Levels and effects of persistent organic pollutants in arctic animals

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1. Introduction

Despite the fact that the Arctic is far from the industrialized world the presence of persistent organic pollutants (POPs) in arctic food webs shows that man-made substances are transported over long distances to these remote areas. Several international reports (AMAP 1998; 2004; EEA 2004) and reviews (Muir et al. 1999; Gabrielsen and Henriksen 2001; Fisk et al. 2003; de Wit et al. 2004) list and document threats to the Arctic ecosystem from long-range transported contaminants such as POPs.

POPs are a diverse group of anthropogenic pollutants that are of industrial and agricultural origin. POPs are rarely used in the Arctic, but they have been documented in arctic wildlife since the beginning of the 1970s. Substances such as polychlorinated biphenyls (PCBs) and chlorinated pesticides (e.g., dichlorodiphenyltrichloroethane (DDT), toxaphenes) were reported in arctic seals, polar bears *(Ursus maritimus)* and glaucous gulls *(Larus hyperboreus)* in the early 1970s (Bogan and Bourne 1972; Bourne and Bogan 1972; Holden 1972; Bowes and Jonkel 1975). Although low levels of POPs have been reported in terrestrial Arctic species, the problems are mainly related to marine organisms. While some POPs (e.g., DDT and PCBs) have decreased in levels during the last 10-20 years, following the introduction of bans and restrictions in use, new persistent pollutants are increasing in the environment due to the fact they are currently being produced in large quantities. Some of these new chemicals include chlorinated naphthalene (PCN), brominated flame retardants (BFRs) and perfluoro-octane sulfonate (PFOS) (AMAP 2004).

Most POPs found in the Arctic are transported from distant industrial and agricultural sources by atmospheric and oceanic currents, as well as river discharges (AMAP 2003). The most important transport route is atmospheric circulation bringing contaminants from the lower latitudes to the Arctic within days (Macdonald et al. 2000). The contaminants are deposited and taken up mainly in the lipid rich food chains of the arctic marine ecosystem (Muir et al. 1992; Borgå et al. 2001; 2004; Fisk et al. 2003). As a result of processes of bioaccumulation and biomagnification, POPs can reach very high concentrations in apex predators such as polar bears, arctic fox (*Alopex lagopus*) and glaucous gulls (Wang-Andersen et al. 1993; Gabrielsen et al. 1995; Bernhoft et al. 1997; de Wit et al. 2004).

The concern about POP levels and possible effects in arctic wildlife increased with the comprehensive surveys performed in the 1980s and 1990s (AMAP 1998; 2004). POPs are known to elicit a range of detrimental effects on biota. For POPs the effects are related to the enzyme-, immune-, hormone- and vitamin systems. Of great concern are contaminants that may have reproductive effects and those that can mimic and disrupt the hormone system (Colborn et al. 1993; Giesy et al. 2003). During the last 5-10 years, a number of field studies have been performed on polar bears and glaucous gulls from Bjørnøya and Svalbard in order to study the relationships between contaminant levels and effects. The levels documented in glaucous gulls and polar bears are high enough to raise concern about the effects on the health of these species.

The present article summarizes some recent studies on the levels and biological effects of POPs in arctic animals. A special emphasis has been put on effect studies on polar bears and glaucous gulls from Svalbard and Bjørnøya.

2. Persistent organic pollutants (POPs)

Environmental contaminants include both industrial chemicals, such as PCBs, hexachlorobenzene (HCB), chlorinated pesticides, such as DDT, chlordanes, hexachloro-cyclohexane (HCH), aldrin/dieldrin, polychlorinated boranes (Toxaphenes) and industrial byproducts such as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) (Muir et al. 1992). Most of these contaminants were developed and put into production more than 50 years ago. The highest production of most of these contaminants was at the end of the 1960s and the start of 1970s (Blus 1995). For some of the new contaminants (e.g., PBDEs) the use has increased drastically in the past decade. Most of the use is in industrial areas of the northern hemisphere that are potential source regions to the Arctic.

2.1 PCBs

PCBs are mixtures of chlorinated hydrocarbons that have been heavily used since 1930 for many industrial purposes such as dielectrics in transformers and large capacitors, heat exchange fluids, paint additives, in carbonless copy paper and plastics (Fisher 1999). At present, the major source of PCB exposure seems to be environmental recycling of PCBs from former usage. There are 209 possible PCBs (congeners), of which about 100 have been found in biological samples (McFarland and Clarke 1989). The properties of PCBs depend on the number of Cl-atoms and their position and include low water solubility, high stability, and semi-volatility, which favour long-range transport. Worldwide PCB production in 2000 was estimated at 1.3 million tonnes (Breivik et al. 2002).

2.2 DDTs

DDT and its metabolites (1,1-dichloro-2,2-bis ethane (DDD) and 1,1-dichloro-2,2-bis ethylene (DDE)) have been found in biota since the 1940s. After the war, DDT was used extensively as a pesticide on a variety of agricultural crops (i.e. cotton and peanuts) and to prevent the spread of diseases to humans by insects (e.g., malaria and typhus). The total global usage was estimated at 2.6 million tonnes up until 1992 (Voldner and Li 1995). DDT and related compounds are very persistent in the environment and their half-lives in soil range from 10 to 15 years. DDT has been declining in the temperate regions of the northern and hemisphere since the 1960s and especially since the mid-1970s when production and use were banned by many western nations (Mellanby 1992).

