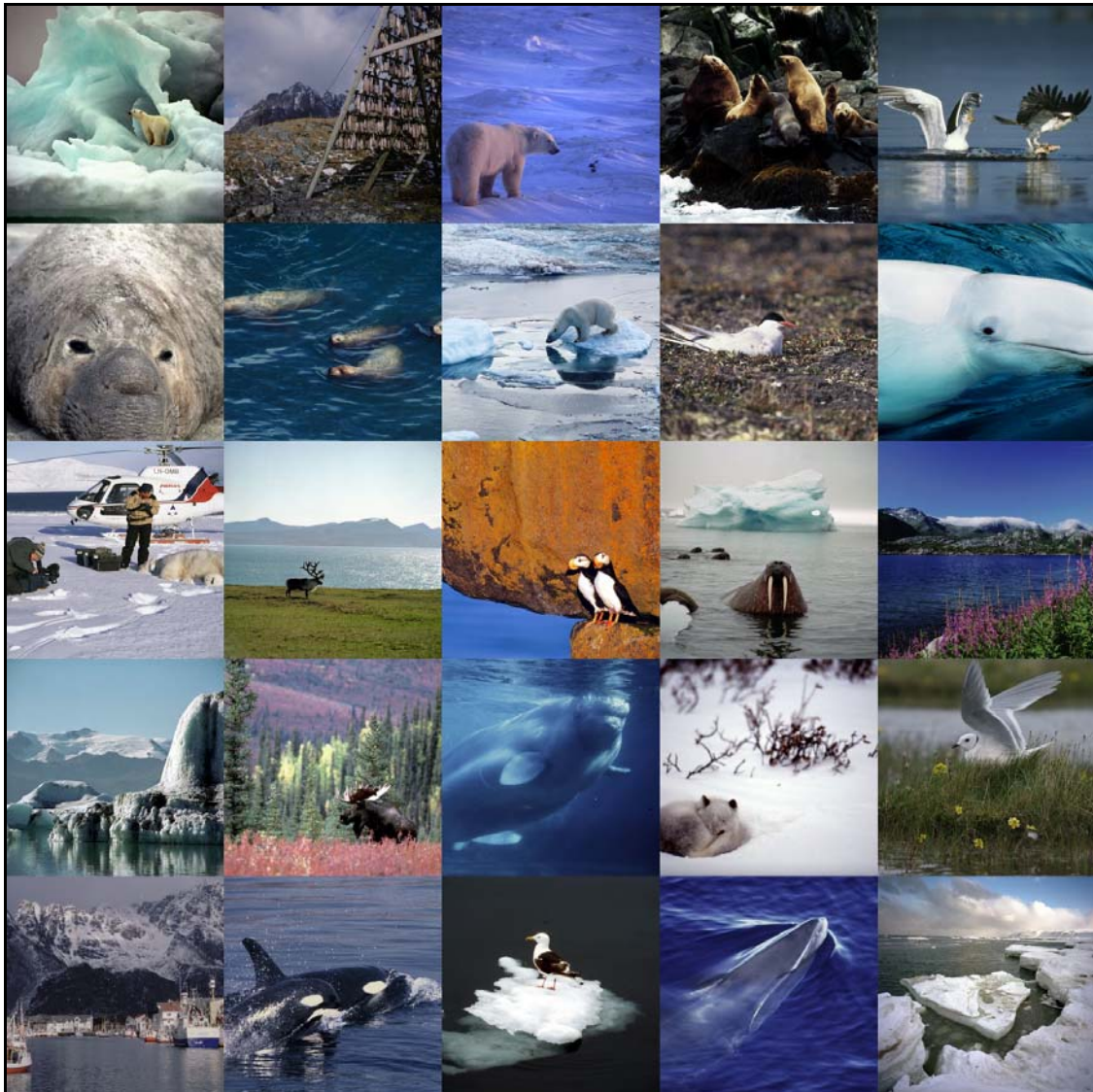


Killing them softly....

Health effects in arctic wildlife linked to chemical exposures

WWF International Arctic Programme and WWF-DetoX



Text: Brettania Walker

Editing: Julian Woolford and Noemi Cano

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- 7- CREDIT: (c) WWF-Canon / Kevin SCHAFER. *Eumetopias jubatus* Steller's sealion Several swimming in the Bering Sea Round Island, Walrus Islands, Alaska, USA
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- 9- CREDIT: (c) WWF-Canon / Hartmut JUNGIUS. Breeding Arctic Tern (*Sterna paradisaea*) in the Terpei Tumus Reserve. Siberian Coastal Tundra, Republic of Sakha, Russian Federation
- 10- CREDIT: (c) WWF-Canon / Kevin SCHAFER. Beluga *Delphinapterus leucas* Arctic Ocean, Arctic.
- 11- CREDIT: (c) WWF-Canon / Tanya PETERSEN. Polar bear *Ursus maritimus* WWF-related activities -, Svalbard and Jan Mayen Islands (NO), Norway.
- 12- CREDIT: (c) WWF-Canon / Wim VAN PASSEL. Reindeer (Europe) *Rangifer tarandus* Arctic. Spitsbergen, Svalbard and Jan Mayen Islands (NO), Norway.
- 13- CREDIT: (c) WWF-Canon / Kevin SCHAFER. Horned puffin *Fratercula corniculata* Bering Sea, Arctic Ocean, Arctic.
- 14- CREDIT: (c) WWF-Canon / Wim VAN PASSEL. Atlantic walrus *Odobenus rosmarus rosmarus* Arctic. Spitsbergen, Svalbard and Jan Mayen Islands (NO), Norway.
- 15- CREDIT: (c) WWF-Canon / WWF-Norway/Frode Johansen. Fireweed *Epilobium angustiflorum* Lofoten, Nordland, Norway.
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- 20- CREDIT: (c) WWF-Canon / Hartmut JUNGIUS. Russian Federation. Ross's Gull (*Rhodostethia rosea*), endemic to the Arctic.
- 21- CREDIT: (c) WWF-Canon / WWF-Norway/Frode Johansen. Harbour of Henningsvær, Lofoten, Norway.
- 22- CREDIT: (c) WWF-Canon / William W. ROSSITER. Killer whale *Orcinus orca* Puget Sound, Port Susan, Washington, USA / United States of America.
- 23- CREDIT: (c) WWF-Canon / Kevin SCHAFER. Slaty-backed gull *Larus schistisagus* Bering Sea, Arctic Ocean, Arctic. Kamchatka, Siberia, Russian Federation.
- 24- CREDIT: (c) WWF-Canon / Morten LINDHARD. Minke whale *Balaenoptera acutorostrata* Norway.
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Contents

Introduction	4
Background.....	4
Health effects	5
Arctic mammals	6
Polar bears	6
Seals and Sea lions	8
Beluga whales.....	12
Birds.....	15
Conclusion	18
Appendix	20
References	21

Introduction

Imagine a region where the sun is hardly seen for months at a time, while during other months the sun never sets, a region where snow and ice are essential to life. The Arctic is a beautiful but unforgiving and harsh environment that resembles a frozen desert. In the tundra area, which means "barren land", the ground is permanently frozen and no trees can grow. Every possible advantage and fine-tuned adaptation is needed for animals and people to successfully call this region home. But amazingly, considering these conditions, the Arctic is a region full of life. It is the home to hares, lemmings, birds, wolverines, reindeer, caribou, musk oxen, seals, walrus, whales, arctic foxes, wolves, and polar bears. This region has also been the home to people for many thousands of years, today the Arctic is inhabited by about 4 million people.

