxicol Environ Health A. 2003 Nov 28;66(22):2119–39.

[7] Testosterone is a male steroid hormone required for development of the reproductive organs, sperm, and secondary sexual characteristics.

[8] Oskam I, Ropstad E, Lie E, Derocher A, Wiig O, Dahl E, Larsen S, Skaare JU. *Organochlorines affect the steroid hormone cortisol in free-ranging polar bears (Ursus maritimus) at Svalbard, Norway*. J Toxicol Environ Health A. 2004 Jun 25;67(12):959–77.

[9] Cortisol is a steroid hormone that regulates many important bodily functions including blood pressure, metabolism, the immune system, and responses to stressors such as physical injury, temperature changes, and psychological reactions.

[10] Hexachlorobenzene, or HCB, was mainly used as a pesticide up until 1965 in order to protect crops from fungus. HCB breaks down very slowly in the environment and levels can build up in the bodies of humans and wildlife.

[11] Braathen M, Derocher AE, Wiig O, Sormo EG, Lie E, Skaare JU, Jenssen BM. *Relationships between PCBs and thyroid hormones and retinol in female and male polar bears.* Environ Health Perspect. 2004 Jun;112(8):826–33.

[12] Skaare JU, Bernhoft A, Wiig O, Norum KR, Haug E, Eide DM, Derocher AE. *Relationships between plasma levels of organochlorines, retinol and thyroid hormones from polar bears (Ursus maritimus) at Svalbard.* J Toxicol Environ Health A. 2001 Feb 23;62(4):227–41.

III. Some Toxic Substances of Concern in the Arctic

The following section provides a brief overview on the production and use of selected groups of chemicals that often have been monitored for and studied in the Arctic for only a short time, as well as general regional background on environmental levels (i.e. in air, snow, sediments, wildlife, humans) and trends in North America and Europe. More detailed information is available in the Appendix.

1. Polychlorinated napthalenes (PCNs)

PCNs are a group of 75 compounds that are structurally similar to PCBs[41] and that were widely used from the 1930s up until the late 1980s. Industrial applications included use as flame-retardants, in transformer and capacitor fluids, fungicides, sealants, and as a plastic and rubber additive. Production and use ended in the United States in 1977 and in most of Europe a few years later. However, unintentional formation through former PCB[42] use, waste incineration, and re-emission from old reservoirs such as landfills has added to the environmental burden even after the 1980s.[43,44]

Polychlorinated napthalenes are capable of long-range transport, slow to break down in the environment and their levels are known to build up in animals.[45,46] PCNs have a tendency to deposit on ocean sediments, potentially placing bottom-feeding species at risk. PCN exposure interferes with communication between cells,[47,48] causes developmental injury to the embryo, and acts as a general hormone disruptor.[49]

So far, contamination with PCNs has been detected in arctic and sub-arctic animals including polar bears from Alaska, ringed seals from the Baltic Sea, Baffin Island, and Svalbard, grey seals from the Baltic Sea, Canadian harp seals, Baffin Island beluga whales, harbor porpoise from the Baltic Sea and Sweden, and 3 bird species in Canada. PCNs have also been found in highly endangered Vancouver Island marmots that live only in the mountains of sub-arctic Vancouver Island, Canada.[50] There are about 100 of these rare marmots left in the world and such chemical contamination may represent an additional threat to their survival. (See Table 8 in the Appendix.)

2. Brominated flame-retardants (BFRs)

Brominated flame-retardants are a diverse group of chemicals – including 5 major forms: tetrabromobisphenol A (TBBPA), hexabromocyclododecane (HBCD), polybrominated diphenyl ethers (PBDEs), and 3 commercial PBDE mixtures called “penta”, “octa” and “deca”. BFRs are added to many common consumer products (e.g. furniture cushions, children’s clothes, computers) to reduce flammability. Asia is the top BFR user, followed by the Americas, and Europe.[51] Although the European Union recently banned “octa” and “penta” BFRs, there are currently no restrictions on another flame retardant of concern, the “deca” commercial mixture, which can break down in the environment into the “octa” and “penta” forms.

The PBDE flame-retardants are slow to break down, attracted to fat, and able to evaporate into and be transported through air.[52] PBDE brominated flame retardants are likely to cause cancer and function as hormone disruptors, adversely affecting reproduction and thyroid hormone function.[53,54,55,56,57] Distinct neurobehavioral effects in rats (e.g. decline in memory function and learning ability) were noted after developmental exposure.[58,59,60] Doubling levels of PBDE have been noted in North America every 4-6 years.[61] Although BFR levels in Europeans are lower than in North Americans,[62] increasing levels detected in European women’s breast milk raise serious concerns about infant exposure.[63]

In the Arctic, brominated flame-retardants have already been detected in polar bears from Svalbard, arctic foxes, Swedish grey seals, ringed seals from Sweden, Norway and Canada, beluga whales from Canada and Norway, Faroe Island pilot whales, and bird species from Greenland, Norway, Canada, and Sweden. Sub-arctic contamination has been documented in the Baltic Sea and the San Francisco Bay as well as in waters off the United Kingdom, Denmark, the Netherlands, Belgium, and southern Sweden. Contaminated species include white-beaked dolphins, minke and sperm whales, and mackerel off the coast of the Netherlands, harbor porpoise in the North Sea and off the coasts of the United Kingdom and Belgium, harbor seals from the North Sea, San Francisco Bay, and off the coast of the Netherlands, blue mussels from Denmark, Swedish salmon, Baltic Sea pike, bird species from the United Kingdom, Norway, Sweden and the Baltic Sea, and endangered Vancouver Island marmots. The “deca” flame retardant has been detected in some polar bears and glaucous gulls from Svalbard, Norway. (See Table 6 in the Appendix.)

3. Perfluorooctanesulfonate (PFOS) and Perfluorooctanoate (PFOA)

Fluorinated compounds, such as PFOS and PFOA, have been produced for over 40 years for use as surface and stain protectors for products such as coated cookware, carpets, upholstery, leather, and paper packing – including fast food wrappers. PFOS was previously used in Scotchguard™ products and was voluntarily phased out by a major producer, 3M Corporation, in 2001 in response to evidence of toxicity. Despite safety concerns, there are few regulations regarding PFOA and it is in widespread use, although some companies are monitoring for environmental contamination and health effects.

Due to their chemical properties, fluorinated compounds were long considered unlikely to spread to sites far from their original source. However, this assumption has been proven wrong and these compounds are now widely found in our bodies and wildlife.[64] Alarmingly, recent studies have shown some fish can break down other fluorinated chemicals – transforming them into more harmful forms including PFOS and PFOA.[65] Studies from the United States and Europe show levels of PFOS are increasing in wildlife and humans. Once in the environment, these chemicals are unusually persistent and do not degrade under normal conditions. PFOS and PFOA have been shown to have harmful effects on cell membranes and communication between cells.[66] Effects including memory decline; impaired learning; decreased reflex time response, and neonatal deaths have been demonstrated in laboratory rats.[67,68,69,70] Harmful liver effects were observed in wood mice living near a fluoro-chemical plant.[71]

The first peer-reviewed scientific reports of PFOA in arctic wildlife were published in 2004. Most studies focused on the Canadian Arctic where PFOA was detected in polar bears, fox, mink, ringed seals, and several bird species. Harbor porpoise from Iceland, Norway, Denmark, Germany, and the Baltic Sea also tested positive for PFOA. PFOS has been detected in polar bears from Alaska, Greenland and Canada, fox from the Canadian Arctic, ringed seals from Norway and Canada, Alaskan Stellar sea lions and Northern fur seals, Canadian grey seals, and several bird species from Canada. Sub-arctic PFOS contamination includes harbor porpoise from northern European and North Sea waters, ringed seals from the Baltic Sea, grey seals from the Baltic and North seas, and eagles from Poland and Germany. Fin and sperm whales, hooded seals, striped, white-beaked, and white-sided dolphins, shrimp, crabs, and starfish from the North Sea are also contaminated. (See Tables 4 and 5 in the Appendix.)

4. Hexachlorobenzene (HCB)

Hexachlorobenzene was formerly used as a fungicide but now has no commercial use. Released during waste incineration, as well as during military activities and firefighting training exercises, it is also formed as a by-product of the production of several other chemicals and metals, and in combustion processes. Global use has been declining and use as a fungicide was banned in the United States in 1984 and in the European Union in 1988, but the re-emission of old HCB from soil continues to add to environmental levels.[72,73]

This pesticide is extremely resistant to degradation and builds up primarily in fatty body tissues. Its presence in amniotic fluid of both humans and farm animals raises concern for exposure of infants.[74,75] In North Americans, levels measured in fat tissue have declined since 1973, but a ubiquitous presence in breast milk of North American women indicates infants may be exposed after birth as well as during fetal development.[76] HCB exposure leads to a wide range of toxic effects, including immune suppression,[77,78] hormone disruption,[79] and cancer.[80] In bird species, environmental exposure to multiple chemicals, including HCB, has been linked to reduced body condition in white-tailed eagles,[81] terns, and herring gulls.[82,83,84]

HCB is a global pollutant with established long-range atmospheric transport, and it is present in arctic snow, air and seawaters.[85] HCB has been detected in arctic wildlife from Alaska, Canada, Russia, Greenland, Norway, and the Barents, North and White seas. Contaminated species include polar bears, wolves, 6 seal species, 6 whale species, 2 porpoise species, walrus, sturgeon, 8 bird species, squid, and endangered Vancouver Island marmots. Environmental exposure to multiple chemicals, including HCB, has been linked to hormone disruption and immune suppression in polar bears[86] and Baltic Sea seals.[87] Exposure to multiple chemicals, including HCB, was associated with thyroid hormone alteration in Arctic-breeding glaucous gulls.[88] (See Table 7 in the Appendix.)

5. Short-chained chlorinated paraffins (SCCPs)

Short-chained chlorinated paraffins are used in the metal processing and building industries, and in rubber and leather treatment. In Europe, use has declined by 9000 tons since 1994, while use has increased in the United States by 5500 tons.[89] As use of other better-studied types of flame-retardants is restricted due to their known hazardous properties, use of SCCPs as flame-retardants may increase.

Chlorinated paraffins are persistent and do not easily break down, they accumulate in the bodies of humans and wildlife, and transformation to other potentially harmful compounds occurs in fish, birds and mammals. Evidence suggests that these chemicals may be transported over long ranges by air and ocean currents. SCCPs inhibit cell-to-cell communication,[90] have the potential to cause cancer, and affect thyroid hormone function.[91,92]

SCCPs are prevalent in Norwegian and United Kingdom environmental samples,[93, 94, 95] and have been reported in air and 50-year-old sediment samples from the Canadian Arctic.[96,97] Thus far in the Arctic or sub-Arctic, SCCPs have been detected in grey and ringed seals from Norway, beluga whales, walrus, and in fish, birds, and ocean sediments from the United Kingdom. (See Table 9 in the Appendix.)

6. Octachlorostyrene (OCS)

This chemical is an inadvertent by-product of production of magnesium, high-temperature processes involving carbon and chlorine, and possibly from some types of incineration and combustion. OCS has no known commercial use and was never produced intentionally.

Octachlorostyrene is persistent and is known to bioaccumulate in the bodies of animals. OCS has a tendency to bind to sediments, is highly toxic to fish, and has been detected in fish from Elb River, Germany[98] and the Midwest, United States.[99,100] Little information is available on health effects associated with OCS exposure. However, secondary sex characteristics were altered in snapping turtles from Canada exposed to a mixture of contaminants including octachlorostyrene.[101]

OCS has been reported in air samples from the Canadian Arctic,[102] soil samples in Ontario,[103] and sediment samples from the Great Lakes basin.[104] An accumulation of this chemical has been detected in coastal fish from Norway[105] and Baltic Sea eels.[106] OCS has been detected in the blood of Swedes,[107] Elb River residents in Germany,[108] and newborn babies from Inuit and local fishermen populations in Quebec,[109] indicating potential OCS contamination of marine food diets from the Atlantic Ocean. OCS found in albatross suggests similar contamination of the marine food web in the Pacific Ocean.[110] In addition, octachlorostyrene has been detected in the waters of several harbors in northern Norway and in Canadian ringed seals, European harbor porpoise, and 2 sub-arctic bird species. A possible metabolite of OCS, hydroxyheptachlorostyrene, has been detected in Canadian polar bears. Hydroxyheptachlorostyrene was shown to bind to proteins in the blood of the polar bears, indicating the potential to disrupt hormone function.[111] (See Table 13 in the Appendix.)