2.3 PBBs and PBDEs

PBBs, PBDEs and tetrabromobisphenol are the three main classes of brominated compounds used as flame retardant additives (Renner 2000). They are used at high volume in electric equipment such as computers, television sets, textiles (clothing), cars, airplanes and other applications (de Boer et al. 1998). Humans may absorb PBBs and PBDEs when they are emitted from electronic circuit boards and plastic computers and cabinets (Zelinski et al. 1993). PBBs and PBDEs show high lipophilicity, high resistance to degradation, and are expected to bioaccumulate effectively in the aquatic and terrestrial food chains. The annual usage of the flame retardants have drastically increased during the last few years. The annual world production in 1998 was estimated at 150 000 tonnes (Sellstrøm and Jansson 1995).

2.4 Perfluorinated alkyl substances (PFAS) and PFOS

In recent years environmental concern has arisen as PFAS have been reported in seabirds and marine mammals in the Arctic (Giesy and Kannan 2001; Smithwick et al. 2005; Verreault et al., submitted). The most pervasive PFAS reported in arctic biota has been PFOS (Kannan et al. 2001). PFOS is used as a refrigerant, surfactant, and as a component in pharmaceuticals, flame retardants, lubricant, paints, adhesives, cosmetics, paper coating, and insecticides. PFOS has been manufactured for over 50 years and has steadily increased its use. The annual US production was 3000 tonnes in 2000 (AMAP 2004).

2.5 PCN

PCNs exist as 75 congeners that are structurally similar to the PCBs and have many similar applications. These include electrical equipment, lubricants, solvents, dyes and sealants. They are also present as impurities in technical PCB and are formed during anthropogenic combustion processes. In the 1920s the worldwide annual production was approximately 9000 tonnes. One of the largest PCN producers voluntarily ceased production in the late 1970s. At the present, information about the world production is limited. Although the use of PCNs has declined over the past few decades, they are not prohibited in most countries and are still being used in many PCB-like applications (AMAP 2004).

3. Levels of POPs in marine food chains

The arctic environment is among the least polluted ecosystems in the world. The POP levels are low in most lower trophic level marine species from the Barents Sea area compared to the Baltic and the North Sea. The POP levels at lower trophic levels in the Barents Sea, are very similar to what is found in Alaska and Canada. High POP levels and possible biological effects are mainly associated with species at the top of the food webs (AMAP 1998, 2004). However, few studies to date have examined the potential effects of various POPs on the lower trophic level of the polar ecosystems.

There are large differences in POPs levels in Arctic animals. These differences may be attributed to several factors such as exposure, ability to metabolize contaminants, ability to excrete compounds, seasonal variation in body mass, age and sex (Bignert et al. 1993; Henriksen et al. 1996). For example, the sex difference in POP levels often seen in birds partly reflects the fact that female birds are able to deposit lipophilic compounds into the egg. In polar bears and other marine mammals, considerable amounts of POPs are also transferred to the foetus and via milk from the mother to the cub. This is one of the main reasons for lower levels of some POPs in sexually mature female polar bears than in males (Bernhoft et al. 1997).

Several detailed studies of the Arctic marine food webs and POP accumulation were carried out in the 1990s in different Arctic regions (e.g. Borgå et al. 2001; Fisk et al. 2001; Muir and Strachan 2003; Hoekstra et al. 2003). These are summarized along with factors of importance for POP flux and food webs in Borgå et al. (2004).

4. Marine invertebrates

Marine invertebrates provide the trophic link from phytoplankton to fish, seabirds and marine mammals in the arctic marine food web. These species do not only carry nutrients and energy, but also POPs. In general, marine invertebrates have low POP levels. In most marine species investigated at lower trophic levels in the Barents Sea area (Borgå et al. 2001; 2002 a-c), the POP levels are low compared to species at lower trophic levels from the sub-arctic and temperate areas (0.01-0.2 µg/g, lipid weight concentrations) (Borgå et al. 2001). In a comparison of the marine food web of the Barents Sea and the Canadian Arctic (Northwater Polynya), POP levels were relatively similar in copepods (*Calanus* spp.), euphausiids (*Thysanoessa* spp.), amphipods (*Themisto libellula*) and polar cod (*Boreogadus saida)* (Borgå et al. 2005a). This in contrast to what is found in higher trophic levels, where these POP levels are higher in the Barents Sea than in the Canadian and Alaskan marine food webs (Norstrom et al. 1998; Muir et al. 2000a; Borgå et al. 2005a). In the same species only hexachloro-cyclohexane (HCH) were higher in the Canadian Arctic marine food web than in the Barents Sea food web due to the proximity to point sources in eastern Asia. In all fish species from the Barents Sea the POP levels are lower than the levels found in the North- and Baltic Seas