While the region may seem tough and well-isolated, it is also surprisingly fragile and connected to the rest of the planet. Despite its remote location, the Arctic is still affected by human activities including global pollution and climate change. Although some pollutants are found naturally in the region or come from local industry, many pollutants of concern are not produced or even widely used in the Arctic. Of special concern are the human-made industrial and agricultural chemicals that travel north largely via air and water currents. Highly volatile chemicals evaporate into the air, travel long distances, and eventually condense and reach the ground as rain or snow. Pollutants are also transported via ocean and river currents, melting sea-ice, and migratory species.

In February 2005, WWF released a report on hazardous chemicals that are reaching the Arctic. This new report summarizes something different and

very important: it discusses not which chemicals are found in the Arctic and at what levels, but rather focuses on what is known about *actual health problems* in arctic mammals and birds linked to chemical exposures.

Background

Although our knowledge is constantly improving, we are still far from fully understanding how chemicals impact the health of wild animals in their natural environments. Only fairly recently have compelling studies come forth showing biological changes and potential health problems are in fact occurring in relation to chemical exposures in arctic species. While these studies are not proof of direct cause-and-effect relationships, they undoubtedly are reason for concern that chemicals are already harming arctic wildlife.

In recent years, scientists' means to detect chemicals have greatly improved. With better testing capabilities came many studies on *levels* of contaminants in wildlife and in humans. However, only in the past few years (approximately 1997 to present) have the first indications of actual *damage* from chemicals become available in regard to arctic species. Biomarkers¹ are often used as indicators of harmful effects. (e.g. immune parameters; thyroid and stress hormone levels, vitamin A levels, P450 enzyme induction²) Alterations in immune and hormone function or levels and vitamin A levels have been the most frequently studied biomarkers of arctic marine mammal health thus far.

For practical and ethical reasons, scientists often study wild animals that have stranded or died naturally. In these cases, information is not available on important factors such as the animal's normal nutritional, immunological, and reproductive status nor do these sick or dead animals adequately represent the larger population of the species. Like

humans, free-ranging animals are exposed to many threats that can affect their health, including combined exposures of many different chemicals. These chemical mixtures make it difficult to differentiate the health effect from one particular chemical from another. Research is also complicated by the fact that basic information on normal metabolism or immune function is almost non-existent for many wild animals. For these reasons, the strongest indications of chemicals' health effects most often comes from laboratory studies using cell culture, tissues, or non-arctic species.

So when we try to definitively answer the question of how exactly chemicals are affecting arctic polar bears, seals, and whales, for example, we find that there is not as clear of an answer as we'd like. Regulators and the public must understand that cause-and-effect relationships can not be elucidated without controlled, captive animal experiments. These are the limitations we have to live with. However, as this report will show, research limitations are *not* justification for indifference to the heavily accumulating warnings that chemicals are already a serious global threat.

Health effects

The main effects that have been studied in arctic wildlife thus far are disturbances of the hormone and immune systems, vitamin A levels, and bone mineral density.

The word hormone comes from the Greek word *horman*, meaning "to set in motion." This is exactly what hormones do—they are chemical messengers that activate an enormous range of events essential for basic health and survival. This system regulates the secretion of hormones that then control almost every body function imaginable—including the

internal organs, neurological function, immune system, hunger and thirst, metabolism, growth, fertility, gender, sex drive, pregnancy, day and night cycles, behavior, and the ability to react to environmental conditions. Thyroid hormones play a role in metabolism regulation, growth, neural/brain development, and reproduction. In cetaceans,³ thyroid hormones are also thought to play a role in regulating heat loss, hair growth, and molting.⁴ Reproductive hormones may regulate the gender of the baby and the proper development of the sex organs.

Some chemicals⁵ can interfere with or mimic natural hormones. Chemicals can alter the hormone system—by affecting production of the normal hormone, preventing transport or binding of the hormone, eliminating the normal hormone or reducing its quantity, or mimicking and displacing a normal hormone. In wildlife, reproductive changes, egg shell thinning in birds, and impaired immune function have been causally related to hormone disrupting chemicals. While hormone disruption has been documented in marine mammals, birds and fish in relation to chemical exposures,^{6,7,8} causal links have not yet been established for most arctic species. Notable exceptions include harbor seals studied under field or semi-field conditions where chemicals called PCBs caused immune and reproductive problems,⁹ and glaucous gulls, fed either control or contaminated eggs, where those gulls fed the contaminated eggs showed chemical changes in their DNA.¹⁰

Alterations in the immune system may result in reduced resistance to disease, increased virus levels, and increased rates of disease transmission within and among populations. It is well known that organochlorine chemicals can adversely affect both the cellular and humoral branches of immunity.¹¹ There are 3

major known classes of persistent organic pollutants that are toxic to the immune system: polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs).

Retinol, also known as vitamin A, is a micronutrient required by almost every tissue in the body. Retinol regulates a range of functions including growth and development and is essential for normal vision, reproduction, cell differentiation, and immunity. Retinol storage and metabolism are known to be affected by metals such as cadmium^{12,13} and by other chemicals such as PCBs and dioxins.^{14,15} A 2001 review¹⁶ pointed out that, in laboratory studies, contaminants are known to disrupt vitamin A physiology and alter the distribution of its essential metabolites and that, in the wild, complex environmental mixtures of chemicals also interfere with vitamin A dynamics in free-ranging marine mammals and other fish-eating wildlife.

Bone mineral density is a measure of the amount of calcium in the bones and the thickness of the bones. Bone mineral density reflects general bone health and is correlated with bone strength and the ability to bear weight. Some hormones (e.g. testosterone and estrogen) that may be disrupted by chemicals are known to regulate bone health.

The greatest concern is that contaminant mixtures may interact with other natural stressors in the Arctic, (e.g. climate change, habitat loss, reduced food supply) resulting in wildlife having reduced ability to successfully deal with every day challenges, (e.g. harsh winters, hibernation, feeding, nesting predation) leading to reduced reproductive capacity, increased likelihood of disease or even death, and population declines.

Arctic mammals

Marine mammals eat invertebrates, fish, birds and other mammals. Increasing accumulation of chemicals up the food chain results in the highest chemical levels generally being found in top predators (e.g. polar bears). Arctic mammals have several characteristics that make them especially vulnerable to chemical exposures: a large amount of body fat and fatty diets (many chemical are preferentially stored in fat), long periods of lactation during early development, sexual maturity that takes 3 to 4 years, long reproductive cycles, and long life spans resulting in chronic chemical exposures over many years. The period during early development when young mammals are nursing is critical because lactation results in large chemical transfers from the mother to the offspring via fatty milk.