7. Methoxychlor and Endosulfan pesticides

These pesticides are currently registered for use in Canada and the United States to protect crops against insects. Agricultural and urban areas in Eurasia and North America are thought to be the most likely source of environmental contamination for both pesticides. There are no global regulations covering endosulfan and methoxychlor, although they are restricted or banned in some countries.

Endosulfan and methoxychlor are persistent, have a high potential for biomagnification and accumulation, and are known to be toxic to aquatic species, birds, and mammals. Methoxychlor and endosulfan are hormone disruptors known to adversely affect reproduction,[112,113,114,115,116] thyroid gland function[117,118,119] and immune response.[120,121] There is also evidence for neurotoxicity[122] and altered reflex response time.[123]

Methoxychlor and endosulfan have been detected in arctic air, water from the arctic ocean, snow from the Canadian Arctic, and snow over Northwest Alaskan sea ice – providing strong evidence for transport by air and ocean currents.[124,125,126] Increasing levels of endosulfan in Canadian arctic air (Nunavut) have been noted since the first Arctic Monitoring and Assessment Program (AMAP) report.[127] Thus far, methoxychlor has been detected in wildlife from arctic Canada, Norway, Russia, Greenland, and in the Barents and North seas. Harbor and harp seals, as well as blue, humpback and minke whales are known to be contaminated. Endosulfan has been detected in wildlife from Russia, Canada, Greenland, Norway, and the White, North and Barents seas as well as in ocean sediments from the Caspian Sea. Contaminated species include minke whales and harbor, harp, and bearded seals. (See Tables 10 and 11 in the Appendix.)

8. Pentachlorophenol (PCP)

Pentachlorophenol is formed during production of several other chemicals and is also formed from metabolism of hexachlorobenzene (HCB) in mammals. PCP was widely used as a pesticide in the past and is currently used as a plant-protecting chemical[128] and as a commercial wood preservative for telephone poles, utility fencing, etc. The United States is the major exporter for PCP use in Europe, where PCP production ended in 1992.

PCP accumulates mainly in organs such as the liver, kidney, and brain. Treated wood is an important environmental source for PCP found in ospreys[129] and commercially raised beef cattle in the United States.[130,131] Toxic effects are not yet well defined although PCP causes cancer in rats[132] and has the potential to disrupt hormones.[133] PCP exposure has had harmful effects on developing salmon embryos[134] and caused deaths in bats exposed to PCP-treated roost boxes.[135] The presence of PCP in amniotic fluid raises concerns for infant exposure.[136]

Infants from Inuit and local fishermen populations in Quebec are contaminated with PCP,[137] indicating polluted marine food diets and/or ongoing HCB exposure and metabolism. Levels of PCP have been linked to fish consumption in Latvian and Swedish men.[138] The first peer-reviewed scientific studies of PCP in sub-arctic wildlife came out in 2004 and showed contamination of the eggs of 4 Norwegian bird-of-prey species – golden eagles, ospreys, peregrine falcons, and white-tailed sea eagles. A breakdown product of PCP has been found in Canadian arctic snow[139] and lake sediments,[140] indicating likely long-range transport of this chemical to remote regions. (See Table 12 in the Appendix.)

IV. Other contaminants of concern, for which arctic data are not yet available

1. Dicofol

The pesticide dicofol has a global usage of 2750 tons/year. Asia leads in total consumption, followed by the United States, and Western Europe.[141] Dicofol is a known hormone disruptor.[142] Multiple contaminant exposure including dicofol has been linked to delayed maturation in female carp and inhibited sperm production in male carp from the Ebro River, Spain;[143] egg shell thinning and altered reproductive behavior in captive American kestrels; [144,145,146] developmental abnormalities of reproductive organs and altered sex hormone status in Florida alligators;[147] and immune suppression in marine toads and frogs from Bermuda.[148] An increased risk among Italian farmers of prostate cancer has been associated with DDT and dicofol pesticide exposure.[149] Although dicofol has not yet been monitored for in remote arctic areas, it is thought to be capable of long-range transport.

2. Bisphenol A

Bisphenol A is globally used in the manufacture of many plastics and has also been used as a fungicide, antioxidant, flame retardant, rubber chemical, and stabilizer. Polycarbonate baby bottles leach Bisphenol A after dishwashing, boiling and brushing, and releases also occur from food cans and other plastic products.[150] In addition, transfer of Bisphenol A to the fetus during pregnancy is of concern.[151,152] Bisphenol A is a hormone disruptor and is toxic to male reproductive organs in rats.[153,154] It affects brain cell survival and development,[155] and has the potential to cause cancer.[156] In salmon, exposure causes behavioral changes and damage to the egg yolk sac.[157] Bisphenol A is already known to be present in the Norwegian and United Kingdom environments.[158]

V. Conclusion

Like the small portion of an iceberg that can actually be seen from above the water, the chemicals discussed in this report are only warnings of the larger problem that, for now, remains beneath the surface. The same can also be said of the Arctic, it represents the visible tip of the iceberg that must serve as an alert: contamination of the Arctic is an early warning of what is also occurring below in more southern regions of the world. The ability to monitor what chemicals have made their way into our bodies, wildlife, and our environment depends on the development of methods used to detect contaminants, the level of scientific and global interest in the issue, and funding for research. Therefore, the evidence of chemicals that have been found in particular arctic species and at certain locations (presented in detail in the Appendix) does not represent the complete picture of arctic wildlife contamination. Many species and specific chemicals have not yet been assessed at all in the Arctic, however, wherever we look in the Arctic we are now detecting contamination from chemicals produced and used in distant regions of the world.

The Arctic was long thought to be pristine and isolated from the actions of the rest of the world, we now know this is not the case. The detected levels of chemicals in the bodies of arctic wildlife are a testament to the widespread presence of these contaminants within the arctic marine food web. The continued poorly regulated use of chemicals will result in increasing levels of contamination in the bodies of arctic marine mammals and bird species in the near future.

Current global threats to arctic marine ecosystems are complex and highly interactive. Pollution, climate change, over-fishing, habitat destruction due to human development and resource utilization, eutrophication,[159] ultra-violet radiation,[160] and introduction of non-native species are all important key factors that alter ecosystems.[161] These many concurrent threats are expected to impair arctic species' resilience and ability to successfully adapt to their changing environment, thus jeopardizing the viability and sustainability of the arctic marine and terrestrial systems as a whole. Pollution-associated and climate-related changes to arctic ecosystems will have dramatic global consequences. The remote arctic region, far from many of the main sources of pollution, is considered a sentinel or indicator that can provide us with an early alert to the threat posed by our use of toxic chemicals. However, it is up to us to act on this early warning while we still have time to protect this unique region and its wildlife, as well as the rest of our planet.

Similar to the older generation of pollutants, current-use toxic substances reaching the Arctic are apparently originating mainly from distant source regions. To date, few studies have assessed the potential harmful health effects to arctic wildlife from newer generation contaminants. However, long-term exposure to the older generation of chemicals has been linked to immunological, behavioral, reproductive, and neurological harmful effects in key species, such as polar bears. Many of the current-use and older generation chemicals share structural similarities and chemical properties, and most likely contribute to common health consequences.

Compelling scientific studies of harmful health effects associated with contaminant exposures are just now becoming available. However, it is essential to heed the lessons from our experience with the last generation of legacy chemicals and to immediately act on the side of precaution to prevent the build up of additional harmful chemicals in our global environment. Vast numbers of both indigenous and non-indigenous peoples and animals are dependent on the Arctic for their very survival. The arctic environment and the great variety of species it supports are extremely sensitive to threats from pollution. The Arctic serves as a global environmental indicator, an early warning system where we can gauge the health of our planet. Learning to protect and conserve the Arctic will not only ensure this magnificent region and its unique wildlife are around for generations to come, but will also serve as an example and a model of how we can live in harmony with nature.

Passing a strong and protective version of the REACH legislation will be a great step towards reducing, and eventually ending, environmental contamination with hazardous chemicals. The Titanic, one of the most modern and advanced ships at its time, was thought to be "practically unsinkable" prior to its fatal collision and the deaths of hundreds of people in 1912. Likewise, we cannot afford to continue with the unsupported and dangerous assumption that chemicals are "safe until proven otherwise." What we already know about the hazards of chemicals, while it may only be the "tip of the iceberg," foreshadows what lies beneath. The time to act and move towards safer, sustainable chemical use is now.

References

[1] Polychlorinated biphenyls, a group of chemicals now banned under the Stockholm Convention due to their hazardous properties.

[2] Dichlorodiphenyltrichloroethane, a chemical widely used to combat malaria- transmitting mosquitoes. DDT is now banned under the Stockholm Convention except for certain malaria control purposes in developing countries. Alternative, safer and effective chemicals are needed to replace DDT.

[3] The Stockholm Convention on Persistent Organic Pollutants is a global treaty to protect human health and the environment from some of the most hazardous chemicals. The treaty entered into force on May 17, 2004 and bans the global use of 12 chemicals – aldrin, chlordane, dichlorodiphenyltrichloroethane (DDT), dieldrin, endrin, heptachlor, mirex, toxaphene, polychlorinated biphenyls (PCBs), hexachlorobenzene, dioxins, and furans. Read more about the Stockholm Convention at http://www.pops.int/

[4] REACH stands for Registration, Evaluation and Authorization of CHemicals. The REACH legislation was first proposed in 2001 and will be voted on in the European Union in 2005–2006. Once passed, REACH aims to provide a higher level of chemical safety and more responsible use of chemicals.

[5] Van Loveren H, Ross PS, Osterhaus AD, Vos JG. *Contaminant-induced immunosuppression and mass mortalities among harbor seals.* Toxicol Lett. 2000; 112–113: 319–24.

[6] Barron MG, Heintz R. Krahn MM. *Contaminant exposure and effects in pinnipeds: implications for Stellar Sea lions decline.* The Science Total Environ. 311 (2003) 111–133.

[7] Derocher AE, Wolkers H, Colborn T, Schlabach M, Larsen TS, Wiig O. *Contaminants in Svalbard polar bear samples archived since 1967, and possible population level effects.* Sci Total Environ. 2003 Jan 1; 301(1–3): 163–74.

[8] Skaare JU, Larsen HJ, Lie E, Bernhoft A, Derocher AE, Norstrom R, Ropstad E, Lunn NF, Wiig O. *Ecological risk assessment of persistent organic pollutants in the arctic.* Toxicology. 2002; 181–182: 193–7.

[9] AMAP 2004, *AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic.* Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xvi+310 pp.

[10] CACAR II 2003. *Canadian Arctic Contaminants Assessment Report II, Sources, Occurrence, Trends and Pathways in the Physical Environment.* 202 pgs.

[11] Carpenter DO, Arcaro K, Spink DC. *Understanding the human health effects of chemical mixtures.* Environ Health Perspect. 2002, 110 Suppl 1:25–42.

[12] Toxic is defined as having to do with poison or something harmful to the body. Toxic substances usually cause unwanted side effects.

[13] Persistent is defined as slow to break down, not easily degradable.

[14] Bioaccumulation refers to the ongoing uptake of toxic substances that remain in the body.

[15] AMAP 2004, *AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic.* Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xvi+310 pp.

[16] A biomarker is a measurable biochemical, physiological, behavioral or other alteration within an organism that, depending upon the magnitude, can be recognized as associated with an established or possible health impairment or disease according to The International Programme on Chemical Safety.

[17] De Guise S, Lagace A, Beland P. *True hermaphroditism in a St. Lawrence beluga whale (Delphinapterus leucas).* J Wildl Dis. 1994; 30(2): 287–90.

[18] Haave M, Ropstad E, Derocher AE, Lie E, Dahl E, Wiig O, Skaare JU, Jenssen M. *Polychlorinated biphenyls and reproductive hormones in female polar bears at Svalbard.* Environ Health Perspect. 2003; 111(4): 431–6.

[19] Wiig O, Derocher AE, Cronin MM, Skaare JU. *Female pseudohermaphrodite polar bears at Svalbard.* J Wildl Dis. 1998; 34(4): 792–6.

[20] A condition where genitalia or secondary sex characteristics are of indeterminate sex or a mixture of both sexes.

[21] Thyroid hormones regulate many important functions including fetal brain development and behavior, growth, metabolism and reproduction.