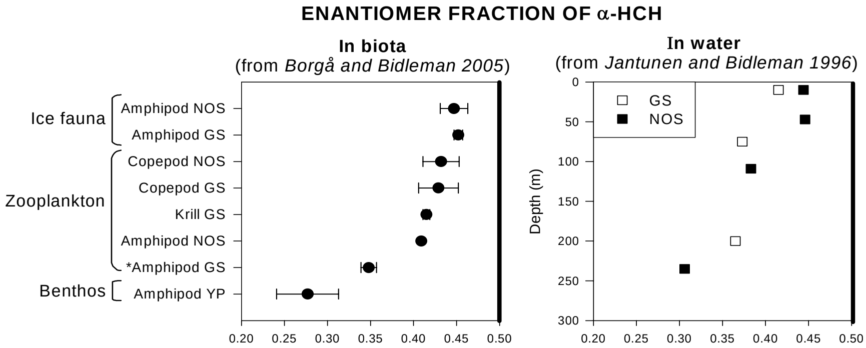

Fig. 1. Enantiomer fractions of α-HCH (mean ± 95 % confidence interval) in invertebrates and water from the Greenland Sea (GS), north of Svalbard (NOS and the Yermak Plateu (YP). * refers to predominantely pelagic amphipods that were collected with a bottom trawl. For details see Jantunen and Bidleman 1996 for water data, and Borgå and Bidleman 2005 for invertebrate data.

(AMAP 2004).

Despite low levels in invertebrates, they differ in POP levels according to diet, size and habitat (Borgå et al. 2002 a-c; Fisk et al. 2003). This has recently also been seen for chiral chlorinated pesticides in ice fauna, zooplankton and benthos (Borgå and Bidleman 2005) (Fig. 1), as well as in invertebrates from the Great Lakes (Wong et al. 2004). In addition, ice fauna differ in levels for some POPs reflecting the sea ice drift route across the Arctic Ocean (Borgå et al. 2002b; Borgå and Bidleman 2005).

Analysis of brominated flame retardant in polar cod has shown low levels compared to fish from other areas. Liver concentrations of PBDEs in herring (*Clupa harengus*) and cod (*Gadus morua*) were 15-60 times higher, respectively than the levels found in polar cod from Svalbard (Wolkers et al. 2004).

5. Seabirds

Seabird species living in the Arctic are contaminated by the same POPs as seabirds living in the south although their levels and proportions may occasionally differ to a certain extent (AMAP 1998; 2004). The POP levels in seabirds are mainly determined by their feeding habits and ability to biotransform contaminants (Borgå et al. 2005a). Common eider (*Somateria mollissima*), which feed on benthic organisms, and little auk (*Alle*

alle), which mainly feed on copepods, have low POP levels (0.5-1.0 µg/g) (Savinova et al. 1995). However, in fish-eating species such as black-legged kittiwakes (*Rissa tridactyla*), common and Brünnich's guillemots (*Uria aalge* and *Uria lomvia*) and puffins (*Fratercula arctica*), the POP levels are somewhat higher (1.0-5.0 µg/g). The highest POP levels (1.0 to 40 µg/g) are found in herring gull (*Larus argentatus*), glaucous gull, great black-backed gull (*Larus marinus*) and the great skua (*Stercorarius skua*) (Savinova, Skaare and Gabrielsen, unpublished). The POP levels in gull species are 5-10 times higher than the other seabird species in the same area. In seabirds, PCBs comprise the majority of POP in all species, followed by DDT, chlordanes, HCB and HCHs (Savinova et al. 1995; Borgå et al. 2001). The high POP levels in herring gull, glaucous gull, great black-backed gull reflect their position on the top of the arctic food web. The levels of POP in different seabird species may also be explained by their migration pattern during the winter. Guillemots from low arctic colonies in Canada have shown higher PCB and HCB levels than guillemots from high arctic colonies (Braune and Donaldson 2000). Most seabird species from Svalbard, which migrate south to the North- or Norwegian Seas during the winter, have higher POP levels than seabirds that live in the Arctic throughout the winter (Borgå et al. 2005a; Savinova, Skaare and Gabrielsen, unpublished). A comparison of POP levels in 5 species of seabirds (black-legged kittiwakes, little auk, black guillemot (*Cepphus grylle*), common guillemot and glaucous gull), between the Barents Sea and the Canadian Arctic, show higher contaminant levels in species from the European Arctic (Barents Sea) (Borgå et al. 2005a).

Analysis of brominated flame retardants (e.g. PBDEs, hexabromocyclododecane (HBCD), PBBs), PFOS and PCN in seabirds have shown concentration in, e.g. glaucous gulls from Bjørnøya that were among the highest reported in any arctic seabirds, although generally lower, occasionally by many fold, compared to species from lower latitudes (Verreault et al. 2005a, 2005b). PFOS levels in glaucous gull plasma were comparable to levels of legacy POPs such as DDTs (Verreault et al., submitted).