Developmental and trans-generational effects may even occur many years after the initial exposures. Many fish and seafood species eaten by arctic mammals are also consumed by people (e.g. fish, crabs, squid, and mollusks). These mammals are, therefore, also important as sentinels for human exposures and health.

Polar bears (*Ursus maritimus*)

The polar bear is the top arctic predator aside from humans. Females usually give birth to cubs every 3 years and nurse the young for up to 2 years, transferring contaminants to the offspring. The polar bears' diet consists mainly of high trophic level ringed, bearded and harp seals and polar bears are known to preferentially eat the fatty blubber of their prey. Arctic-wide studies have confirmed polar bears are heavily contaminated with chemicals, especially organochlorines and PCBs. In some locations, such as Svalbard, Norway, PCB levels are considered to be alarmingly high.¹⁷ Newer chemicals, such as the PBDE brominated flame

retardants (BFRs) and fluorochemicals such as PFOS, are also showing up in polar bears.^{18,19,20,21} The physical and chemical properties and use patterns of BFRs are similar to PCBs and, thus, it is suspected that BFRs may be transported long distances to the Arctic in a similar manner as PCBs.²²

Information on health effects in polar bears linked to chemical exposures became available in 2000 when a study²³ reported immunotoxic effects in Svalbard polar bears. The bears had IgG antibody²⁴ levels that were negatively correlated with PCBs and HCB.²⁵ In 2001, thyroid hormone and vitamin A alterations were also shown to be associated with organochlorine exposures in Svalbard polar bears.²⁶ Then in 2003, a study²⁷ reported male Svalbard polar bears had pesticide and PCB levels associated with changes in testosterone concentrations. The researchers concluded chronic exposures to organochlorines in male polar bears could possibly aggravate reproductive toxicity. The same year, a study²⁸ of female Svalbard polar bears with offspring (cubs or yearlings) led to a similar conclusion, reporting associations between the female reproductive hormone progesterone²⁹ and PCB levels.

In 2004, a study reported that polar bears in East Greenland from a polluted period (1966-2002) had decreased bone mineral density when compared to bears from a relatively pre-polluted period (1892-1932).³⁰ High PCB and CHL levels associated with reduced skull bone mineral density in sub-adults and DDT and dieldrin³¹ were associated with reduced skull bone mineral density in adult males. The researchers stated bone mineral density reductions may be due to effects on the hormone system caused by organochlorine exposure, PBDEs, and also climate change. These

results were consistent with a 2003 study³² of grey seals.

A 2004 study³³ found that PCBs were correlated with thyroid hormones in both male and female polar bears from the Barents Sea region. PCBs were related to 5 thyroid hormone variables in female polar bears and to 2 in males. The researchers suggested the learning ability and behavior of the bears may be impacted and that reproduction could also be affected via hormone disruption. Vitamin A was also studied but the researchers found no correlations between vitamin A concentrations and PCBs. Another study³⁴ of Svalbard, Norway, polar bears investigated associations between cortisol³⁵ and organochlorine exposure and reported that high concentrations of organochlorines may alter cortisol concentrations in polar bears. In a 2004 study³⁶ of both Svalbard, Norway, and Churchill, Canada, polar bears, organochlorines were associated with the bears' ability to produce antibodies that fight infections.

In 2005, a study³⁷ was published in which researchers examined East Greenland polar bear samples for cell and tissue changes associated with organohalogen contaminants. The study reported that the organohalogen exposure concentrations are unlikely to have resulted in harmful effects at the tissue level, although other chemicals (e.g. SigmaCHLs, SigmaHCHs, HCB and dieldrin) were related to increased numbers of follicles in the spleen.³⁸ Also in 2005, a study was published on a second stage of research investigating organochlorine exposures in polar bears from Svalbard, Norway, and from the western Hudson Bay area of Churchill, Canada.³⁹ Results showed high levels of organochlorine exposure were associated with specific lymphocyte⁴⁰ proliferation responses and some aspects of cell-mediated immunity.⁴¹

This could have implications for proper antibody⁴² and lymphocyte production. When bears were challenged with tetanus toxoid⁴³ following vaccination, bears with higher levels of PCBs plus organochlorines had diminished immune responses.

Overall, these polar bear studies support the conclusion that organochlorines are immunotoxic to polar bears, potentially leading to impaired resistance to fight off infectious diseases, and that hormone disruption is also a concern.

Recent studies show that concentrations and geographical trends of PBDEs and HBCD (brominated flame retardants) in polar bears parallel PCB and perfluorinated acid concentrations and that eastern North America and western Europe are the likely source regions for these chemicals.^{44,45} However, no studies have yet investigated the health effects of newer chemicals, such as brominated flame retardants or fluorochemicals, in arctic species.

Seals and Sea lions

In addition to pollution, climate change and commercial fishing, arctic seals face another threat—predation—as they share their habitat with humans, foxes, wolves, dogs, and polar bears. Increasing numbers of studies indicate contaminants may be impacting marine mammal health, and possibly contributing to population declines.⁴⁶ PCBs have been shown to affect vitamin A maintenance in adult as well as neonatal seals.⁴⁷

Phocid⁴⁸ seal pups have a short lactation period of between 4-60 days. During lactation the mother eats less or fasts, resulting in fat from her blubber being mobilized and going into the milk. A study of harbor seal pups from Svalbard, Norway, showed contaminants in the mother's milk and contaminants detected in the pups are

similar, suggesting that young pups are probably unable to metabolize contaminants and consequently accumulate all ingested chemicals.⁴⁹ Seals that eat fish, have a long life span, accumulate fat reserves and are high on the food chain build up contaminants and are, therefore, good sentinels for chemical effects on immune function.⁵⁰ Known pinniped⁵¹ effects associated with persistent contaminants include skeletal deformities, adrenal gland pathology,⁵² uterine blockage, impaired reproduction, P450 enzyme induction, immunotoxicity, and changes in vitamin A and thyroid hormone levels. Recent pinniped mass deaths have led to the speculation that persistent contaminants are affecting the immune system of wildlife to an extent that makes animals more susceptible to infections.⁵³

This section summarizes what is known about effects related to chemical exposures in some seal and sea lion species whose range includes the Arctic.