[22] Colborn T. *Clues from wildlife to create an assay for thyroid system disruption.* Environ Health Perspect. 2002, 110 (suppl 3): 363–367.

[23] Howdeshell KL. *A model of the development of the brain as a construct of the thyroid system.* Environ Health Perspect. 2002;110 Suppl 3: 337–48.

[24] Schantz SL, Widholm JJ. *Cognitive effects of endocrine-disrupting chemicals in animals.* Environ Health Perspect. 2001;109(12): 1197–206.

[25] Verreault J, Skaare JU, Jenssen BM, Gabrielsen GW. *Effects of Organochlorine Contaminants on Thyroid Hormone Levels in Arctic Breeding Glaucous Gulls, Larus hyperboreus.* Environ Health Perspect. 2004; 112(5): 532–7.

[26] Weis LM, Rummel AM, Masten SJ, Trosko JE, Upham BL. *Bay or baylike regions of polycyclic aromatic hydrocarbons were potent inhibitors of Gap junctional intercellular communication.* Environ Health Perspect. 1998; 106(1): 17–22.

[27] Zoeller TR, Dowling AL, Herzig CT, Iannacone EA, Gauger KJ, Bansal R. *Thyroid hormone, brain development, and the environment.* Environ Health Perspect. 2002; 110 Suppl 3: 355–61.

[28] Beckmen KB, Blake JE, Ylitalo GM, Stott JL, O'Hara TM. *Organochlorine contaminant exposure and associations with hematological and humoral immune functional assays with dam age as a factor in free ranging northern fur seal pups (Callorhinus ursinus).* Mar Pollut Bull. 2003; 46(5): 594–606.

[29] Bernhoft A, Skaare JU, Wiig O, Derocher AE, Larsen HJ. *Possible immunotoxic effects of organochlorines in polar bears (Ursus maritimus) at Svalbard.* J Toxicol Environ Health A. 2000; 59(7): 561–74.

[30] Braathen M, Derocher AE, Wiig O, Sormo EG, Lie E, Skaare JU, Jenssen BM. *Relationships between PCBS and Thyroid hormones and Retinol in female and male polar bears.* Environ. Health. Perspec. 2004; 112:826–833.

[31] de Swart RL, Ross PS, Vos JG, Osterhaus AD. *Impaired immunity in harbor seals (Phoca vitulina) exposed to bioaccumulated environmental contaminants: review of a long-term feeding study.* Environ Health Perspect. 1996; 104 Suppl 4:823–8

[32] Jenssen BM, Haugen O, Sormo EG, Skaare JU. *Negative relationship between PCBs and plasma retinol in low-contaminated free-ranging gray seal pups (Halichoerus grypus).* Environ Res. 2003; 93(1): 79–87.

[33] Lie E, Larsen HJ, Larsen S, Johansen GM, Derocher AE, Lunn NJ, Norstrom RJ, Wiig O, Skaare JU. *Does high organochlorine (OC) exposure impair the resistance to infection in polar bears (Ursus maritimus)? Part I: Effect of OCs on the humoral immunity.* J Toxicol Environ Health A. 2004; 67(7): 555–82.

[34] Oskam IC, Ropstad E, Dahl E, Lie E, Derocher AE, Wiig O, Larsen S, Wiger R, Skaare JU. *Organochlorines affect the major androgenic hormone, testosterone, in male polar bears (Ursus maritimus) at Svalbard.* J Toxicol Environ Health A. 2003; 66(22): 2119–39.

[35] Skaare JU, Bernhoft A, Wiig O, Norum KR, Haug E, Eide DM, Derocher E. *Relationships between plasma levels of organochlorines, retinol and thyroid hormones from polar bears (Ursus maritimus) at Svalbard.* J Toxicol Environ Health A. 2001; 62(4): 227–41.

[36] Smits JE, Bortolotti GR. *Antibody-mediated immunotoxicity in American kestrels (Falco sparverius) exposed to polychlorinated biphenyls.* J Toxicol Environ Health A. 2001; 62(4): 217–26.

[37] Sormo EG, Skaare JU, Jussi I, Jussi M, Jenssen BM. *Polychlorinated biphenyls and organochlorine pesticides in Baltic and Atlantic gray seal (Halichoerus grypus) pups.* Environ Toxicol Chem. 2003; 22(11): 2789–99.

[38] Van Loveren H, Ross PS, Osterhaus AD, Vos JG. *Contaminant-induced immunosuppression and mass mortalities among harbor seals.* Toxicol Lett. 2000; 112–113: 319–24.

[39] Birnbaum LS, Fenton SE. *Cancer and developmental exposure to endocrine disruptors.* Environ Health Perspect. 2003; 111(4): 389–94.

[40] Martineau D, Lemberger K, Dallaire A, Labelle P, Lipscomb TP, Michel P, Mikaelian I. *Cancer in wildlife, a case study: beluga from the St. Lawrence estuary, Quebec, Canada.* Environ Health Perspect. 2002;110(3): 285–92.

[41] Polychlorinated biphenyls. A group of chemical compounds now banned under the Stockholm Convention.

[42] Polychlorinated biphenyls. A group of chemical compounds now banned under the Stockholm Convention.

[43] Falandysz J. *Chloronaphthalenes as food-chain contaminants: a review.* Food Addit Contam. 2003; 20(11): 995–1014.

[44] Falandysz J. *Polychlorinated naphthalenes: an environmental update.* Environ Pollut. 1998; 101(1): 77–90.

[45] Lundgren K, Tysklind M, Ishaq R, Broman D, van Bavel B. *Flux estimates and sedimentation of polychlorinated naphthalenes in the northern part of the Baltic Sea.* Environ Pollut. 2003; 126(1): 93–105.

[46] Lundgren K, Tysklind M, Ishaq R, Broman D, van Bavel B. *Polychlorinated naphthalene levels, distribution, and biomagnification in a benthic food chain in the Baltic Sea.* Environ Sci Technol. 2002; 36(23): 5005–13.

[47] Upham BL, Weis LM, Trosko JE. *Modulated gap junctional intercellular communication as a biomarker of PAH epigenetic toxicity: structure-function relationship.* Environ Health Perspect. 1998; 106 Suppl 4: 975–81.

[48] Weis LM, Rummel AM, Masten SJ, Trosko JE, Upham BL. *Bay or baylike regions of polycyclic aromatic hydrocarbons were potent inhibitors of Gap junctional intercellular communication*. Environ Health Perspect. 1998; 106(1): 17–22.

[49] An exogenous substance that changes endocrine function and causes adverse effects at the level of the organism, its progeny and/or (sub) populations of organisms.

[50] Lichota, G.B., M. McAdie, and P.S. Ross. *Endangered Vancouver Island marmots (*Marmota vancouverensis*): sentinels of atmospherically delivered contaminants to British Columbia, Canada. Environmental Toxicology and Chemistry.* 2004. 23: 402–407.

[51] BFR use is 117,950 tons, 53,900 tons, and 29,460 tons per year for Asia, the Americas, and Europe respectively.

[52] Rahman F, Langford KH, Scrimshaw MD, Lester JN. *Polybromianted diphenyl ether (PBDE) flame retardants.* The Science of the Total Environment 2001, 275: 1–17.

[53] Birnbaum LS, Staskal DF. *Brominated flame-retardants: cause for concern?* Environ Health Perspect. 2004; 112(1): 9–17.

[54] Darnerud PO. *Toxic effects of brominated flame-retardants in man and in wildlife.* Environ Int. 2003 29(6): 841–53.

[55] Darnerud PO, Eriksen GS, Johannesson T, Larsen PB, Viluksela M. *Polybrominated diphenyl ethers: occurrence, dietary exposure, and toxicology.* Environ Health Perspect. 2001; 109 Suppl 1:49–68.

[56] Hooper K., McDonald TA. *The PBDEs: An Emerging Environmental Challenge and Another Reason for Breast-Milk Monitoring Programs.* Environ. Health Perspect 2000; 108 (5): 387–392.

[57] Legler J, Brouwer A. *Are brominated flame retardants endocrine disruptors?* Environ Int. 2003; 29(6): 879–85.

[58] Branchi I, Capone F, Alleva E, Costa LG. *Polybrominated diphenyl ethers: neurobehavioral effects following developmental exposure.* Neurotoxicology. 2003; 24(3): 449–62.

[59] Eriksson P, Jakobsson E, Fredriksson A. *Brominated flame-retardants: a novel class of developmental neurotoxicants in our environment?* Environ Health Perspect. 2001; 109(9): 903–8.

[60] Viberg H, Fredriksson A, Jakobsson E, Orn U, Eriksson P. *Neurobehavioral derangements in adult mice receiving decabrominated diphenyl ether (PBDE 209) during a defined period of neonatal brain development.* Toxicol Sci. 2003; 76(1): 112–20.

[61] Hites RA. *Polybrominated diphenyl ethers in the environment and in people: a meta-analysis of concentrations.* Environ Sci Technol. 2004; 38(4): 945–56.

[62] Sjodin A, Patterson DG Jr, Bergman A. *A review on human exposure to brominated flame retardants – particularly polybrominated diphenyl ethers.* Environ Int. 2003; 29(6): 829–39.

[63] Darnerud PO, Eriksen GS, Johannesson T, Larsen PB, Viluksela M. *Polybrominated diphenyl ethers: occurrence, dietary exposure, and toxicology.* Environ Health Perspect. 2001; 109 Suppl 1:49–68.

[64] Olsen GW, Church TR, Miller JP, Burris JM, Hansen KJ, Lundberg JK, Armitage JB, Herron RM, Medhdizadehkashi Z, Nobiletti JB, O'Neill EM, Mandel JH, Zobel LR. *Perfluorooctanesulfonate and other fluorochemicals in the serum of American Red Cross adult blood donors.* Environ Health Perspect. 2003; 111(16): 1892–901

[65] Tomy GT, Tittlemier SA, Palace VP, Budakowski WR, Braekevelt E, Brinkworth L, Friesen K. *Biotransformation of N-ethyl perfluorooctanesulfonamide by rainbow trout (Onchorhynchus mykiss) liver microsomes.* Environ Sci Technol. 2004;38(3): 758–62.

[66] Hu W, Jones PD, DeCoen W, King L, Fraker P, Newsted J, Giesy JP. *Alterations in cell membrane properties caused by perfluorinated compounds.* Comp Biochem Physiol C Toxicol Pharmacol. 2003;135(1): 77–88.

[67] Austin ME, Kasturi BS, Barber M, Kannan K, MohanKumar PS, MohanKumar SM. *Neuroendocrine effects of perfluorooctane sulfonate in rats.* Environ Health Perspect. 2003; 111(12): 1485–9.

[68] Grasty RC, Grey BE, Lau CS, Rogers JM. *Prenatal window of susceptibility to perfluorooctane sulfonate-induced neonatal mortality in the Sprague-Dawley rat.* Birth Defects Res Part B Dev Reprod Toxicol. 2003; 68(6): 465–71.

[69] Lau C, Thibodeaux JR, Hanson RG, Rogers JM, Grey BE, Stanton ME, Butenhoff JL, Stevenson LA. *Exposure to perfluorooctane sulfonate during pregnancy in rat and mouse. II: postnatal evaluation.* Toxicol Sci. 2003; 74(2): 382–92.

[70] Thibodeaux JR, Hanson RG, Rogers JM, Grey BE, Barbee BD, Richards JH, Butenhoff L, Stevenson LA, Lau C. *Exposure to perfluorooctane sulfonate during pregnancy in rat and mouse. I: maternal and prenatal evaluations.* Toxicol Sci. 2003;74(2): 369–81.

[71] Hoff PT, Scheirs J, Van de Vijver K, Van Dongen W, Esmans EL, Blust R, De Coen W. *Biochemical effect evaluation of perfluorooctane sulfonic acid-contaminated wood mice (Apodemus sylvaticus).* Environ Health Perspect. 2004; 112(6): 681–6.

[72] Bailey RE. *Global hexachlorobenzene emissions.* Chemosphere. 2001; 43(2): 167–82. Review.

[73] Ma J, Venkatesh S, Jantunen LM. *Evidence of the impact of ENSO events on temporal trends of hexachlorobenzene air concentrations over the Great Lakes.* Sci Total Environ. 2003; 313(1–3): 177–84.

[74] Foster W, Chan S, Platt L, Hughes C. *Detection of endocrine disrupting chemicals in samples of second trimester human amniotic fluid.* J Clin Endocrinol Metab. 2000; 85(8): 2954–7.