5.1 Glaucous gulls

The glaucous gull has a circumpolar distribution in the Arctic. It is one of the largest gulls breeding in the Arctic and the only numerous avian predator in Svalbard, Frans Josef Land and Novaya Zemlya (Bakken and Tertitski 2000). The glaucous gulls breeding in the Barents Sea area do not migrate long distances. They winter mainly in the northern part of the Atlantic Ocean and remain there from November to March (Yudin and Firsova

1988). In Svalbard, the glaucous gull is both a predator and a scavenger (Løvenskiold 1964). On Bjørnøya, its diet consists mainly of eggs, chicks, adult birds, and crabs *(Hyas araneus*), as well as offal from fishing boats (Bakken and Tertitski 2000).

PCBs and DDT are the most common POP measured in Glaucous gulls. PCBs and DDT constitutes on average 72 and 22 %, respectively, of the total pollution load measured in plasma (Verreault et al. 2005a). This is mainly due to the efficient bioaccumulation potential of PCBs and DDT and the ability of glaucous gulls to metabolize other POPs, although lower levels relative to marine mammals such as polar bear.

On Bjørnøya the sum PCB concentration in brain tissue of glaucous gulls found dead vary from 1 to 30 µg/g (wet weight (ww)), while healthy individuals vary from 0.5 to 10 µg/g (ww). In other tissue (muscle, liver and fat) the sum PCB varies from 0.5 to 23 µg/g (ww) (Gabrielsen et al. 1995; Sagerup et al. 2000). In blood from healthy glaucous gulls of normal body condition from Bjørnøya, the sum PCB were 0.6 µg/g (ww) in male gulls and 0.3 µg/g (ww) in female gulls (Bustnes et al. 2001; 2003; Verreault et al. 2004). At Bjørnøya, the POP levels vary within the population. Bustnes et al. (2001) studied two colonies, a few kilometers from each other, and found a large variation in POP concentration. Birds, which nested on the cliffs, had higher POP concentration than birds that nested at sea-level. While the birds on the cliffs were eating seabird eggs and chicks, the birds at sea-level fed more on fish, and thus were feeding at a lower trophic level. The concentration of sum PCB and sum DDT in glaucous gull were higher in the Barents Sea and Jan Mayen area than in Baffin Bay. The highest concentration was found around Frans Josef Land (Savinova, Skaare and Gabrielsen, unpublished data).

In glaucous gulls from Bjørnøya the levels of PCN ranged from 1.3 to 126 ng/g (lipid weight (lw)) in plasma and 1.8 to 162 ng/g (lw) in eggs (Verreault et al. 2005a). Of the PCB metabolites the hexa-chlorinated methylsulfonyl ($MeSO_2$)-PCB congener (range 13.5-551 ng/g (lw) was found in the plasma whereas the penta-chlorinated congeners 3'- and 4'-$MeSO_2$-CB101 (range 4.5-38.1 ng/g (lw)) dominated in the eggs from glaucous gulls (Verreault et al. 2005a). Of the PBDEs the plasma levels in glaucous gulls varied between 8.2 and 67.5 ng/g (ww) (Verreault et al. 2005b). The levels of PBDEs were 10 times lower than the concentration of sum PCB (sum 47 congeners). Of the brominated compounds that have been reported as naturally-occurring in the marine environment and/or metabolites of PBDEs, the methoxylated (MeO) and hydroxylated (OH)- PBDEs were found in plasma of glaucous gulls (Verreault et al. 2005b). The level of perfluorooctane sulfonate (PFOS) in plasma (48.1-349 ng/g (ww)) was the most pervasive perfuorinated alkyl substance (PFAS) found in glaucous gulls. The levels of PFOS in glaucous gulls are also the highest reported in any arctic seabird (Verreault et al., submitted).

6. Arctic fox

The arctic fox is an opportunistic feeder, which eats cached food, scavenged carcasses of seabirds, terrestrial birds, seals, Svalbard reindeer and Svalbard ptarmigans (Fuglei 2000). Some arctic foxes follow polar bears on the sea ice, feeding on remnants of seals killed by polar bears (Hiruki and Stirling 1989). The levels of PCBs in arctic fox show a great variation (1.0-45 µg/g), which probably reflects what they feed on (Wang-Andersen et al. 1993; Severinsen and Skaare 1997). Foxes sampled on the coast, which are feeding on marine species, have higher POP levels than foxes living inland, which feed on reindeer carcasses and terrestrial birds. Foxes in Canada, inland Iceland, and Alaska have lower POP levels than foxes along the coast of Iceland and on Svalbard (AMAP 2004). The reason for this may be that foxes from the coast of Iceland and Svalbard eat more marine species than foxes in Europe and in Canada.