Harbor seals (*Phoca vitulina*)

There has been much interest in whether contaminants played a role in the mass deaths of seals infected with morbillivirus⁵⁴ in northwestern Europe in the 1980s. A study that followed the deaths of more than 17,000 North and Baltic Sea harbor seals led to the conclusion that a morbillivirus was the cause.⁵⁵ Chemicals including PCBs, PCDDs, and PCDFs are known to be immunotoxic at low doses in studies of laboratory animals. In harbor seals, immunotoxicity has also been documented in juvenile captive harbor seals fed Baltic Sea herring for 2.5 years in a semi-field research design that limited other variables that might have affected immune function. The control group was fed herring from the less contaminated Atlantic Ocean. Immune differences were first noted 4-6 months

after the start of the study. PCBs were thought to be responsible for the effects seen on immunity (impaired natural killer cell⁵⁶ and T cell⁵⁷ function), which may lead to decreased resistance to viral infections. This may indicate the morbillivirus infections and mass deaths of harbor seals in the 1980s were exacerbated by chemical exposures.^{58,59,60,61} Follow up experiments⁶² in rats exposed to contaminated herring from the earlier seal study showed that the herring was also immunotoxic to rats. Then a 2002 *in vitro* study⁶³ of harbor seals from north-central California showed a relationship between benzo(a)pyrene, a cancer causing substance, and suppression of T cell division. Alterations in T cell function and cell-mediated immunity could make these seals less resistant to viral infections. Researchers have concluded that mixtures of environmental contaminants including PCBs, PCDFs, and PCDDs may present a risk of immune toxicity to wild seals.⁶⁴

The San Francisco Bay, California, harbor seal population faces habitat loss and degradation in addition to environmental pollution. PBDE brominated flame retardant levels in the San Francisco Bay harbor seals have increased dramatically over the decade prior to 2002.⁶⁵ In a 2005 study,⁶⁶ researchers measured blood levels of PCBs, DDE, and PBDEs in free-ranging San Francisco Bay harbor seals. When compared with older samples, the researchers found PCB levels in harbor seal blood had decreased during the past decade, but were still at levels potentially high enough to lead to harmful reproductive and immune problems. The researchers also noted a positive association between the number of white blood cells and chemicals (i.e. PBDEs, PCBs, and DDE) and an inverse relationship between the number of red blood cells and PBDE

levels. The scientists noted that although these findings do not necessarily signify disease, they should be seen as indications of contaminant-induced changes, which might lead to increased rates of infection and anemia in seals exposed to high levels of chemicals.

Another 2005 study⁶⁷ of harbor seals investigated immune function in response to PAH and PCB exposures. The researchers noted altered lymphocyte function in relation to the chemical exposures, via disruption of T cell receptor signaling and cytokine⁶⁸ production. Findings were consistent with previous human and rodent studies. In addition to persistent organic chemicals, a recent study⁶⁹ provided the first evidence that exposure to metals (e.g. lead, tin, aluminum, chromium, nickel) may also be impacting the health of harbor seals from the North Sea. A relationship was noted between the T-lymphocyte immune response and the level of metals in the blood.

Harbor seal pups from southern British Columbia, Canada, were temporarily kept in captivity for an immune toxicity study.⁷⁰ A significant correlation was observed between PCB blubber levels and both T and B-cell lymphocyte proliferation. Results showed that PCBs, in particular, were associated with changes in lymphocyte proliferation, with implications for increased disease susceptibility. Another study⁷¹ of British Columbia harbor seals showed PBDEs are an emerging problem that may affect the health of this species.

Research has suggested harbor seals may be a species that is particularly vulnerable to the immunotoxic effects of contaminants. In a study⁷² of harbor and grey seals, PCBs were linked to differences in immune function for harbor seals, but not for grey seals. Another 2005 study⁷³ reported for the

first time on levels of fluorinated chemicals in stranded harbor seals from the Dutch Wadden Sea, a nursery and feeding ground for seals whose range also includes the North Sea. PFOS was the main compound detected in all seal samples. Although no health effect studies have yet been done for arctic species in relation to fluorochemicals, this study is worrying. The Wadden Sea harbor seal population has already been reduced by about 25% as a result of hunting and virus outbreaks and fluorinated chemicals, which accumulate in the liver and kidneys, have been linked to liver toxicity, developmental problems, and postnatal deaths in animal studies.⁷⁴

Ringed seals (*Phoca hispida*)

Arctic ringed seals are also contaminated with fluorochemicals. A 2005 study⁷⁵ of ringed seals from Greenland determined PFOS was the main fluorochemical found. A significant temporal trend with increasing chemical concentrations was noted in both the East and West Greenland sampling locations. The range of the Saimaa ringed seals (*Phoca hispida saimensis*) includes Lake Haukivesi in Finland. This population is in decline. Between 1981-2000, mercury and organochlorine contaminants were measured in these seals. Today, chemical concentrations in the blubber of Saimaa ringed seals are similar of those of ringed seals from the Arctic.⁷⁶ A recent study⁷⁷ showed that levels of polychlorinated dibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs) in the blubber of ringed seals from NWT, Canada, have not changed significantly between 1981 and 2000.

Grey seals (*Halichoerus grypus*)

A 2001 report⁷⁸ discussed changes in the kidneys of grey and ringed seals from the Baltic and the Gulf of Bothnia.

Populations of grey and ringed seals declined severely in the Baltic during the 1960s and 1970s. Adult seals have lesions of the female reproductive organs, intestines, kidneys, adrenal glands, and skulls. The authors noted that the prevalence and extent of the kidney changes were age-related and thus correlated with the time of exposure to contaminants. Similar findings were recorded in 5 grey seals from Swedish zoological gardens fed polluted Baltic fish for most of their lives, illustrating the negative impacts high levels of chemicals can have on seals.

In a 2003 study,⁷⁹ relationships were examined between vitamin A and PCB levels in blood of wild neonatal grey seals. Vitamin A concentrations were negatively correlated with PCBs. It is possible that the vitamin A-depressing effect of PCBs was caused by PCB metabolites that interfere with substances that transport vitamin A in the blood and increase excretion of vitamin A. This result is in agreement with explanations of how vitamin A levels are depressed in relation to PCB levels in rodents.

Another 2003 study⁸⁰ investigated exposure to and effects of contaminants in Baltic ringed and grey seals. Ringed and grey seals in the Baltic Sea show effects, including reproductive problems, which have resulted in decreased reproductive capacity. Seals from less polluted areas were used as comparisons in the study. In both Baltic seal populations, the levels of some biochemical parameters differed from those of the reference seals, and some parameters showed clear correlations chemical levels. Vitamin A levels showed a negative correlation with the individual contaminant levels.

Brominated flame retardants (e.g. PBDEs, HBCD) have been detected in

ringed seals from Svalbard, Greenland, and the Russian and Canadian Arctic.⁸¹

Northern elephant seals (*Mirounga angustirostris*)

Elephant seals are so-called because they are the largest seals. Males have a distinctive long, floppy nose. While feeding, elephant seals can stay submerged for 20-minute to 2-hour dives at depths of 300 to 800 meters and sometimes as deep as 1500 meters. The elephant seal will stay at sea for 300 days at a time while diving continuously. These seals travel back and forth between their breeding and molting locations in Mexico and California to their feeding locations in Alaska or the north Pacific Ocean and then return to their breeding colonies to molt 2 to 6 months after breeding. They may travel up to 21,000 miles in a year, the longest migration known for any mammal. Females give birth to a single pup that they nurse for 1 month. The seals have a life span of up to 22 years. Their diet includes fish and cephalopods, including squid, octopus, and small sharks.⁸²

Northern elephant seals were hunted almost to extinction in the 19th century. Although they are now in recovery, there is a genetic bottleneck in the existing population. All elephant seals today are descended from a small number of seals, potentially making the seals more susceptible to disease and pollution. A 1997 study⁸³ found northern elephant seals with higher levels of PCBs and DDE were more likely to have skin disease and lower body weight. Skin disease consisted of skin ulcers and occasionally massive skin tissue death. Mortality from poisoning caused by bacteria and toxins entering the bloodstream increased significantly with the severity of the skin lesions. Serum⁸⁴ and blubber concentrations of several PCBs and DDE were negatively

correlated with body weight. The average levels of PCB and DDE in the serum of seals with skin disease were elevated when compared to apparently healthy seals.