[75] Kamarianos A, Karamanlis X, Goulas P, Theodosiadou E, Smokovitis A. *The presence of environmental pollutants in the follicular fluid of farm animals (cattle, sheep, goats, and pigs).* Reprod Toxicol. 2003;17(2): 185–90.

[76] Lorber M, Phillips L. *Infant exposure to dioxin-like compounds in breast milk.* Environ Health Perspect. 2002; 110(6): A325–32.

[77] Ezendam J, Staedtler F, Pennings J, Vandebriel RJ, Pieters R, Boffetta P, Harleman JH, Vos JG. *Toxicogenomics of subchronic hexachlorobenzene exposure in Brown Norway rats.* Environ Health Perspect. 2004; 112(7): 782–91.

[78] Michielsen CC, van Loveren H, Vos JG. *The role of the immune system in hexachlorobenzene-induced toxicity.* Environ Health Perspect. 1999; 107 Suppl 5: 783–92.

[79] Ralph JL, Orgebin-Crist MC, Lareyre JJ, Nelson CC. *Disruption of androgen regulation in the prostate by the environmental contaminant hexachlorobenzene.* Environ Health Perspect. 2003;111(4): 461–6.

[80] Erturk E, Lambrecht RW, Peters HA, Cripps DJ, Gocmen A, Morris CR, Bryan GT. *Oncogenicity of hexachlorobenzene.* IARC Sci Publ. 1986; (77): 417–23.

[81] Kenntner N, Krone O, Oehme G, Heidecke D, Tataruch F. *Organochlorine contaminants in body tissue of free-ranging white-tailed eagles from northern regions of Germany.* Environ Toxicol Chem. 2003; 22(7): 1457–64.

[82] Grasman KA, Fox GA. *Associations between altered immune function and organochlorine contamination in young Caspian terns (Sterna caspia) from Lake Huron, 1997–1999.* Ecotoxicology. 2001;10(2): 101–14.

[83] Grasman KA, Scanlon PF, Fox GA. *Geographic variation in hematological variables in adult and prefledgling herring gulls (Larus argentatus) and possible associations with organochlorine exposure.* Arch Environ Contam Toxicol. 2000; 38(2): 244–53.

[84] Grasman KA, Fox GA, Scanlon PF, Ludwig JP. *Organochlorine-associated immunosuppression in prefledgling Caspian terns and herring gulls from the Great Lakes: an ecoepidemiological study.* Environ Health Perspect. 1996; 104 Suppl 4: 829–42.

[85] AMAP 2004, *AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic*. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xvi+310 pp.

[86] Oskam IC, Ropstad E, Dahl E, Lie E, Derocher AE, Wiig O, Larsen S, Wiger R, Skaare JU. *Organochlorines affect the major androgenic hormone, testosterone, in male polar bears (Ursus maritimus) at Svalbard.* J Toxicol Environ Health A. 2003; 66(22): 2119–39.

[87] Sormo EG, Skaare JU, Jussi I, Jussi M, Jenssen BM. *Polychlorinated biphenyls and organochlorine pesticides in Baltic and Atlantic gray seal (Halichoerus grypus) pups.* Environ Toxicol Chem. 2003; 22(11): 2789–99.

[88] Verreault J, Skaare JU, Jenssen BM, Gabrielsen GW. *Effects of Organochlorine Contaminants on Thyroid Hormone Levels in Arctic Breeding Glaucous Gulls, Larus hyperboreus.* Environ Health Perspect. 2004; 112(5): 532–7.

[89] EB.AIR/WG.5/2003/3, 15 May 2003. United Nations Economic and Social Council 15 pgs.

[90] Kato Y, Kenne K. *Inhibition of cell-cell communication by commercial chlorinated paraffins in rat liver epithelial IAR 20 cells.* Pharmacol Toxicol. 1996;79(1): 23–8.

[91] Hallgren S, Darnerud PO. *Polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs) and chlorinated paraffins (CPs) in rats-testing interactions and mechanisms for thyroid hormone effects.* Toxicology. 2002; 177 (2–3): 227–43.

[92] Tomy GT, Fisk AT, Westmore JB, Muir DC. *Environmental chemistry and toxicology of polychlorinated n-alkanes.* Rev Environ Contam Toxicol. 1998; 158: 53–128.

[93] Campbell I, McConnell M. *Chlorinated paraffins and the environment. 1. Environmental occurrence.* Environ. Sci. Tech. 1980, 14:1209–1214.

[94] Nicholls CR. Alchin CR, Law RJ. *Levels of short and medium chain length polychlorinated n-alkanes in environmental samples from selected industrial areas in England and Wales.* Environ. Pollut. 2001, 114: 415–430.

[95] Z_SFT, *Screening of brominated flame retardants and chlorinated paraffins.* http://www.nilu.no/index.cfm, News release, 4 March, 2004.

[96] CACAR II 2003. *Canadian Arctic Contaminants Assessment Report II, Sources, Occurrence, Trends and Pathways in the Physical Environment.* 202 pgs.

[97] Stern G Evans M. *Persistent organic pollutants in marine and lake sediments.* In: CACAR II 2003 report. B.3 : 100–115.

[98] Bester K, Biselli S, Ellerichmann T, Huhnerfuss H, Moller K, Rimkus G, Wolf M. *Chlorostyrenes in fish and sediment samples from the river Elbe.* Chemosphere. 1998; 37(9–12): 2459–71.

[99] Kuehl DW, Kopperman HL, Veith GD, Glass GE. *Isolation and identification of polychlorinated styrenes in Great Lakes fish.* Bull Environ Contam Toxicol. 1976; 16(2): 127–32.

100 Li H, Drouillard KG, Bennett E, Haffner GD, Letcher RJ. *Plasma-associated halogenated phenolic contaminants in benthic and pelagic fish species from the Detroit River.* Environ Sci Technol. 2003; 37(5): 832–9.

101 de Solla SR, Bishop CA, Van der Kraak G, Brooks RJ. *Impact of organochlorine contamination on levels of sex hormones and external morphology of common snapping turtles (Chelydra serpentina serpentina) in Ontario, Canada.* Environ Health Perspect. 1998; 106(5): 253–60.

102 CACAR II 2003. *Canadian Arctic Contaminants Assessment Report II, Sources, Occurrence, Trends and Pathways in the Physical Environment.* 202 pgs.

103 Sanderson M, Weis IM. *Concentrations of two organic contaminants in precipitation, soils and plants in the Essex region of Southern Ontario.* Environ Pollut. 1989; 59(1): 41–54.

104 Marvin C, Painter S, Williams D, Richardson V, Rossmann R, Van Hoof P. *Spatial and temporal trends in surface water and sediment contamination in the Laurentian Great Lakes.* Environ Pollut. 2004; 129(1): 131–44.

105 Ofstad EB, Lunde G, Martinsen K, Rygg B. *Chlorinated aromatic hydrocarbons in fish from an area polluted by industrial effluents.* Sci Total Environ. 1978;10(3): 219–30.

106 Karl H, Lehmann I. *Organochlorine residues in the edible part of eels of different origins.* Z Lebensm Unters Forsch. 1993;197 (4): 385–8.

107 Hovander L, Malmberg T, Athanasiadou M, Athanassiadis I, Rahm S, Bergman A, Wehler EK. *Identification of hydroxylated PCB metabolites and other phenolic halogenated pollutants in human blood plasma.* Arch Environ Contam Toxicol. 2002; 42(1): 105–17.

108 Lommel A, Kruse H, Muller E, Wassermann O. *Organochlorine pesticides, octachlorostyrene, and mercury in the blood of Elb River residents, Germany.* Arch Environ Contam Toxicol. 1992; 22(1): 14–20.

109 Sandau CD, Ayotte P, Dewailly E, Duffe J, Norstrom RJ. *Pentachlorophenol and hydroxylated polychlorinated biphenyl metabolites in umbilical cord plasma of neonates from coastal populations in Quebec.* Environ Health Perspect. 2002; 110(4): 411–7.

110 Muir DC, Jones PD, Karlsson H, Koczansky K, Stern GA, Kannan K, Ludwig JP, Reid H, Robertson CJ, Giesy JP. *Toxaphene and other persistent organochlorine pesticides in three species of albatrosses from the north and south Pacific Ocean.* Environ Toxicol Chem. 2002; 21(2): 413–23.

111 Sandau, C.D., A.J. McAlees, R.J. Letcher, I.A.T.M. Meerts, B. Chittim, A. Brouwer, R.J. Norstrom. *Identification of 4-hydroxy-heptachlorostyrene in polar bear plasma and its binding affinity to transthyretin: a metabolite of octachlorostyrene?* Environ. Sci. Technol. 2000; 34(18): 3871–3877.

112 Kojima H, Katsura E, Takeuchi S, Niiyama K, Kobayashi K. *Screening for Estrogen and Androgen Receptor Activities in 200 pesticides by in vitro Reporter Gene Assays using Chinese Hamster ovary Cells.* Environ. Health Perspect. 2004; 112 :524–531.

113 Lorenzen A, Williams KL, Moon TW. *Determination of the estrogenic and antiestrogenic effects of environmental contaminants in chicken embryo hepatocyte cultures by quantitative-polymerase chain reaction.* Environ Toxicol Chem. 2003; 22(10): 2329–36.

114 Park D, Hempleman SC, Propper CR. *Endosulfan exposure disrupts pheromonal systems in the red-spotted newt: a mechanism for subtle effects of environmental chemicals.* Environ Health Perspect. 2001; 109(7): 669–73.

115 Pickford DB, Morris ID. *Effects of endocrine-disrupting contaminants on amphibian oogenesis methoxychlor inhibits progesterone-induced maturation of Xenopus laevis oocytes in vitro.* Environ Health Perspect. 1999; 107(4): 285–92.

116 Saiyed H, Dewan A, Bhatnagar V, Shenoy U, Shenoy R, Rajmohan H, Patel K, Kashyap R, Kulkarni P, Rajan B, Lakkad B. *Effect of endosulfan on male reproductive development.* Environ Health Perspect. 2003; 111(16): 1958–62.

117 Lafuente A, Gonzalez-Carracedo A, Romero A, Esquifino AI. *Methoxychlor modifies the ultradian secretory pattern of prolactin and affects its TRH response.* Med Sci Monit. 2003; 9(5): PI37–42.

118 Sinha N, Lal B, Singh TP. *Effect of endosulfan on thyroid physiology in the freshwater catfish, Clarias batrachus.* Toxicology. 1991;67(2): 187–97.

119 Zhou LX, Dehal SS, Kupfer D, Morrell S, McKenzie BA, Eccleston ED Jr, Holtzman JL. *Cytochrome P450 catalyzed covalent binding of methoxychlor to rat hepatic, microsomal iodothyronine 5'-monodeiodinase, type I: does exposure to methoxychlor disrupt thyroid hormone metabolism?* Arch Biochem Biophys. 1995 ;322(2): 390–4.

120Ayub S, Verma J, Das N. *Effect of endosulfan and malathion on lipid peroxidation, nitrite and TNF-alpha release by rat peritoneal macrophages.* Int. Immunopharmacol. 2003; 3 (13-14): 1819-28.

121 Guo TL, Zhang XL, Bartolucci E, McCay JA, White KL Jr, You L. *Genistein and methoxychlor modulate the activity of natural killer cells and the expression of phenotypic markers by thymocytes and splenocytes in F0 and F1 generations of Sprague-Dawley rats.* Toxicology. 2002; 2;172(3): 205–15.

122 Kang KS, Park JE, Ryu DY, Lee YS. *Effects and neuro-toxic mechanisms of 2, 2', 4, 4', 5, 5'-hexachlorobiphenyl and endosulfan in neuronal stem cells.* J Vet Med Sci. 2001; 63(11): 1183–90.

[123] Palanza P, Morellini F, Parmigiani S, vom Saal FS. *Prenatal exposure to endocrine disrupting chemicals: effects on behavioral development.* Neurosci Biobehav Rev. 1999; 23(7): 1011–27.

[124] CACAR II 2003. *Canadian Arctic Contaminants Assessment Report II, Sources, Occurrence, Trends and Pathways in the Physical Environment.* 202 pgs.

[125] Garbarino JR, Snyder-Conn E, Leiker TJ, Hoffman GL. *Contaminants in arctic snow collected over northwest Alaska Sea ice.* Water, Air Soil pollution 2002; 139: 183–214.