7. Seals

The POP levels in different seal species from the Barents Sea area are low (10-50 times lower) when compared to seal species from the North Sea and the Baltic Sea. The PCB levels in ringed seal (*Phoca hispida*), harp seal (*Phoca groenlandica*), bearded seal (*Erignathus barbatus*) and Atlantic walrus (*Odobenus rosmarus*) are found at concentrations averaging 1.0-5.0 µg/g (ww) (AMAP 1998; 2004). The PCB levels in blubber of harp seals from the East Ice (Russian area) were three times higher (3.0 µg/g) (ww) than the levels in West ice (Greenland area) (Espeland et al. 1997; Kleivane et al. 1997). However, this comparison is confounded by a significant difference in blubber thickness between the two areas (less blubber in the East Ice seals), which could have increased the pollution levels in seals from the east. A geographical study of PCBs and DDTs in ringed seal blubber has shown higher levels - in samples from the Yenisey Gulf in the Russian Arctic, Svalbard and eastern Greenland compared to western Greenland and the Canadian Arctic (Muir et al. 2000). The ringed seal from Svalbard has PCB levels four times higher than seals from the western Canadian Arctic and Alaska (Wolkers et al. 1998; Muir et al.

2000). The highest levels of toxaphene, a chlorinated pesticide, have been found in harp seal collected east of Svalbard. The levels of toxaphene (Tox 26 and Tox 50) were 20 times higher than in ringed seal samples west of Svalbard (Wolkers et al. 1998; Wolkers et al. 2000).

In ringed seal, the levels of PBDEs were 10-20 times higher than Canadian seals. However, the levels were substantially lower than in seals from more southern latitudes (Wolkers et al. 2004).

8. Whales

The levels of POPs in different whale species also reflect their feeding habits. Beluga (*Delphinapterus leucas*), narwhal (*Mondon monoceros*) and harbour porpoise (*Phocoena phocoena*), which feed mainly on fish, have higher POP levels (5-6 µg/g) (ww) in their blubber than minke whales (*Balaenoptera acutorostrata*) (2-4 µg/g) (ww), which feed on krill and amphipods. Levels of POPs increase with age and there are large differences between males (highest level) and females. There are also geographical differences in the POP levels in whales. PCBs and DDTs increase from the west to the east in minke whales (Hobbs et al. 2002). In minke whales, the levels of POPs are also higher on the coast of Lofoten Island in northern Norway compared to the Svalbard and the Kola areas (Kleivane and Skaare 1998). In beluga whales most POPs are lower in southern Alaska than in eastern Canada and Svalbard (Wolkers 2002). The levels in recent measurements from the northeast Atlantic are 2-3 times lower than those made in the 1990s. This may be explained in part by changes in feeding habits to almost exclusively krill after the collapse of the capelin (*Mallotus villosus*) stocks in 1986 (AMAP 2004). Geographical differences in POP levels can also be explained by differences in migration pattern.

In killer whales (*Orcinus orca*) from Lofoten, which feed on herring, the highest PCB and DEE levels have been found of all whale species studied so far (Wolkers, pers. com.). The PCB levels were comparable to the levels found in polar bears from Svalbard.

Levels of PBDEs in beluga whales from Svalbard were 10-20 times lower than beluga whales from Canada. In addition, the levels in beluga whales were lower than in whales from more southern latitudes (Wolkers et al. 2004). The reason for higher levels in seals and whales in the European Arctic compared to the Canadian Arctic is probably due to a more effective PBDE transport from lower latitudes to the European Arctic.

Very high PCB levels (20-30 µg/g) (ww) have been found in harbour porpoise blubber samples from northern Norway. The levels of PCBs and DDTs are comparable to the Baltic Sea and North Sea and are the highest measured in any whale species from the Arctic (Berggren et al. 1999). The levels in harbour porpoises from Greenland are much lower. The reason for the high PCB levels in harbour porpoise from northern Norway is not fully understood. The levels of PCBs in pilot whales (*Globicephala melas*) from Faeroe Islands are higher than most other whales. Levels of other POPs are also comparably high (Dam and Bloch 2000). For example, the levels of brominated compounds in pilot whales are an order of magnitude higher than in other arctic marine mammals examined to date (van Bavel et al. 2001). Narwhal from west Greenland and the Canadian Arctic have similar POP levels. The levels in narwhal from Svalbard were considerably higher (Wolkers 2002).

9. Polar bears

Polar bears are widely distributed throughout the Arctic. They move south with the ice in the autumn and winter and then north as the pack ice melts in the spring and summer. Their primary prey are ringed seal and bearded seal (Stirling et al. 1982). Kleivane et al. (2000) also showed that polar bears from eastern Svalbard feed upon harp seals. Polar bears eat almost exclusively the blubber of seals. Polar bears have a very good capacity for oxidative biotransformation (e.g. via cytochrome P450 (CYP) 1A enzymes) of most POPs, as evidenced by high levels of PCB metabolites (i.e. OH-PCBs and $MeSO_2$ –PCBs) found in plasma and tissues (Letcher et al. 1996; Sandau et al. 2000; Sandala et al. 2004; Verreault et al. 2005c).