Stellar sea lions (*Eumetopias jubatus*)

Stellar sea lions were listed as endangered in 1997, in the western portion, and threatened, in the eastern portion, of their range in the North Pacific Ocean. Populations declined by 75% between 1976 and 1990. This specie's range includes Alaska, the Aleutian Islands, the Bering Sea, the Kuril Islands, the Okhotsk Sea, and the Commander Islands in Russia and south to the Channel Islands off California. In addition to chemicals, threats include nutritional stress due to changes in fish availability to lower fat fish, competition with commercial fisheries for food, human caused deaths, increased predation (e.g. by sharks and killer whales), subsistence harvest or harassment, and climate change. Females reproduce after reaching 4 to 6 years of age and have at most a single pup each year. Pups are born from late May through early July and mothers stay with their pups for about 9 days before beginning trips to sea to feed. Females mate again 11 to 14 days after giving birth. Weaning is not sharply defined as it is for most other pinniped species, but probably takes place gradually during the winter and spring prior to the following breeding season. It is not uncommon to observe 1- or 2-year old sea lions still nursing.⁸⁵

A 2003 research paper⁸⁶ summarized what is known about impacts of contaminants in this species. The researchers' conclusion was that although studies to date had not yet linked exposures to health effects in Stellar sea lions, contaminants were still suspected as one possible cause of the continuing species decline. Sea lion

tissues are known to be contaminated with butyltins, mercury, PCBs, DDT, chlordanes and hexachlorobenzene. Sea lion habitats and prey are contaminated with additional chemicals including mirex, endrin, dieldrin, hexachlorocyclohexanes, TCDD, cadmium and lead. In addition, many sea lion haul-outs and rookeries are located near other hazards including radioactivity, solvents, and chemical weapon dumps. PCB and DDT concentrations measured in a few sea lions during the 1980s were the highest recorded for any Alaskan pinniped. While exposure to PCBs and DDTs may be declining, these sea lions are likely exposed to a multitude of other newer contaminants that have not yet been monitored. Field studies have been limited in scope and have not yet linked contaminant exposures to adverse sea lion health or population effects.

California sea lions (*Zalophus californianus*)

Male California sea lions are known to migrate away from breeding areas along the California coast as far as Washington and British Columbia, little is known about whether the females and young also migrate. California sea lions are found in near-shore waters along the Pacific coast with rookeries off the west coast of Vancouver Island to Baja California. The population was estimated at about 145,000 animals and increasing in 1990 but threats include net entanglement and environmental contaminants. Sea lions' diet consists of fish, small sharks, squid, octopus, and other cephalopods.

A 2005 study⁸⁷ of PCBs and DDT in California sea lions found no relationship between vitamin E levels and these contaminants. A small but statistically insignificant relationship was found between serum thyroxine⁸⁸ levels and PCB levels. PCBs were negatively correlated with vitamin A and the thyroid

hormone T3.⁸⁹ In another 2005 study,⁹⁰ chemical levels found were greater than those known to affect reproductive success, vitamin A, and thyroid hormone levels in studies of captive harbor seals. An unusually high prevalence of abnormal tissue growth (18% of stranded dead adults) and high levels of contaminants were found. PCBs were associated with the probability of sea lions dying with carcinoma cancer.⁹¹ California sea lions have an unusually high prevalence of cancers, most of which are genitourinary (e.g. prostate, bladder, and testicular). Scientists have found that sea lions with cancer have higher levels of contaminants in their tissues than sea lions dying from other causes.

Beluga whales

The word "cetacean" comes from the Latin word *cetus*, meaning "whale or sea monster". The only arctic cetacean species for which scientific studies of health effects related to chemical exposures are currently available is the beluga whale.

The word beluga means "the white one" in Russian and the beluga is also known as the "singing whale" or "sea canary" because of its underwater noises. Sounds range from high-pitched whistles to squeaks and grunts. Belugas have a good sense of hearing and can detect objects by echo-location. Belugas live in Canadian, Russian, Greenlandic, and North American waters including the Bering and Beaufort Seas and the Hudson Bay. Adults may grow to almost 5 meters in length and weigh 500-1500 kilograms. Belugas often stay together in close-knit groups of the same gender and age. Females give birth to a single calf every three years, following a 14-15 month pregnancy. The calves nurse for 1 to 2 years and are born with brown or grey skin that gradually turns white by the time they are 6-8 years old. Belugas

prefer shallow coastal waters and swim up river inlets where pollutants are concentrated, as a result they can be studied as models of long-term exposure to chemicals and can be used to predict health problems that could emerge in highly exposed wildlife and human populations over time.

Belugas are mainly an arctic species, however, the population of 500-700 whales found farthest south does not migrate and is isolated in the Saint Lawrence estuary in Canada. The estuary population was once estimated to be about 50,000 but was devastated by hunting up until the 1950s. Despite an end to wide-scale hunting, since the 1970s the population has declined from approximately 5,000 individuals to 500-700. Even receiving endangered protection status in 1983 has not allowed the population to recover. Several factors, including chronic exposure to toxic chemicals such as organochlorine pesticides, polycyclic aromatic hydrocarbons and heavy metals such as mercury and lead are likely the cause. The bodies of some belugas from the estuary are so contaminated that their carcasses are treated as toxic waste. While the isolated St. Lawrence beluga whales are much more contaminated than belugas from more northern waters, the St. Lawrence population is easier to study and serves as an indicator as to how pollutants may affect belugas worldwide.