[126] Welch HE, Muir DC, Billeck BN. *Brown Snow: A long-range transport event in the Canadian Arctic.* Environ Sci Technol 1991; 25:280–28

[127] AMAP 2004, *AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic.* Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xvi+310 pp.

[128] Czaplicka M. *Sources and Transformations of chlorophenols in the natural environment.* Science of the Total Environment 2004, 322: 21–39.

[129] Elliott JE, Machmer MM, Henny CJ, Wilson LK, Norstrom RJ. *Contaminants in ospreys from the Pacific Northwest: I. Trends and patterns in polychlorinated dibenzo-p-dioxins and -dibenzofurans in eggs and plasma.* Arch Environ Contam Toxicol. 1998; 35(4): 620–31.

[130] Fries GF, Feil VJ, Zaylskie RG, Bialek KM, Rice CP. *Treated wood in livestock facilities: relationships among residues of pentachlorophenol, dioxins, and furans in wood and beef.* Environ Pollut. 2002; 116(2): 301–7.

[131] Huwe JK, Davison K, Feil VJ, Larsen G, Lorentzsen M, Zaylskie R, Tiernan TO. *Levels of polychlorinated dibenzo-p-dioxins and dibenzofurans in cattle raised at agricultural research facilities across the USA and the influence of pentachlorophenol-treated wood.* Food Addit Contam. 2004; 21(2): 182–94.

[132] National Toxicology Program. *NTP Toxicology and Carcinogenesis Studies of Pentachlorophenol (CAS NO. 87–86–5) in F344/N Rats (Feed Studies).* Natl Toxicol Program Tech Rep Ser. 1999; 483: 1–182.

[133] Jung J, Ishida K, Nishihara T. *Anti-estrogenic activity of fifty chemicals evaluated by in vitro assays.* Life Sci. 2004 ;74(25): 3065–74.

[134] Maenpaa KA, Penttinen OP, Kukkonen JV. *Pentachlorophenol (PCP) bioaccumulation and effect on heat production on salmon eggs at different stages of development.* Aquat Toxicol. 2004; 68(1): 75–85.

[135] Shore RF, Myhill DG, French MC, Leach DV, Stebbings RE. *Toxicity and tissue distribution of pentachlorophenol and permethrin in pipistrelle bats experimentally exposed to treated timber.* Environ Pollut. 1991;73(2):101–18.

[136] Bradman A, Barr DB, Claus Henn BG, Drumheller T, Curry C, Eskenazi B. *Measurement of pesticides and other toxicants in amniotic fluid as a potential biomarker of prenatal exposure: a validation study.* Environ Health Perspect. 2003; 111(14): 1779–82.

[137] Sandau CD, Ayotte P, Dewailly E, Duffe J, Norstrom RJ. *Pentachlorophenol and hydroxylated polychlorinated biphenyl metabolites in umbilical cord plasma of neonates from coastal populations in Quebec.* Environ Health Perspect. 2002; 110(4): 411–7.

[138] Sjoedin A, Hagmar L, Klasson-Wehler E, Bjoerk J, Bergman, A. *Influence of the consumption of fatty Baltic Sea fish on plasma levels of halogenated environmental contaminants in Latvian and Swedish men.* Environ Health Persp. 2000; 108: 1035–1041.

[139] Welch HE, Muir DC, Billeck BN. *Brown Snow: A long-range transport event in the Canadian Arctic.* Environ Sci Techbol 1991; 25:280–28.

[140] CACAR II 2003. *Canadian Arctic Contaminants Assessment Report II, Sources, Occurence, Trends and Pathways in the Physical Environment.* 200 pgs.

[141] EB.AIR/WG.5/2003/3, 15 May 2003. United Nations Economic and Social Council 15 pgs.

[142] Kojima H, Katsura E, Takeuchi S, Niiyama K, Kobayashi K. *Screening for Estrogen and Androgen Receptor Activities in 200 pesticides by in vitro Reporter Gene Assays using Chinese Hamster ovary Cells.* Environ. Health Perspect. 2004; 112 :524–531.

[143] Lavado R, Thibaut R, Raldua D, Martin R, Porte C. *First evidence of endocrine disruption in feral carp from the Ebro River.* Toxicol Appl Pharmacol. 2004; 196(2): 247–57.

[144] MacLellan KN, Bird DM, Fry DM, Cowles JL. *Reproductive and morphological effects of o,p'-dicofol on two generations of captive American kestrels.* Arch Environ Contam Toxicol. 1996; 30(3): 364–72.

[145] Wiemeyer SN, Clark DR Jr, Spann JW, Belisle AA, Bunck CM. *Dicofol residues in eggs and carcasses of captive American kestrels.* Environ Toxicol Chem. 2001; 20(12): 2848–51.

[146] MacLellan KN, Bird DM, Shutt LJ, Fry DM. *Behavior of captive american kestrels hatched from o,p'-dicofol exposed females.* Arch Environ Contam Toxicol. 1997; 32(4): 411–5.

[147] Guillette LJ Jr, Gross TS, Masson GR, Matter JM, Percival HF, Woodward AR. *Developmental abnormalities of the gonad and abnormal sex hormone concentrations in juvenile alligators from contaminated and control lakes in Florida.* Environ Health Perspect. 1994; 102(8): 680–8

[148] Linzey D, Burroughs J, Hudson L, Marini M, Robertson J, Bacon J, Nagarkatti M, Nagarkatti P. *Role of environmental pollutants on immune functions, parasitic infections and limb malformations in marine toads and whistling frogs from Bermuda.* Int J Environ Health Res. 2003; 13(2): 125–48.

[149] Settimi L, Masina A, Andrion A, Axelson O. *Prostate cancer and exposure to pesticides in agricultural settings.* Int J Cancer. 2003;104(4): 458–61.

[150] Kawamura Y, Sano H, Yamada T. *Migration of bisphenol A from can coatings to drinks.* J Food Hyg Soc Jpn 1999, 40: 158–165.

[151] Schonfelder G, Wittfoht W, Hopp H, Talsness CE, Paul M, Chahoud I. *Parent bisphenol A accumulation in the human maternal-fetal-placental unit.* Environ Health Perspect. 2002;110(11): A703–7.

[152] Takahashi O, Oishi S. *Disposition of orally administered 2,2-Bis(4-hydroxyphenyl)propane (Bisphenol A) in pregnant rats and the placental transfer to fetuses.* Environ Health Perspect. 2000; 108(10): 931–5.

[153] Takahashi O, Oishi S. *Testicular toxicity of dietary 2,2-bis(4-hydroxyphenyl)propane (bisphenol A) in F344 rats.* Arch Toxicol. 2001; 75(1): 42–51.

[154] Takahashi O, Oishi S. *Testicular toxicity of dietarily or parenterally administered bisphenol A in rats and mice.* Food Chem Toxicol. 2003; 41(7): 1035–44.

[155] Sato K, Matsuki N, Ohno Y, Nakazawa K. *Effects of 17beta-estradiol and xenoestrogens on the neuronal survival in an organotypic hippocampal culture.* Neuroendocrinology. 2002; 76(4): 223–34.

[156] Schrader TJ, Langlois I, Soper K, Cherry W. *Mutagenicity of bisphenol A (4,4'-isopropylidenediphenol) in vitro: effects of nitrosylation.* Teratog Carcinog Mutagen. 2002; 22(6): 425–41.

[157] Honkanen JO, Holopainen IJ, Kukkonen JV. *Bisphenol A induces yolk-sac oedema and other adverse effects in landlocked salmon (Salmo salar m. sebago) yolk-sac fry.* Chemosphere. 2004;55(2): 187–96.

[158] Z_SFT, *Screening of brominated flame retardants and chlorinated paraffins.* http://www.nilu.no/index.cfm, News release, 4 March, 2004.

[159] A process where water bodies receive excess nutrients that stimulate excessive plant growth. Enhanced plant growth reduces dissolved oxygen levels and can cause other organisms to die.

[160] Crumb D. *The effects of UV-b radiation and endocrine disrupting chemicals (EDCs) on the biology of amphibians.* Environ. Rev. 2001, Vol 1: 61–80.

[161] MacDonald RW, Morton B, Johannessen SC. *A review of marine environmental contaminant issues in the North Pacific: the dangers and how to identify them*. 2003 Environ. Rev. 11: 103–139

Appendix

Table 1.

Arctic species found to be contaminated with chemicals discussed in this report, regulations, and likely health effects.

Chemical or group	Arctic species detected in	Regulations	Indicated likely effects based on scientific studies*
Polychlorinated napthalenes (PCNs)	Beluga whale, grey seal, harbor porpoise, harp seal, polar bear, ringed seal	No restriction or ban on production or use, but worldwide production ended in general in the 1970–1980s.	Interferes with communication between cells, developmental injury to the embryo, general hormone disruption
Brominated flame retardants (BFRs)	Beluga whale, black guillemot, black-legged kittiwake, glaucous gull, golden eagle, grey seal, guillemot, harbor porpoise, harbor seal, northern fulmar, osprey, peregrine falcon, pike, pilot whale, polar bear, ringed seal, salmon, thick-billed murre, uvak, white-beaked dolphin, white-tailed sea eagle	EU ban on “octa” and “penta” forms, ban on some forms in electrical equipment by 2006. No ban on “deca” form.	Hormone disruption, neurobehavioral function, brain development, altered reproduction, cancer
Perfluorooctanesulfonate (PFOS) and/or Perfluorooctanoate (PFOA)	Arctic fox, black guillemot, common loon, crabs, fin whale, grey seal, harbor porpoise, harbor seal, hooded seal, mink, northern fulmar, northern fur seal, polar bear, ringed seal, shrimp, sperm whale, starfish, stellar sea lion, striped dolphin, white-beaked dolphin, white-sided dolphin	Voluntary phase-out of PFOS in 2001 by major manufacturer. No regulation of PFOA.	Memory decline, impaired learning, decreased reflex time response, altered cell communication, liver effects, cancer, developmental toxicity, hormone disruption
Chlorobenzenes	Alaskan murre, amphipod, bearded seal, beluga whale, black guillemot, black-legged kittiwake, blue whale, bowhead whale, common eiders, dovekie, glaucous gull, grey seal, grey whale, harbor porpoise, harbor seal, harp seal, hooded seal, humpback whale, ivory gull, minke whale, northern fulmar, polar bear, ringed seal, thick-billed murre, walrus, wolves	Banned in the United States and Europe in the 1970–1980s, hexachlorobenzene now banned under the Stockholm (POPs) Convention.	Hormone disruption, immune suppression
Chlorinated paraffins	Beluga whale, grey seal, ringed seal, walrus, fish	No restriction or ban on production or use.	Thyroid hormone function
Octachlorostyrene (OCS)	Polar bear, ringed seal	Never produced intentionally or commercially.	Alteration of secondary sex characteristics
Methoxychlor and/or Endosulfan pesticides	Bearded seal, blue whale, harp seal, humpback whale, minke whale, ringed seal	Restricted or banned in some countries.	Hormone disruption, reproductive and immune effects, neurotoxicity
Pentachlorophenol (PCP)	Golden eagle, osprey, peregrine falcon, white-tailed sea eagle	Purchase and use restricted since the 1980s.	Cancer, hormone disruption, reproductive and developmental effects

* Most studies done in the laboratory and not necessarily on arctic species, or effects known from human health studies.

Abbreviations used in appendix: d (detectable); n.d. (not detectable); kg (kilogram); kt (kiloton); mg/g (miligrams per gram); mg/kg (miligrams per kilogram); ng/ml (nanograms per mililiter); ng/g (nanograms per gram); mg/kg (miligrams per kilogram); mg/g (miligrams per gram); pg/g (picograms per gram); SD (standard deviation); SE (standard error); t (ton); µg/g (micrograms per gram); µg/kg (micrograms per kilogram); yr (year); POPs (persistent organic pollutants); EU (European Union).