Two studies (Andersen et al. 2001; Lie et al. 2003) investigating PCB and pesticide concentrations in polar bears from Svalbard, Frans Josef Land, Kara Sea, East Siberian Sea and Chukchi Sea (samples collected between 1987 and 1995) combined with earlier findings (Bernhoft et al. 1997; Norstrom et al. 1998) indicated that polar bears from Frans Josef Land and the Kara Sea have the highest sum PCB, sum chlordane and sum DDT levels among arctic animals. A decreasing trend was seen both east and west of these regions. At Svalbard, 35 mother/cub pairs were sampled between 1995 and 1998 (Lie et al. 2000) and the sum PCB geometric mean concentrations in plasma were 12 300 ng/g (lw) in cubs, 5820 ng/g (1w) in females with cubs, 6820 ng/g (1w) in yearlings, and 2945 ng/g (1w) in females with yearlings. In cubs, the sum PCB concentrations were significantly higher than in the other three groups. The reason for a higher sum

PCB concentration in cubs was due to lactational transfer from their mothers.
In a recent circumpolar study (1996-2002) of polar bears from Alaska, Canada, Greenland and Svalbard the PCB and DDT levels were highest in the East Greenland and the Svalbard population (Fig. 2). In this study the levels of PCB and DDE levels were 6 and 3 times higher, respectively, in polar bears from east Greenland and Svalbard when compared to polar bears from Alaska and Canada (Verreault et al. 2005c). In polar bears from Svalbard the levels of PCNs ranged from 1.2 to 52 ng/g (lw) in fat samples. Compared to other marine species (e.g. the beluga whale, 0.04-0.4 ng/g (lw)) the PCN concentration is much higher (Gabrielsen et al. 2004). Of the PCB metabolites, a sum $MeSO_2$-PCB (ranging between 162 to 279 ng/g (lw)) was found in the fat samples of polar bears (Verreault et al. 2005c). The concentration of sum OH-PCB in Svalbard polar bear plasma from females ranged between 4.15 and 394 ng/g (ww) (Verreault et al. 2005b)(data for East Greenland polar bears see Sandala et al. 2004). PCB-metabolites are transferred from the polar bear females to the cubs

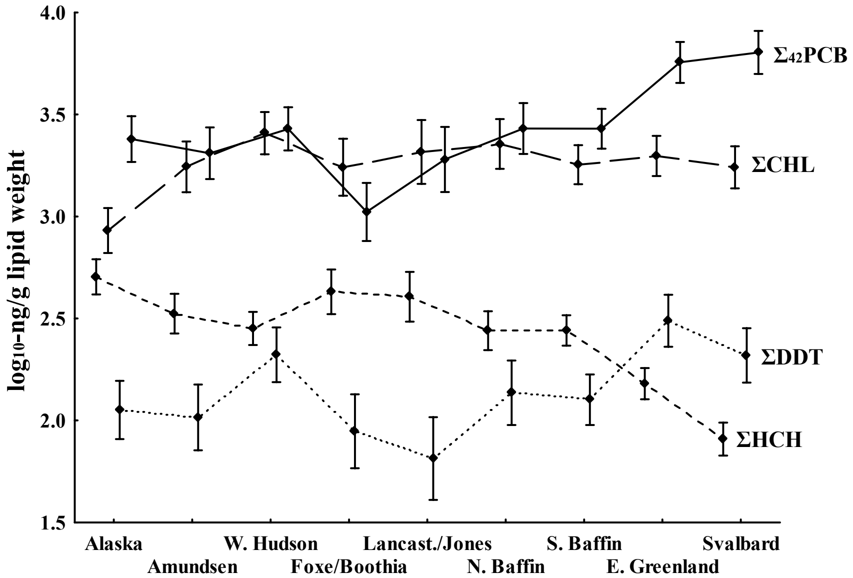

Fig. 2. Age-adjusted mean Σ (chlordanes) CHL, ΣHCH, ΣDDT, and Σ_{42}PCB concentrations (log_{10}- transformed ng g^{-1} lipid weight) plotted with 95% confidence intervals (vertical bars) in adipose tissue of female polar bears from nine Arctic and Subarctic populations listed in order of longitude (Verreault et al. 2005c).

via milk, resulting in concentrations that are approximately three times higher in the cubs than in the mother. While polar bears in the European Arctic usually have the highest levels of contaminants, the levels of PBDEs are low compared to Alaska, Canada and Greenland (Muir et al., in prep.). PBDEs in polar bear from Svalbard varied between 2.7 and 9.7 ng/g (ww). Of the brominated metabolites both the MeO and OH PBDEs (partly natural components in the marine environment, e.g. found in algae and sponges) were found in plasma of polar bears (Verreault et al. 2005b). Because the PBDE congener profile in the polar bear is comprised almost uniquely of PBDE 47, this may indicate that the polar bears have an effective metabolism of most PBDEs. The levels of PFOS (range 56.7 to 150 ng/g (ww)) were the most pervasive PFASs found in plasma from polar bears (Gabrielsen et al. 2004). In a geographical trend study, the PFOS concentration in liver samples of polar bears from south Hudson Bay and east Greenland were significant higher than in polar bears from Svalbard, high Arctic and the western Northwest Territories (Canada). The high concentration in polar bears from south Hudson Bay and east Greenland was suggested to be due to the proximity to sources in Europe and eastern North America (Smithwich et al. 2005).