Belugas from Canada, Greenland, Alaska, and Norway have been screened for contaminants. Concentrations of pesticides called CHBs in belugas from Svalbard, Norway, are at the high end of the range compared to other arctic beluga populations. The overall organochlorine burden also differs in belugas from Svalbard compared with belugas from other arctic areas. Male belugas were

found to have higher CHB concentrations than other mammals (e.g. seals and polar bears) from Svalbard.⁹² However, organochlorine levels in Svalbard belugas are lower than those of beluga from the St Lawrence River, Canada. In Svalbard beluga, PCB and DDT levels are thought to be below the levels associated with harmful effects on reproductive or immune function.⁹³

A study that involved feeding rats a diet of either St. Lawrence beluga blubber, St. Lawrence plus arctic beluga blubber, or a control diet for 2 months found rats showed no immune differences based on diet, a result that was not consistent with other studies of immune suppression from organochlorine exposure. However, the lack of effect may have been due to study design (e.g. route, level or duration of exposure). It is also thought that marine mammals are much more sensitive to chemical exposures than some other species such as rats.⁹⁴

In addition to threats from boat collisions, oil spills, noise pollution, entanglements in fishing gear and declining food resources, the Saint Lawrence estuary and its wildlife continues to receive the waste and discharges from one of the most industrialized regions of the world. Some of the chemicals found in the Saint Lawrence estuary are known to cause cancer, especially a concern for long-lived animals such as belugas with life spans of 35-50 years. Belugas dig into the estuary sediments to feed on bottom-dwelling invertebrates. Cancer-causing chemicals, such as polycyclic aromatic hydrocarbons, are produced by a nearby aluminium smelter and end up in the sediments where they are taken up by invertebrate species later eaten by belugas. A study of 263 dead belugas discovered between 1983-1999 from the Gulf of St. Lawrence found hormone

gland lesions, frequent bacterial infections and a large number of cancer tumors.^{95,96,97,98,99,100,101,102,103}

Studies of dead belugas have also found parasitic infections, other infectious diseases, cancers (especially intestinal), and lesions indicating reproductive and immune problems. St. Lawrence belugas have a cancer rate that is higher than that detected in any other wild animal population and this cancer rate is not linked to old age. The most recent studies of belugas found dead between 1994-1998 show similar problems as found in belugas that died between 1982 to 1993. Samples from live belugas in the estuary also show chemical contamination levels similar to the dead belugas but with some differences in specific chemicals present.

A cell culture study of the blood of arctic belugas exposed to pollutants showed that when exposed to organochlorine pesticide concentrations comparable to those measured in St. Lawrence beluga tissues, the arctic belugas' immune cells were not as efficient in performing their normal function.¹⁰⁴

Recently, newer chemicals such as brominated flame-retardants and fluorinated chemicals have also been detected in belugas in addition to older chemicals such as benzo(a)pyrene, PCBs, DDT, mercury, and lead.¹⁰⁵ PBDE brominated flame retardants were measured in fat samples of 54 stranded adult belugas collected between 1988 and 1999 in the St. Lawrence Estuary. The accumulation of these chemicals increased exponentially between 1988-1999. Although PBDE levels are from 10 to 25 times higher than levels in belugas sampled in the northern Arctic, they are still considered low. However, growing demand for products containing these chemicals and the lack of adequate regulations and controls on their use,

may result in wildlife becoming increasingly contaminated with flame retardant chemicals. An increasing number of studies indicate links between PBDEs and hormonal and neurological problems, and possibly cancers. PBDE exposures could therefore obstruct the recovery of this threatened population.¹⁰⁶ Fluorinated chemicals, including PFOS, were detected in belugas in 2004.¹⁰⁷ Although the St. Lawrence population is isolated and more contaminated than arctic belugas, they likely serve as good models for how pollutants affect the species in general.^{108,109,110}

In 2004, a study¹¹¹ reported on the effects of organochlorines on beluga immune function, specifically phagocytosis.¹¹² The study showed reductions in phagocytosis in relation to PCB exposure, possibly placing belugas at higher risk of infectious diseases that would normally be non-threatening with a fully functioning immune system. A 2005 study¹¹³ of Svalbard, Norway, belugas tested for three forms of a dangerous pesticide called toxaphene. The toxaphene concentrations in Svalbard belugas were found to be at the high end of the range compared to other arctic beluga populations. Male Svalbard belugas have several orders of magnitude higher concentrations of SigmaCHBs compared to seals and polar bears from the same area. Other 2005 studies^{114,115} of belugas in arctic Canada detected organochlorines, PCBs and mercury. For mercury, virtually all the samples analyzed, except blubber, were at levels exceeding the Canadian consumption guideline for fish.¹¹⁶

In a 2005 study¹¹⁷, researchers determined and compared the *in vitro* metabolism of PCB congeners using beluga whale hepatic microsomes of belugas from western Hudson Bay, Canada. Results suggested that

potentially toxic metabolites, in addition to the original pollutants, may be contributing to contaminant-related stress health effects in belugas. And in 2006, researchers measured PCBs, chlorinated pesticides, and PBDEs in belugas and narwhals (*Monodon monoceros*) from Svalbard, Norway.¹¹⁸ A large range of chemicals were found at high levels, with PCB, pesticide, and PBDE levels being higher in narwhals than belugas. The researchers concluded that, compared with other marine mammals from the same area, contaminant levels are among the highest ever measured and that belugas and narwhals are excellent indicator species to use to track a wide range of contaminants in the Arctic.

Faroe Island long-finned pilot whales are also known to be contaminated with brominated flame retardants and, in fact, have the highest concentrations of PBDEs detected in an arctic marine mammal thus far. The high levels may be due to the geographic range of the whales or to their behavior.¹¹⁹

Birds

Many chemicals that are attracted to fat (e.g. PCBs, organochlorine pesticides) are taken up and excreted in egg yolks. As is the case for mammals through lactation, in birds chemical exposures to the embryo during the most critical early development phase also occur.¹²⁰ Birds, like mammals, are susceptible to alterations in hormone levels and their reproductive cycle is controlled by hormones. Thyroid hormones regulate metabolic heat production, growth, body weight, nervous system development, cell differentiation, hatching, molting, and reproduction. Altered thyroid hormones may cause decreased metabolic rate and sensitivity to cold. A recent study¹²¹ of quail found exposure to several different chemicals resulted in changes in adult male sexual behavior,

altered neurotransmitters, impaired reproductive and immune related end points, and altered steroid hormones. Recent research suggests the neural system and the female reproductive system of bird embryos are very sensitive to the effects of female hormone disrupting chemicals.¹²² Eggs are good avian contaminant monitoring tools, and also serve as sentinels for human health since some people in arctic regions are known to eat bird eggs. Furthermore, marine birds serve as indicators of the health of the arctic marine ecosystem.¹²³

Many gulls are top predators that accumulate fat reserves during parts of the year.¹²⁴ Sea birds, such as gulls, have long life spans, low reproductive rates and a delayed onset of reproduction. Population stability therefore depends on a high adult survival rate and even small reductions in the adult survival rate may have large consequences for the overall population growth rate. In addition to the well documented effects of DDT on egg shell thinning and broken eggs, contaminants can also interfere with hormones and decrease bone deposition, resulting in less calcium for the eggs. Recent studies of gulls are adding to the evidence of harmful effects linked to chemical exposures in arctic birds. Organochlorines (e.g. PCBs, DDE, dieldrin) have been linked to decreased parent attentiveness, impaired courtship behavior, and neurological effects (impaired avoidance behavior) in birds.¹²⁵

Gulls

In some locations, such as Svalbard, Norway, PCB levels are considered to be alarmingly high in glaucous gulls, which are top predators, and research has shown immune suppression related to PCB exposure.¹²⁶ Glaucous gull studies^{127,128,129} have shown associations between contaminants and

effects on reproduction, behavior, immune function and development. In 2004, a study¹³⁰ was published on the effects of organochlorines on thyroid hormone levels in glaucous gulls from the Barents Sea. The researchers found organochlorines were correlated with thyroid hormone ratios in male gulls and that thyroxine (T4)¹³¹ levels were lower in gulls with higher chemical levels while triiodothyronine (T3) levels were higher in more exposed gulls.