Table 2.
Contaminant groups covered in the report

Product Acronym	CAS Registry Number (a unique numeric identifier)	Chemical Name or Group
PCNs	P07454000*	Polychlorinated naphthalenes
PFOS	754-91-6	Perfluorooctane sulphonate
PFOA	335-67-1	Perfluorooctanoicacid
FRs		Flame Retardants
o HBCD	o 25637-99-4	o Hexabromocyclododecane
o BPA	o 80-05-7	o Bisphenol A
o TBBPA	o 79-94-7	o Tetrabromobisphenol A
o PBDE	o No number assigned	o Polybrominated diphenyl ethers
Agrochemicals		
	o 72-43-5	o Methoxychlor
	o 115-29-7	o Endosulfan & Endosulfan Sulfate
	o 115-32-2	o Dicofol
SCCPs / MCPPs	CO4875000	Short/medium chain chlorinated paraffins
PCP	87-86-5	Pentachlorophenol
CBs	o 108-90-7	Chlorobenzenes
o Tri-CB	o 12002-48-1	o Trichloro
o Tetra-CB	o 12408-10-5	o Tetrachloro
o Penta-CB	o 608-935	o Pentachloro
o Hexa-CB	o 118-74-1	o Hexachloro
OCs		Organochlorines
	o 61593-44-0	o Octachlorostyrene
	o 29082-74-4	o Heptachlorostyrene (metabolite of OCS)

Table 3.
Summary of chemical production and uses

Product	Production	Scale/Time	Source/Function
Polychlorinated napthalenes o Tetra o Penta o Hexa o Hepta o Octa	Variable	Various times and countries	Multiple industrial applications: dielectrics for flame-proofing and insulating global in the energy, electric and automobile industries, preservatives with some fungicidal and insecticide activities for the wood, paper and textile industries, impregnate in paper inlays in gas-masks, additives in engines, lubricants for graphic electrodes, separators in batteries, in grinding wheel lubricants, high boiling capacity solvents, heat exchange fluids, dye carriers and in dye production, additives in rubber industry, flame retardant, moisture-proof sealant for chemically resistant gauge fluids and instrumental seals, casting materials for alloys, refractive index testing materials, masking compounds in electroplating, temporary binders in the manufacture of ceramic components, paint; sealant plasticizers, fungicides, insecticides; binding agents; combustion related emission (waste incineration)
Fluorinated Compounds o PFOS o PFOA	5.6 million pounds/yr USA	USA & others	Fire-fighting foams; herbicide and insecticide formulations; greases and lubricants, adhesives, paints, polishes; chemical intermediate; emulsifier; surface and stain protectors (kitchen ware, paper, food packaging, leather, carpet, upholstery); metal plating; photographic/semiconductor applications
Flame Retardants	Europe, Asia, N.America	Global	Interior household and office applications (monitors, televisions, computers, furniture, textiles, seat cushions)
o HBCD	Europe 9500 t/yr Asia 3900 t/yr N. America 2800 t/yr	Global	Additive flame retardant; polystyrene foam used as thermal insulation
o Bisphenol A		Global	Reactive flame retardant; also used in plastics, resins, rubber, and as a stabilizer.
o Tetrabromobisphenol A	Asia 89400 t/yr N. America 18000 t/yr Europe 11600 t/yr	Global	Reactive flame retardant; circuit boards in electronic equipment
o Polybrominated diphenyl ethers (PBDEs)	N. America 33100 t/yr, Asia 24650 t/yr, Europe 8360 t/yr	Global	Additive flame retardant
Chlorinated paraffins	15 000 tons t/yr Europe, 20 000 tons t/yr USA	Global, since 1930	Plasticisers in paint, sealants and adhesives; additive for metal working lubricants; flame retardant additive in rubber; PVC coated mats and wallpaper; leather goods such as shoes
Methoxychlor	0.14 – 0.27 kt/yr	USA 1988–92	Insecticide to protect crops
Endosulfan	0.81 kt USA	USA/ Canada 1990s	Broad spectrum insecticide
Dicofol		Global	Pesticide, especially against mites
Pentachlorophenol (PCP)	400 kt for wood treatment < 30000 t/yr global production	USA, cumulative 1970–1995	Restricted use pesticide; wood preservative for utility poles, railroad ties, and wharf pilings; industrial by-product.; produced during production of other chemicals; HCB is metabolized into PCP in mammals
Chlorobenzenes o Trichloro o Tetrachloro o Pentachloro o Hexachlorobenzene	12000 –96000 kg/yr emission (1990s)	USA 1933 – late 1970s	Intermediates in synthesis of pesticides; dielectric fluids; pyrotechnic composition for the military; raw material for rubber; wood preservative; waste incineration; releases from improper storage and disposal; remission of old contamination occurs from soil
Octachlorostyrene o Octachlorostyrene o Heptachlorostyrene			Produced during incineration and combustion processes involving chlorinated compounds.; by-product of magnesium

Table 4.
Perfluorooactane Sulfonate (PFOS) levels in arctic species

Species	References	Location	Tissue
Arctic fox	Martin et al. 2004	Canadian Arctic	Liver (range; ng/g wet weight) o 6.1–1400 o 250 (mean)
Black guillemot	Martin et al. 2004	Canadian Arctic	Liver (ng/g wet weight) o n.d.
Common loon	Martin et al. 2004	Canadian Arctic	Liver (range; ng/g wet weight) o 11–26 o 20 (mean)
Fin whale	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (ng/g wet weight) o <10
Grey seal	Giesy and Kannan 2001	Baltic Sea	Plasma (range; ng/ml) o 14–76 o 37 (mean)
Grey seal	Giesy and Kannan 2001	Canadian Arctic	Plasma (range; ng/ml) o 11–49 o 28 (mean)
Grey seal	Kannan et al. 2001 Kannan et al. 2002	Baltic Sea	Blood (mean +/-SD; ng/ml) o 42 + 21 o 43.9 + 19 o 25.5 + 9.6 Liver (range; ng/g wet weight) o 148–360 (male) o 140–290 (female)
Grey seal	Kannan et al. 2001 Kannan et al. 2002	Sable Island, Canada	Blood (mean +/-SD; ng/ml) o 27. + 11
Grey seal	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (range; ng/g wet weight) o 11–233 o 88 (mean) Kidney (range; ng/g wet weight) o 23–167 o 81 (mean)
Harbor porpoise	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (range; ng/g wet weight) o 12–395 o 93 (mean) Kidney (range; ng/g wet weight) o <10–821
Harbor porpoise	Van de Vijver et al. 2004	Northern Europe Iceland Norway Denmark German Baltic Sea	Liver (mean + SE; ng/g) o 38 + 14 o 213 + 195 o 270 + 171 o 534 + 357
Harbor seal	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (range; ng/g wet weight) o <10–532 Kidney (range; ng/g wet weight) o <10–489
Hooded seal	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (ng/g wet weight) o <10 Kidney (ng/g wet weight) o <10

Species	References	Location	Tissue
Mink	Martin et al. 2004	Canadian Arctic	Liver (range; ng/g wet weight) o 1.3–20 o 8.7 (mean)
Northern fulmar	Martin et al. 2004	Canadian Arctic	Liver (range; ng/g wet weight) o 1.0–1.5 o 1.3 (mean)
Northern fur seal	Kannan et al. 2001	Alaska	Liver (range; ng/g, wet weight) o <10–122 o 38 (mean) Blood (range; ng/ml) o <6–12 o 5 (mean)
Northern fur seal	Giesy and Kannan 2001	Coastal waters Alaska	Liver (range; ng/g, wet weight) o <35–120
Polar bear	Giesy and Kannan 2001	Alaska	Liver (range; ng/g, wet weight) o 180–680 o 350 (mean)
Polar bear	Kannan et al. 2001	Alaska	Liver (range; ng/g, wet weight) o 175–678 o 350 (mean) Blood (range; ng/ml) o 26–52 o 34 (mean)
Polar bear	Martin et al. 2004	Canadian Arctic	Liver (range; ng/g wet weight) o 1700-4000 o 3100 (mean)
Polar bear	Martin et al. 2002	Greenland	Liver (mean; ng/g wet weight) o 900
Ringed seal	Giesy and Kannan 2001	Canadian Arctic	Plasma (range; ng/ml) o <3–12
Ringed seal	Giesy and Kannan 2001	Baltic Sea	Plasma (range; ng/ml) o 16–230 o 110 (mean)
Ringed seal	Giesy and Kannan 2001	Norwegian Arctic	Plasma (range; ng/ml) o 5–14 o 9 (mean)
Ringed seal	Kannan et al. 2001; Kannan et al. 2002	Baltic Sea	Blood (mean +/-SD; ng/ml) o 133 + 47 o 92 + 81 o 242 + 142 Liver (range; ng/g wet weight) o 130–1100 (male) o 170–1000 (female)
Ringed seal	Kannan et al. 2001	Norwegian Arctic	Blood (mean +/-SD; ng/ml) o 8.1 + 2.5 o 10.1 + 2.7
Ringed seal	Martin et al. 2004	Canadian Arctic	Liver (range; ng/g wet weight) o 8.6–23 o 16 (mean)
Ringed seal	Martin et al. 2004	Canadian Arctic	Liver (range; ng/g wet weight) o 10–37 o 19 (mean)

Species	References	Location	Tissue
Sperm whale	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (range; ng/g wet weight) o 19–52 o 36 (mean) Kidney (ng/g wet weight) o 12
Stellar sea lion	Kannan et al. 2001	Alaska	Blood (ng/ml) o <6
Striped dolphin	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (ng/g wet weight) o 11 Kidney (ng/g wet weight) o <10
White-beaked dolphin	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (range; ng/g wet weight) o 14–443 o 132 (mean) Kidney (range; ng/g wet weight) o 13–290 o 87 (mean)
White-sided dolphin	Van de Vijver et al. 2003	Southern North Sea Coast	Liver (range; ng/g wet weight) o <10–26 Kidney (ng/g wet weight) o 18
Shrimp	Van de Vijver et al. 2003	North Sea	Soft Tissue (range; ng/g wet weight) o 19–520
Crab	Van de Vijver et al. 2003	North Sea	Soft Tissue (range; ng/g wet weight) o 24–877
Starfish	Van de Vijver et al. 2003	North Sea	Soft Tissue (range; ng/g wet weight) o 9–176

Table 5.
Perfluorooctanoate (PFOA) levels in arctic species

Species	Reference	Location	Tissue
Arctic fox	Martin et al. 2004	Canadian Arctic	Liver (ng/g wet weight) o <2.0
Black guillemot	Martin et al. 2004	Canadian Arctic	Liver (ng/g wet weight) o <2.0
Common loon	Martin et al. 2004	Canadian Arctic	Liver (ng/g wet weight) o <2.0
Mink	Martin et al. 2004	Canadian Arctic	Liver (ng/g wet weight) o <2.0
Harbor porpoise	Van de Vijver et al. 2004	Northern Europe o Iceland o Norway o Denmark o German Baltic Sea	Liver (ng/g wet weight) o < 62 (detection limit)
Northern fulmar	Martin et al. 2004	Canadian Arctic	Liver (ng/g wet weight) o <2.0
Polar bear	Martin et al. 2004	Canadian Arctic	Liver (range; ng/g wet weight) o 2.9–13 o 8.6 (mean)
Ringed seal	Martin et al. 2004	Canadian Arctic	Liver (ng/g wet weight) o <2.0

Table 6.
Brominated Flame Retardant (BFR) levels in arctic species

Species	Chemical	Reference	Location	Tissue
Beluga whale	PBDE o # 47 o # 66 o # 99 o # 100 o # 154	Wolkers et al. 2004	Norwegian Arctic	Blubber (geometric mean; ng/g lipid) o 161 (male) o 28.9 (female)
Beluga whale	PBDE	Stern and Ikonoumu 2000	Baffin Island, Canada	Blubber (range (year), pg/g lipid); estimated from graph; o 2000 – 3000 (1982) o 3000 – 4000 (1986) o 8000 – 10000 (1992) o 15000 – 16000 (1997)
Black guillemot	PBDE	Vorkamp et al. 2004	Greenland	Liver (range ng/g wet weight) o 0.79–3.0 (female) o 1.2–2.6 (male)
Black guillemot	PBDE	Vorkamp et al. 2004	Greenland	Liver (range ng/g wet weight) o 0.66–1.4 (juvenile) o 2.6–2.7 (male/1 year old) o 3.8–9.5 (female/adult) o 1.7–5.1 (male/adult)
Black guillemot	PBDE	Vorkamp et al. 2004	Greenland	Eggs (range ng/g wet weight) o 1.8–3.1
Black-legged kittiwake	PBDE	Braune and Simon 2004	Nunavut, Canada	Egg (ng/g wet weight) o 3
Glaucous gull	PBDE # 47 PBDE # 99	Herzke et al. 2003	Svalbard & Bear Island, Norway	Liver: (range; ng/g wet weight) o 2 –25
Golden eagle	TBBPA	Berger et al. 2004	Norway	Eggs (pg/g wet weight) o 13
Grey seals		Jansson et al. 1993 Sellstroem et al. 1993	Sweden	Blubber: (ng/g lipid) o 650 o 40
Guillemot	HBCD	Sellstrom et al. 2003*	Baltic Sea	Eggs (range; ng/g lipid) o 34–300
Guillemot	PBDE o # 47 o # 99 o # 100	Sellstrom et al. 2003*	Baltic Sea	Eggs (range; ng/g lipid) o 45–2700 o 2.0–320 o 1.0–540
Harbor porpoise	PBDE o # 28 o # 47 o # 100 o # 99 o # 154 o # 153	Boon et al. 2002	North Sea	Liver (range (mean); ng/g wet weight) o 5.0–86 (26) o 1.2–4877 (1331) o 0.3–2142 (562) o 0.5–2494 (715) o 0.2–1054 (331) o 0.1–504 (185)
Harbor porpoise	PBDE o # 28 o # 47 o # 100 o # 99 o # 154 o # 153	Boon et al. 2002	North Sea	Blubber (range (mean); ng/g wet weight) o 7.6–36 (22) o 245–1312 (864) o 47–479 (242) o 43–764 (406) o 12–801 (178) o 5.6–768 (149)