10. Temporal trends in POPs in arctic seabirds and marine mammals

In general, the levels of most POPs- (i.e. PCB, DDT and HCB), which have been taken out of production and use in the 1970s and 1980s, show a decline. However, the decline has occurred with varying rates in different regions of the Arctic (AMAP 1998; 2004). This is also an explanation why animals differ in regional trends. Trend studies of DDT and PCB levels in seabird eggs and marine mammals (polar bears, seals and whales) from the Arctic and sub-Arctic show a clear reduction during the last 15-20 years (Braune and Donaldson 2000; Barrett et al. 1996; Henriksen et al. 2001; Verreault et al. 2005c; Muir et al. 2001; Stern and Addison 1999). In seabird eggs from northern Norway, there is a reduction in DDT and PCBs of 80-90 % between 1973 and 1993 (Barrett et al. 1996). In the Canadian Arctic, a similar reduction has been shown in eggs from guillemots, northern fulmars and black-legged kittiwakes (Braune and Donaldson 2000). In marine mammals (seals and whales), the reduction in DDT and PCBs are not great as those observed in seabirds (AMAP 2004). In polar bears from Svalbard, both PCB and HCB decreased significantly during the 1990s (Henriksen et al. 2001). The shape of the decline for polar bear suggests a levelling off in the latter part of the sampling period. Data from beluga also indicate that decline will be slow during the coming decade.

While PCBs and pesticides seem to be declining in the environment, the PBDE concentrations in arctic wildlife are increasing. Although the levels in the Arctic are still relatively low, a study in Canada showed a dramatic increase over a period of 15 years. In samples from blubber of ring seal and beluga, the levels increased by 3-9 times since the beginning of 1980s (Ikonomou et al. 2002). Generally, a doubling every five years seems to be the rule. Herring gull eggs from the Great Lakes in North-America show a similar increase as seen in ringed seal (Norstrom et al. 2002). The sources of environmental PBDE contamination include leakage from consumer products and industrial facilities that manufacture PBDEs as well as from disposal sites of products containing PBDEs. There are no temporal trend data from the European Arctic. If nothing is done to the "PCB of the 21st century" (i.e. proper restriction) the PBDEs may reach the same levels as PCBs in a few decades.

11. Effect studies

Ecological risk assessment of contaminants in arctic animals comprises assessments of exposures and effects, and risk characterization. In order to identify possible effects of contaminant exposure in free ranging animals from remote areas, two approaches are generally used. The first involves extrapolation and comparison. Possible effects are determined by comparing levels of contaminants in the species of interest to levels known to cause toxic effects in laboratory species (e.g., rats) or from observations on affected animals in the wild (AMAP 2004). The second approach investigates biological and potential toxic effects by studying biomarkers (indicators of biological responses) of contaminant exposure (AMAP 2004). Such studies may reveal subtle biological changes/disturbances associated with low and sub-lethal concentrations of contaminants. However, the significance of such effects for the health of the individual is often not obvious, and validity of extrapolating between biomarker responses measured in individuals and population level effects is not easily established. Thus, ecological risk assessment of contaminant exposure in free-ranging species will always be rather difficult without captive studies to demonstrate direct cause and effects (AMAP 2004).

Ecological risk assessment of contaminants in animals in the Arctic comprises assessments of exposures and effects, and risk characterization.

12. Effects of POPs in arctic animals

In field studies of Arctic free-living wildlife, it is difficult to prove a causal relationship between a suspected effect and specific contaminants. Thus, assessments of possible effects are based on associations between biological parameters and tissue contaminant concentrations. Some biological responses (or *biomarkers of exposure*) are quite specifically related to contaminant exposure (*e.g.* cytochrome P450 enzyme activities, accumulation of highly carboxylated porphyrins and thyroid hormone disruption), but are difficult to interpret in terms of consequences for the health of the individual, and populations (Peakall 1992). Other responses may be more directly coupled to the survival or reproduction of the individual, but influenced by a large variety of confounding factors.

Sometimes it is possible to compare the levels of POPs found in wildlife with effect thresholds derived from laboratory studies or environmental levels that are believed to have been implicated in observed effects (e.g., declines in bird populations). Such a process is not simple. For many arctic species, laboratory studies do not exist and comparisons should be made with caution since there are problems with extrapolating data across species. Also, unlike most laboratory studies, animals in the wild are exposed to a suite of different contaminants. They are also usually exposed to lower concentrations than laboratory animals. Furthermore, wild species are exposed to weathered mixtures of contaminants due to changes in composition of many POPs caused by abiotic degradation, metabolism, and filtering through the food web. Differences in species sensitivities to the effect of POPs also make it difficult to know which laboratory species best represent those in the Arctic. Arctic species differ from laboratory animals due to their fat dynamics, differences in life styles and life strategies, and differences in toxicokinetics (AMAP 2004).