In birds, thyroid hormones regulate metabolism, growth, weight, nervous system function, egg hatching, molting, and reproduction.¹³² Therefore, any hormonal alteration is of concern. High organochlorine levels in gulls have also been associated with reproductive problems, reduced parental attentiveness during egg incubation, alterations in feathers,¹³³ and lymphocyte levels.¹³⁴ In a test of gull antibody response to diphtheria toxoid, organochlorines were found to cause impairment of the humoral immunity.¹³⁵

A 2005 study¹³⁶ of great black-backed gulls (*Larus marinus*) from the subarctic Norwegian coast investigated organochlorine exposures and effects on reproductive outcomes. These gulls are top predators and opportunistic feeders in subarctic and temperate marine areas and share a similar ecology as glaucous gulls. In the study, female gulls with high levels of organochlorines laid their eggs later, suffered more nest predation, and had a greater decline in egg volume than less contaminated female gulls. These outcomes are likely to affect overall reproductive success because prior studies have shown egg size is related to the weight and size of the chick at hatching, growth rate, and survival. Larger chicks may kill or out-compete smaller ones. Despite relatively low organochlorine levels the great black-backed gulls still showed clear harmful

effects, as was the case for glaucous gulls from Bear Island with higher organochlorine levels. While the authors concluded that organochlorines were triggering these reproductive outcomes, they pointed out that food stress may be a deciding factor in whether organochlorines have a harmful health impact on the gulls. Food stress in combination with organochlorines may be the trigger for harmful effects.

A study¹³⁷ published in 2005 looked at levels of persistent chemicals (i.e. PCBs, PCDDs, PCDFs) in 214 eggs from 4 gull species collected between 2001-2002 from 12 locations in northern Norway, including Svalbard, and the Faroe Islands. Eggs were collected from herring gulls (*Larus argentatus*), great black-backed gulls (*L. marinus*), lesser black-backed gulls (*L. fuscus*) and glaucous gulls (*L. hyperboreus*). Due to the contaminant levels found, the researchers advised children, young women and pregnant and nursing women to not eat gull eggs and advised that all others should limit egg consumption to an absolute minimum.

Glaucous gulls (*Larus hyperboreus*)
Glaucous gulls are large pearl-grey birds that breed on coastal cliffs and tundra, islands, and lake sides in arctic Canada, Alaska, Greenland, and the Queen Elizabeth Islands. During winter the gulls may also be found as far south as the Great Lakes and central California in the United States. These gulls are top arctic predators and feed on fish, carrion, small rodents, shellfish, eggs and young of other bird species, berries, and scraps left from the meals of other arctic species. They are long-lived with an average lifespan of 10 years. Gulls build nests on rocky cliffs lined with grass or seaweed. Two to three eggs are produced each year, usually during May, and chicks hatch in June. The young

gulls take 4 years to develop adult feathers and coloration.

Research on glaucous gulls at Bear Island has reported wing feather asymmetry related to increasing organochlorine levels (i.e. HCB and PCBs) likely resulting from developmental stress. Wing feather asymmetry is a good early indicator of environmental quality. Feathers are molted and grown annually and stressors that lead to asymmetry can increase the energetic costs of flying. Thyroid hormones regulate the shedding of feathers and growth of new feathers.

Since the late 1980s, dead, dying, and abnormally behaving glaucous gulls have been noted on Bear Island in the northeastern Atlantic. The number of breeding pairs has been reduced by half since 1997 on some parts of cliff. (Bustnes, unpublished data) Samples taken between 1997-2000 showed female gulls with the highest persistent organochlorine levels were more likely to lay nonviable eggs and to have chicks with poorer hatching body condition. Adult survival also decreased with increasing DDE, PCB, HCB, and oxychlorane levels. Birds with high organochlorine levels laid their eggs earlier. Effects at the embryo stage may result in the death of the embryo or reduce its quality. Adult bird survival is the parameter to which the population growth rate is most sensitive in long-lived bird species. The nesting period is a vulnerable time because of predation and starvation and birds with poorer body condition have more nest predation.¹³⁸ Negative correlations have also been noted between thyroid hormones and high organochlorines (i.e. HCB, oxychlorane, DDE, PCBs) in male glaucous gulls.¹³⁹

In another study¹⁴⁰ that sampled glaucous gulls from Bear Island between 1997-2001, organochlorine chemicals

(i.e. HCB, oxychlorane, DDE, PCBs) were shown to alter the immune system and to impair humoral immunity, potentially leaving the gulls more susceptible to infections and disease. Associations between organochlorines and white blood cell levels suggested organochlorines result in more resources being needed to produce white blood cells. Organochlorines were also linked to heterophil¹⁴¹ levels and B and T cells. High HCB levels were associated with decreased response to diphtheria toxoid in females. Decreased feeding efficiency, decreased reproduction and survival, high nematode parasite loads, and asymmetry in wings were all noted.

Another 2005 study¹⁴² provides additional indications that organochlorines (particularly HCB, oxychlorane, DDE and PCBs) are having effects on glaucous gull populations in the Norwegian Arctic. The study showed PCBs and oxychlorane were related to parental time away from the nest site. Among some female gulls, where fish dominated the diet, early chick growth was negatively related to maternal levels of all four chemicals. This was not true, however, for females whose diet was dominated by eggs. As previously reported¹⁴³ in relation to food stress, results indicate additional environmental stressors may be fundamental in causing reproductive effects due to organochlorines in this gull population. Over three breeding seasons, the researchers also studied links between blood chemical levels and the likelihood that the gulls would return to the same breeding ground the following year. The return rate was negatively associated with blood levels of oxychlorane. When oxychlorane blood levels declined by 60% between 1997 and 2000, there was a significant increase in the gulls' return rate to the breeding grounds.

Glaucous gulls from Bear Island, in the northeastern Atlantic, were sampled in 1998. The gulls' time absent from the nest site when not incubating and the number of total absences increased in relation to increasing PCB blood levels, likely due to neurological or endocrine effects resulting in behavioral impairment. Birds with higher organochlorine levels spend more time away on feeding trips than birds with lower organochlorine levels. Both male and female gulls participate in nesting, defending and feeding babies and the nesting period is a vulnerable time because of predation and starvation.¹⁴⁴

A 2005 study¹⁴⁵ analyzed 62 un-hatched eggs collected from six predatory bird species in Norway. The eggs were tested for brominated flame retardants. (i.e. PBDE, PBB, and TBBPA) The highest PBDE levels were found in white-tailed sea eagle eggs, followed by eggs of peregrine falcon and osprey. Two types of flame retardants, called BB 101 and 153, were found in eggs of all the bird species. TBBP A was detected in all of the eight eggs tested, from four different bird of prey species. Brominated flame retardants have also recently been detected in peregrine falcon eggs from Sweden,¹⁴⁶ and in eggs of great blue herons, double-crested cormorants and osprey from Canada.¹⁴⁷ In the Canadian study, PBDEs increased exponentially with a doubling time of 5.7 years in heron and cormorant eggs.