*long-term study 1996–2001

Species	Chemical	Reference	Location	Tissue
Harbor porpoise	PBDE	Covaci et al. 2002	North Sea	Blubber (range; µg/g lipid) o 0.41–5.81
Harbor seal	PBDE o # 28 o #47 o #100 o #99 o #154 o #153	Boon et al. 2002	North Sea	Liver (range (mean); ng/g wet weight) o 4.1–28 (16) o 95–5065 (1328) o 807–271 (83) o 29–1580 (454) o 2.6–163 (44) o 7.5–692 (222)
Harbor seal	PBDE o # 28 o #47 o #100 o #99 o #154 o #153	Boon et al. 2002	North Sea	Blubber (range (mean); ng/g wet weight) o 1.1–49 (9.7) o 57–9248 (1236) o 6.2–543 (82) o 11–3065 (396) o 2.4–83 (21) o 3.4–720 (98)
Northern fulmar	PBDE	Braune & Simon 2004	Nunavut, Canada	Liver (not detectable/detectable (year)) o n.d (1975) o d (1993) Egg (not detectable/detectable) o d
Osprey		Jansson et al 1993 Sellstroem et al. 1993	Sweden	Muscle: (ng/g lipid) o 1800 o 140
Osprey	TBBPA	Berger et al. 2004	Norway	Eggs(pg/g wet weight) o 10
Peregrine falcon	PBDE o # 47 o # 99 o # 100 o #153 o # 154 o # 183 o # 209	Lindberg et al. 2004	South Sweden	Eggs (range (mean); ng/g lipid) o 15–1600 (270) o 140–8000 (1100) o 100–2700 (450) o 500–3400 (1300) o 57–1100 (240) o 58–1300 (310) o <20–430 (130)
Peregrine falcon	PBDE o # 47 o # 99 o # 100 o #153 o # 154 o # 183 o # 209	Lindberg et al. 2004	North Sweden	Eggs (range (mean); ng/g lipid) o 22–3800 (360) o 110–9200 (860) o 77–5200 (540) o 270–16000 (1900) o 50–4400 (410) o 56–700 (270) o 28–190 (110)
Peregrine falcon	HBCD	Lindberg et al. 2004	South Sweden	Eggs (range; ng/g lipid) o 79–2400 o 520 (mean)
Peregrine falcon	HBCD	Lindberg et al. 2004	North Sweden	Eggs (range; ng/g lipid) o 34–590 o 220 (mean)
Peregrine falcon	TBBPA	Berger et al. 2004	Norway	Eggs (pg/g wet weight) o 4.2

Species	Chemical	Reference	Location	Tissue
Pike	PBDE	Burreau et al. 2004	Baltic Sea	Soft Tissue (median; ng/g wet weight)
	o # 28			o 2.0
	o # 35			o 1.2
	o # 49			o 11
	o # 47			o 71
	o # 66			o 1.0
	o # 100			o 22
	o # 99			o 5.6
	o # 155			o 1.5
	o # 154			o 8.0
	o # 153			o 1.6
	o # 183			o 0.038
	o # 209			o 1.7
	o # 203			o 0.043
Pilot whale	PBDE # 47 PBDE # 99	Lindstrom et al. 1999	Faroe Islands, Denmark	Blubber (mean; ng/g lipid): Young: o 3160 (males) o 3038 (females) Adult o 843 (females) o 1610 (males)
Polar bear	PBDE o # 47	Wolkers et al. 2004	Norwegian Arctic	Lipid (geometric mean; ng/g lipid) o 27.4 (male) o 45.6 (female)
Ringed seal	PBDE o # 47 o # 66 o # 99 o # 100	Wolkers et al. 2004	Norwegian Arctic	Lipid (geometric mean; ng/g lipid) o 18.3
Ringed seal	PBDE	Ikonomou et al. 2002	Holman Island, Canada	Blubber (mean; (year); pg/g lipid weight) Males, adult o 572 (1981) o 1863 (1991) o 3437 (1996) o 4622 (2000)
Ringed seal		Jansson et al 1993 Sellstroem et al. 1993	Sweden	Congener profile: tetra > penta > hepta > octa Blubber: (ng/g lipid) o 47 o 1.7
Salmon	HBCD	Remberger et al. 2004	Sweden	Homogenate (mean; µg/kg lw) o 51
Thick-billed murre	PBDE	Braune & Simon 2004	Nunavut, Canada	Egg (ng/g) d (1993)
Uvak	PBDE # 47 PBDE # 99 PBDE # 100 PBDE # 153	Christensen et al. 2002	Greenland	Liver: (mean; µg/kg wet weight) o 7.1 (female) o 12.0 (male)
White-beaked dolphin	PBDE	De boer et al. 1998	Netherlands	Blubber (range; µg/kg wet weight)
	o # 47			o 5500
	o # 99			o 1000
	o # 209			o 10
White-tailed sea eagle	TBBPA	Berger et al. 2004	Norway	Eggs (range; pg/g wet weight) o 7.2

Table 7.
Chlorobenzene levels in arctic species

Species	Chemical	Reference	Location	Tissue
Alaskan murre	Hexachlorobenzene	Vander pol et al. 2004	Alaska	Eggs: (mean + SE; ng/g; wet weight) o 62.2 + 20 o 83.7 + 16
Amphipod	Hexachlorobenzene	Blais et al. 2003	Canada	Soft tissue (range, ng/g wet weight) o 0.19–8.85
Bearded seal	Hexachlorobenzene	Muir et al. 2003	White Sea, Russia	Blubber (range; ng/g wet weight) o 5.4–6.7 (males)
Bearded seal	Pentachlorobenzene	Muir et al. 2003	White Sea, Russia	Blubber (range; ng/g wet weight) o 0.7–1.2 (males)
Bearded seal	Chlorobenzene o tri o tetra	Muir et al. 2003	White Sea, Russia	Blubber (range; ng/g wet weight) o 8.4–8.6(males) o 60–115 (males)
Bearded seal	Chlorobenzene o di o tri o penta o hexa	Hoekstra et al. 2003	Beaufort Chukchi Sea	Blubber (mean + SE; ng/g wet weight) o 57 + 9.5
Beluga whale	Chlorobenzene o di o tri o penta o hexa	Hoekstra et al. 2003	Beaufort Chukchi Sea	Blubber (mean + SE; ng/g wet weight) o 330 + 30
Black guillemot	Hexachlorobenzene	Vorkamp et al. 2004	Greenland	Eggs (range ng/g wet weight) o 19–32
Black guillemot	Hexachlorobenzene	Vorkamp et al. 2004	Greenland	Eggs (range ng/g wet weight) o 21–50
Black guillemot	Hexachlorobenzene	Vorkamp et al. 2004	Greenland	Liver (range ng/g wet weight) o 7.3–27 (female) o 12–29 (male)
Black guillemot	Hexachlorobenzene	Vorkamp et al. 2004	Greenland	Liver (range ng/g wet weight) o 6.8–14 (juvenile) o 11–14 (male/ 1 year old) o 14–50 (female/adult) o 8.5–51 (male/adult)
Black guillemot	Hexachlorobenzene	Buckman et al. 2004	Baffin Bay, Canada	Liver (mean + SE; ng/g wet weight) o 7.5 +1.2 Lipid (mean + SE; ng/g wet weight) o 222 + 25.4
Black legged kittiwake	Hexachlorobenzene	Buckman et al. 2004	Baffin Bay, Canada	Liver (mean + SE; ng/g wet weight) o 11.6 +1.1 Lipid (mean + SE; ng/g wet weight) o 186 +19.1
Blue whale	Hexachlorobenzene	Metcalfe et al. 2004	St.Lawrence, Canada	Blubber (mean + SD ; µg/kg lipid) o 225.8 +322.6 (males) o 90.0 + 32.9 (females) o 101.3 (calves)
Bowhead whale	Chlorobenzene	Hoekstra et al. 2002	Alaska	Blubber (geometric mean; ng/g wet weight) o 106

Species	Chemical	Reference	Location	Tissue
Bowhead whales	Chlorobenzenes	Hoekstra et al. 2002	Alaska	Blubber: (mean + SE; ng/g) o 100 + 7.0 Liver: (mean + SE; ng/g) o 3.1 + 0.3
Bowhead whales	Chlorobenzene o di o tri o penta o hexa	Hoekstra et al. 2003	Beaufort Chukchi Sea	Blubber (mean + SE; ng/g wet weight) o 196 + 20
Common eiders	Hexachlorobenzene	Franson et al. 2004	Alaska	Eggs: (mean + SE, µg/kg wet weight) o 7.47 + 0.432
Dovekie	Hexachlorobenzene	Buckman et al. 2004	Baffin Bay, Canada	Liver (mean + SE, ng/g wet weight) o 2.0 + 0.33 Lipid (mean + SE, ng/g wet weight) o 63.5 + 5.4
Glaucous gull	Hexachlorobenzene	Buckman et al. 2004	Baffin Bay, Canada	Liver (mean + SE, ng/g wet weight) o 26.1 +1.8 Lipid (mean + SE, ng/g wet weight) o 427 + 31.9
Gray whale	Hexachlorobenzene	Krahn et al. 2001	Pacific	Blubber (mean + SE; ng/g wet weight) o 100 + 41 (biopsy) o 230 + 32 (subsistence) o 350 + 130 (stranded; 1988–1991) o 510 + 130 (stranded; 1999)
Grey seal	Hexachlorobenzene	Hobbs et al. 2002	St.Lawrence, Canada	Blubber (mean + SE; ng/g lipid) o 54.1 + 28.6
Harbor porpoise	Chlorobenzene o tri o tetra o penta o hexa	Covaci et al. 2002	Belgian North Sea Coast	Liver (range; µg/g lipid) o nd–0.4 o 0.2–16.5 o 0.5–37.7 o 0.9–241.6
Harbor porpoise	Hexachlorobenzene	Borrell et al. 2004	Maniitsoq, Greenland	Blubber (mean + SE; mg/kg) o 0.07 (female; adult) o 0.21 + 0.1 (male; adult)
Harbor porpoise	Hexachlorobenzene	Borrell et al. 2004	Nuuk, Greenland	Blubber (mean + SE; mg/kg) o 0.103 + 0.09 (female; adult) o 0.30 + 0.11 (male; adult)
Harbor porpoise	Hexachlorobenzene	Borrell et al. 2004	Paamiut, Greenland	Blubber (mean + SE; mg/kg) o 0.16 + 0.06 (female; juvenile) o 0.08 (male; adult)
Harbor seal	Hexachlorobenzene	Hobbs et al. 2002	St.Lawrence, Canada	Blubber (mean + SE; ng/g lipid) o 5.67 + 2.38
Harp seal	Hexachlorobenzene	Muir et al. 2003	White Sea	Blubber (range; ng/g wet weight) o 17–77 (females)
Harp seal	Pentachlorobenzene	Muir et al. 2003	White Sea	Blubber (range; ng/g wet weight) o 5.3–20 (females)
Harp seal	Chlorobenzene o tri o tetra	Muir et al. 2003	White Sea	Blubber (range; ng/g wet weight) o 12–43 (females) o 51–199 (females)
Harp seal	Hexachlorobenzene	Hobbs et al. 2002	St.Lawrence, Canada	Blubber (mean + SE; ng/g lipid) o 110 + 54