Another study¹⁴⁸ tested for a group of fluorochemicals in blood, liver, brain, and egg samples of adult glaucous gulls in the Norwegian Arctic. Perfluorooctane sulfonate (PFOS) was the main fluorochemical found in all samples and was present at concentrations that are the highest reported so far in any arctic seabird specie or population. The detected levels of fluorochemicals suggest these glaucous gulls are

bioaccumulating these chemicals to an extent that there is the potential for altered biological processes.

Mixtures of pollutants found in the arctic marine environment have been determined to cause harmful changes to gull DNA.¹⁴⁹ DNA changes were quantified in liver samples from gulls fed hen eggs compared with gulls fed environmentally contaminated gull eggs. Chemically exposed gulls had a significantly increased level of DNA changes and the level of CYP1A enzyme was significantly higher in the liver of exposed male gulls and was correlated to the blood levels of organochlorine chemicals.

Another 2005 study¹⁵⁰ investigated new or lesser-studied and legacy organochlorine contaminants and metabolites in plasma and eggs of glaucous gulls collected from major breeding colonies on Bear Island in the Norwegian Arctic. The researchers concluded that a complex mixture of contaminants and metabolites may be contributing to stress in breeding glaucous gulls. And in 2006, a summary article¹⁵¹ was published outlining adverse effects linked to chemicals in glaucous gulls. Chemicals found in the gulls were ranked in relation to 19 different outcome parameters, indicating adverse effects. Oxychlorane and HCB were often reliable predictors of harmful effects. The study results indicate that complex mixtures of chemicals may interact to contribute to adverse effects.

Conclusion

Biological effect studies incorporating both *in vivo* and *in vitro* experiments are now available for several arctic mammal and bird species that indicate chemical exposures may already be affecting the health of these species. While only controlled experimental studies can ever demonstrate direct cause and effect relationships, the evidence thus far for

arctic species demonstrates considerable changes that are very likely influenced or caused by chemical exposures. Some of these alterations are potentially quite serious (e.g. immune suppression, hormone disturbances, altered behavior). The data discussed in this report, taken together, indicate contaminants have the potential to adversely impact the health of not only the specific species and populations studied, but probably other marine mammals and birds as well. Chemical exposures are especially of concern for wildlife when one considers that many species are already facing other concurrent and serious threats to survival and, in some cases, large population declines.

Newer chemicals, such as brominated flame retardants and fluorinated chemicals, are also being detected in arctic species such as harbor seals, glaucous gulls and polar bears. However, biological effect studies in arctic species are still completely lacking for these chemicals. Additional well-designed studies are needed to assess these newer chemicals and also effects from chemical mixtures, which are the norm in nature. Additional research and knowledge on basic health parameters such as normal immune and hormone function in arctic species is also needed.

However, decision makers must learn to understand and recognize the inherent difficulties in wildlife toxics research and must accept that judgments have to be made in the absence of definitive cause

and effect evidence in order to protect these species. The accumulating evidence thus far is certainly enough to show that a move towards more precautionary chemical legislation must be carefully considered and that additional funding should be provided for wildlife toxics research.

WWF does not argue that pollutants are the only or even the most important threat facing arctic species. However, we insist the time to act to improve chemical legislation is long overdue especially when this can be done in a way that has minimal economical impact- and in fact has the potential for great economic and environmental savings. WWF blood testing of the European public and politicians has shown none of us are immune from the risk of dangerous chemical exposures. Many arctic peoples are also known to be heavily contaminated. While some chemicals, such as PCBs and DDT, are stable or decreasing, many new chemicals are showing up at the same time.

In order to avoid a repeat of the chemical mistakes of the past we need improved chemical safety now. The proposed new EU chemicals law, REACH, offers EU legislators a once-in-a-lifetime opportunity to ensure a high level of protection against hazardous chemicals for humans, wildlife and the environment. It is an opportunity for safer chemicals that we cannot afford to miss.

As Sheila Watt-Cloutier of the Inuit Circumpolar Conference eloquently said in 2005:

"Inuit are being poisoned from afar by toxins—PCBs, DDT and other chemicals—carried to the Arctic on air currents. These chemicals contaminate the food web we depend upon: seals, whales, walrus and end up in our bodies and the nursing milk of our mothers in high levels. So what a world we have created when Inuit women have to think twice about nursing their babies.

I think by now you see these issues are not just about the environment or wildlife; these issues are about children, families, and communities. This is about people—the cultural survival of an entire people—, which, of course, are connected to the survival of the planet as a whole. What happens in the Arctic is important to all of us. The Arctic is indeed the health barometer—the early warning—for the rest of the world."

Appendix: Acronyms and Definitions

BFRs: brominated flame retardants, a large group of compounds used to prevent fires

CHBs: chlorobornanes

CHLs: chlordane compounds

Cytochrome P450 oxidase: a group of oxidative enzymes important in vertebrate physiology. The cytochrome P450 system is likely the most important factor in phase I metabolism in mammals.

DDE: dichlorodiphenyldichloroethylene, a chemical similar to DDT that contaminates commercial DDT preparations

DDT: dichlorodiphenyltrichloroethane, a pesticide once widely used to control insects

EDCs: endocrine disrupting chemicals

HCB: hexachlorobenzene

HCHs: hexachlorocyclohexane isomers

OCs: organochlorine pesticides

PAHs: polycyclic aromatic hydrocarbons

PBDEs: polybrominated diphenyl ethers, widely used as flame-retardants

PCBs: polychlorinated biphenyls

PCDDs: polychlorinated dibenzo-p-dioxins

PCDFs: dibenzofurans

PFOS: perfluorooctane sulfonate

POPs: persistent organic pollutants

TBBPA: tetrabromobisphenol-A, a brominated flame retardant, considered the most important individual BFR used in industry

TCDD: tetrachlorodibenzo-p-dioxin

T3: triiodothyronine, a thyroid hormone

T4: thyroxine, a thyroid hormone

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- 1 Biomarkers are used to indicate or measure a biological process (e.g. levels of specific hormones, proteins, immune cells, or vitamins in the blood or another tissue). Biomarkers are important because harmful effects may be taking place long before animals or people show recognizable symptoms of disease. In this way biomarkers can be used as an early detection system.
- 2 A group of oxidative enzymes important in vertebrate physiology. The cytochrome P450 mixed-function monooxygenase system is probably the most important element of Phase I metabolism in mammals.
- 3 The group of marine mammals with teeth, including whales, porpoises and dolphins.
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