Species	Chemical	Reference	Location	Tissue
Harp seal	Hexachlorobenzene	Zitko et al. 1998	Labrador, Canada	Blubber (median; ng/g wet weight) o 65 (juvenile-female) o 110 (juvenile-male)
Hooded seal	Hexachlorobenzene	Hobbs et al. 2002	St.Lawrence, Canada	Blubber (mean + SE; ng/g lipid) o 20.5 + 4.8
Humpback whale	Hexachlorobenzene	Metcalfe et al. 2004	St.Lawrence, Canada	Blubber (mean + SD; µg/g lipid) o 172.2 + 120.9 (calves) o 153.0 + 99.8 (adults)
Ivory gull	Hexachlorobenzene	Buckman et al. 2004	Baffin Bay, Canada	Liver (mean + SE; ng/g wet weight) o 18.3 + 2.6 Lipid (mean + SE, ng/g wet weight) o 396 + 108
Minke whale	Hexachlorobenzene	Hobbs et al. 2003	Greenland	Blubber (range; ng/g lipid) o <1 –544 (female) o <1–264 (male) o 6.16–112 (female)
Minke whale	Hexachlorobenzene	Hobbs et al. 2003	Jan Mayen, territory of Norway	Blubber (range; ng/g lipid) o 4.11– 205 (female) o 128–215 (male)
Minke whale	Hexachlorobenzene	Hobbs et al. 2003	North Sea	Blubber (range; ng/g lipid) o 2.09–234 (female) o 3.15–2060 (male)
Minke whale	Hexachlorobenzene	Hobbs et al. 2003	Lofoten, Norway	Blubber (range; ng/g lipid) o 56.6–213 (female) o 62–199 (male)
Minke whale	Hexachlorobenzene	Hobbs et al. 2003	Svalbard, Norway	Blubber (range; ng/g lipid) o 2.5–250 (female)
Minke whale	Hexachlorobenzene	Hobbs et al. 2003	Barents Sea	Blubber (range; ng/g lipid) o 25.6–334 (female) o 190–351 (male)
Northern fullmar	Hexachlorobenzene	Buckman et al. 2004	Baffin Bay, Canada	Liver (mean + SE; ng/g wet weight) o 17.4 + 1.6 Lipid (mean + SE, ng/g wet weight) o 410 + 29.9
Polar bear	Hexachlorobenzene	Corsolini et al. 2002	Alaska	Liver: (range ng/g wet weight) o <1.1–50 o 16 (mean)
Polar bear	Hexachlorobenzene	Kucklick et al. 2002	Alaska	Lipid: (mean + SE; ng/g; wet weight) o 183 +/- 153
Polar bear	Hexachlorobenzene	Lie et al. 2003	Norway and Russia	Blood (range; ng/g lipid weight) o 30–399 (Svalbard, Norway) o 95–1964 (Franz Josef land) o 86–974 (Kara Sea) o 119–345 (East Siberian Sea) o 125–844 (Chukchi Sea)
Ringed seal	Hexachlorobenzene	Kucklick et al. 2002	Alaska	Blubber (mean + SE; ng/g wet weight) o 17.4 +/- 10.1
Ringed seal	Hexachlorobenzene	Muir et al. 2003	White Sea	Blubber (range; ng/g wet weight) o 3.2–15 (males & females/juvenile) o 10–18 (females/juvenile/adult) o 8.9–19 (males/juvenile/adult)

Species	Chemical	Reference	Location	Tissue
Ringed seal	Pentachlorobenzene	Muir et al. 2003	White Sea	Blubber (range; ng/g wet weight) o 0.1–33 (males & females/juvenile) o 0.01–7.6 (females/juvenile/adult) o 0.01–6.6 (males/juvenile/adult)
Ringed seal	Chlorobenzene o tri o tetra	Muir et al. 2003	White Sea	Blubber (range; ng/g wet weight) o 7.5–22 (males & females/juvenile) o 42–158 (males & females/juvenile) o 20–98 (females/juvenile/adult) o 44–133 (females/juvenile/adult) o 15–60 (males/juvenile/adult) o 43–125 (males/juvenile/adult)
Ringed seal	Chlorobenzene o di o tri o penta o hexa	Hoekstra et al. 2003	Beaufort Chuchki Sea	Blubber (mean + SE; ng/g wet weight) o 48 + 7.8
Thick-billed murre	Hexachlorobenzene	Buckman et al. 2004	Baffin Bay, Canada	Liver (mean + SE; ng/g wet weight) o 9.8 +1.2 Lipid (mean + SE; ng/g wet weight) o 149 +13.6
Walrus	Chlorobenzenes	Muir et al. 2000	Greenland	Blubber (range; ng/g wet weight) o 3.68–33.1 (females; 1978) o 13.7–29.3 (females; 1988) o 4.47–43.6 (males; 1978) o 11.8–25.7 (males; 1988) o 38.4–82.3 (males; 1989)
Wolves	Hexachlorobenzene	Shore et al. 2001	Russia	Liver (range; ng/g wet weight) o 5.08 – 12.5

Table 8.
Polychlorinated naphthalene (PCN) levels in arctic species

Species	Reference	Location	Tissue
Beluga whale	Helm et al. 2002	Baffin Island, Canada	Blubber: (range; pg/g lipid weight) o 35.9–383 o penta > hexa > tetra
Grey seal	Koistininen (1990)* Paasiverta and Rantio (1991)* Jansson et al. (1993)	Baltic Sea	Blubber: (mean; ng/g lipid) o 20 o 0.05–0.2 (range) o 0.1 o 0.89 o hexa
Harbor porpoise	Fernandez et al. 1996	Baltic Sea	Blubber: (range; ng/g lipid) o 1.7–2.4 (male) o 2.0–2.4 (female) o tetra > hexa > penta

Species	Reference	Location	Tissue
Harbor porpoise	Ishaq et al. 2000	Sweden	Wet weight concentration (pg/g): Blubber (520) > fat (730) > liver (520) > brain (22) PCN congener abundance: Tetra: muscle, kidney, and brain Hexa: lipid rich tissue and liver No. 66/67= 80–100 % of total Blubber congener abundance: hexa > penta > tetra
Polar bear	Corsolini et al. 2002	Alaska	Liver : (mean (range); pg/g wet weight) o 370 (<0.1–945) penta > tetra > hexa
Ringed seal	Helm et al. 2002	Baffin Island, Canada	Blubber (range, pg/g lipid): o 35.4–71.3 o tetra > penta > tri
Ringed seal	Koistininen 1990* Paasiverta and Rantio 1991*	Baltic Sea	Blubber: (range, ng/g lipid) o n.d.–0.04
Ringed seal	Jansson et al. 1993	Svalbard, Norway	Blubber: (ng/g lipid) o 0.022 o tetra and penta

* cited in Helm et al. 2002

Table 9.
Short chained and medium chained chlorinated paraffins in arctic species

Species	Reference	Location	Tissue
Beluga whale	Tomy et al. 2000	Arctic	Blubber (mean + SD; µg/g wet weight) o 0.19 + 0.06
Beluga whale	Bennie et al. 2000	St.Lawrence, Canada	Liver (range, µg/g wet weight) o 1.1–59
Beluga whale	Bennie et al. 2000	St.Lawrence, Canada	Blubber (range, µg/g wet weight) o 6.4–166
Grey seal	Janson et al. 1993	Norway	Blubber (composite; ng/g lipid) o 280
Ringed seal	Janson et al 1993	Norway	Blubber (composite; ng/g lipid) o 130
Ringed seal	Tomy et al. 2000	Arctic	Blubber (mean + SD; µg/g wet weight) o 0.52 + 0.17
Walrus	Tomy et al. 2000	Arctic	Blubber (mean + SD; µg/g wet weight) o 0.43 + 0.06

Table 10.
Endosulfan in arctic species

Species	Reference	Location	Tissue
Bearded seal	Muir et al. 2003	White Sea, Russia	Blubber (range, ng/g wet weight) o 4.2–6.5 (males)
Harp seal	Muir et al. 2003	White Sea, Russia	Blubber (range, ng/g wet weight) o 2.7–11 (females)
Harp seal	Zitko et al. 1998	Labrador, Canada	Blubber (median, ng/g wet weight) o 0.04 (juvenile-female) o 0.04 (juvenile-male)
Minke whale	Hobbs et al. 2003	Greenland	Blubber (range; ng/g lipid) o <1–18.4 (female) o < 1–20.4 (female) o <1–7.93 (male)
Minke whale	Hobbs et al. 2003	Jan Mayen, territory of Norway	Blubber (range; ng/g lipid) o < 1–11.7 (female)
Bearded seal	Muir et al. 2003	White Sea, Russia	Blubber (range, ng/g wet weight)
Minke whale	Hobbs et al. 2003	Barents Sea	Blubber (range; ng/g lipid) o < 1–33.6 (female) o < 1–30. (male)
Ringed seal	Muir et al. 2003	White Sea	Blubber (range, ng/g wet weight) o < 0.1–9.3 (males and females/juvenile) o 0.1–0.5 (females /juvenile/adult) o < 0.1 (males, juvenile/adult)

Table 11.
Methoxychlor in arctic species

Species	Reference	Location	Tissue
Blue whale	Metcalfe et al. 2004	St.Lawrence, Canada	Blubber (mean + SD; µg/kg lipid) o 44.6 + 46.1 (males) o 7.3 + 13.5 (females) o 8.3 (calves)
Harp seal	Zitko et al. 1998	Labrador, Canada	Blubber (median, ng/g wet weight) o 0.41 (juvenile-female) o 0.68 (juvenile-male)
Humpback whale	Metcalfe et al. 2004	St.Lawrence, Canada	Blubber (mean + SD; µg/kg lipid) o 4.9 + 0.0 (calves) o 4.8 + 2.2 (adults
Minke whale	Hobbs et al. 2003*	Greenland	Blubber (range; ng/g lipid) o < 33.3–1730 (female) o < 87.7–1420 o < 177–1180 (male)
Minke whale	Hobbs et al. 2003*	Jan Mayen, territory of Norway	Blubber (range; ng/g lipid) o < 120–670 (female) o 325–1060 (male)
Minke whale	Hobbs et al. 2003*	North Sea	Blubber (range; ng/g lipid) o 81.5–733 (female) o 116–1490 (male)
Minke whale	Hobbs et al. 2003*	Lofoten, Norway	Blubber (range; ng/g lipid) o 162–922 (female) o 236–1260 (male)

Species	Reference	Location	Tissue
Minke whale	Hobbs et al. 2003*	Svalbard, Norway	Blubber (range; ng/g lipid) o 115–678 (female)
Minke whale	Hobbs et al. 2003*	Barents Sea	Blubber (range; ng/g lipid) o 104–2110 (female) o 483–944 (male)

* Sum of cis and trans chlordane, oxychlordane; cis and trans-nonachlor; heptachlor, heptachlor expoxide; and methoxychlor.

Table 12.
Pentachlorophenol in Norwegian birds of prey

Species	Reference	Location	Tissue
Golden eagle	Berger et al. 2004	Norway	Eggs (pg/g wet weight) o 267 o 125
Osprey	Berger et al. 2004	Norway	Eggs (pg/g wet weight) o 1350
Peregrine falcon	Berger et al. 2004	Norway	Eggs (pg/g wet weight) o 110
White-tailed sea eagle	Berger et al. 2004	Norway	Eggs (pg/g wet weight) o 173

Table 13.
Octachlorostyrene (or hydroxheptachlorostyrene) levels in arctic species

Species	Reference	Location	Tissue
Polar bear*	Sandau et al. 2000	Canada	Plasma (mean + SD; ng/g wet weight) o 9.11 +3.85 Liver (mean + SD; ng/g wet weight) o 156 + 115 Fat tissue (mean + SD; ng/g wet weight) o 14 + 12
Polar bear	Sandau et al. 2000	Canada	Plasma (mean + SD; ng/g wet weight) o 0.348 + 0.188
Ringed seal*	Sandau et al. 2000	Canada	Plasma (mean + SD; ng/g wet weight) o 0.266 + 0.086
Ringed seal*	Sandau et al. 2000	Canada	Plasma (mean + SD; ng/g wet weight) o 0.062 + 0.023

* Hydroxyheptachlorostyrene

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