In studies, which investigate biological and potential toxic effects by studying biomarkers of contaminant exposure, there are also limitations. It is not possible to determine causality, only that a statistical association has been found between a biomarker and the contaminant in question. Most POPs co-vary, and thus, it is not possible to state equivocally that the biomarker response has been caused by a particular contaminant. There may be other contaminants not analyzed, or biological parameters, that are just as important, or the response may be a result of synergistic, additive or antagonistic effects of contaminant mixtures. Biological variables such as age, sex, body condition, and presence of disease, or other stresses may also act as confounders, as they can cause similar biological effects as those seen from POPs. Therefore, for most reported biological effects in wildlife, the evidence for a causal link with a specific chemical contaminant is weak or non-existent. This is mainly due to the complexity of contaminant mixtures, the lack of data on chemical exposure, species sensitivity and mechanisms of action. Understanding the linkage between contaminants and health effects (e.g., reduced fitness or immunosuppression) is most likely to come from studies in laboratory animals. Crucial in establishing causal evidence for chemical-induced wildlife effects are semi-field or laboratory studies using the wildlife species of concern. Semi-field studies represent a useful approach to bridge the gap between the controlled conditions of laboratory experiments and environmental-exposure conditions in the field (AMAP 2004).

In the following assessment, results are presented in which associations have been reported between biological parameters and contaminant levels in glaucous gulls and polar bears from the Svalbard area. Levels of specific POPs are compared to no-observed adverse effect levels (NOAEL) or no-observed effect levels (NOEL), and the lowest observed adverse effect level (LOAEL) or lowest observed effect levels (LOEL) known to cause subtle effect in sensitive species. The purpose of these comparisons are to assess the likelihood that glaucous gull and polar bears may be at risk for effects of some POPs and to identify the contaminants associated with these effects.

12.1 Glaucous gulls

The NOEL range for sum PCB was 1.3 to 11.0 µg/g (ww) for effects related to reproductive success in seabirds. The LOEL range for various endpoints of reproductive success (hatching success, egg mortality, deformities, and parental attentiveness) ranged from 3.5 to 22 µg/g sum PCBs/g (ww) in eggs. For adults, sum PCB concentrations in brain tissue higher than 300 µg/g (ww) were associated with mortality. For dioxin-like compounds, the NOAEL range for reproductive effects was 1.5 to 200 pg toxic equivalency quotient (TEQ)/g (ww) in eggs, and the LOAEL range for various reproductive endpoints (deformities, hatching success, and mortality) ranged from 10 to 2200 pg TEQ/g (ww) in eggs (Barron et al. 1995; Giesy et al. 1994; Bosveld and van den Berg 1994). In eggs from peregrine falcons, DDE residues of 15 to 20 µg/g (ww) would result in eggshell thinning (Peakall et al. 1990).

In glaucous gull eggs from Svalbard/Bjørnøya, the sum PCB is close to or above NOEL and LOEL levels found for reproduction effects. Glaucous gull eggs from Bjørnøya are close to or above LOEL levels which have effects on hatching success in chickens and NOEL levels for hatching success in Foster terns (*Sterna forsteri*). The sum PCB in eggs from Bjørnøya is not above the levels that are related to increased egg mortality. The sum PCB found in liver from glaucous gulls from Bjørnøya is above levels reported to cause toxic effects in birds (AMAP 2004). The TEQ concentration was calculated to 2500 µg/g in glaucous gulls (Daelemans et al. 1992). These TEQ levels exceed all NOAELS and LOAELS for reproductive effects and LD_{50} in the range of other bird species (AMAP 2004). Sum DDT levels in eggs and liver exceed Canadian and U.S. Environmental Protection Agency (EPA) guideline levels for protecting wildlife. Thus glaucous gulls that prey on seabird eggs, chicks and adults have intake of sum PCB, sum DDT and TEQs high enough to cause effects.

12.1.1 Reproductive effects

Glaucous gulls from Bjørnøya with high levels of sum PCB were more often away from the nest and spent more time away than birds with low levels. Increased time away from the nest in glaucous gulls with high PCB levels may indicate that they needed more time to search for food than individuals with low PCB levels (Bustnes et al. 2001). Thus, chick survival may decrease for parents with elevated PCB exposure due to the fact that their parents spend less time protecting the chicks.

In glaucous gulls from Bjørnøya, the females with high POP levels (HCB, oxychlordane, DDE and PCBs) had a greater possibility for embryo mortality or unfertilized eggs than females with low POP levels. Also, the body condition at hatching was poorer in the first chick in a clutch (glaucous gulls normally lay 2-3 eggs) compared to the other chicks in females with high POP levels, suggesting that the female shunts a larger percentage of POPs to the first chick in the clutch. A negative relationship was also found between chick body condition (e.g., body mass) and the parents' blood concentration of HCB, β-HCH and PCB 28 for the second chick in a clutch. Except for the negative relationship found between the concentration of some POPs and date of egg laying no relationship was found toward other reproductive parameters (e.g.; clutch size, egg size, number of days incubating, predation of eggs and early chick survival) and the level of POPs (Bustnes et al. 2003).

Many POPs can disrupt endocrine function (Colborn et al. 1993). Female glaucous gulls from Bjørnøya, with high POP levels, produced more male chicks compared to females with low POP levels (Erikstad et al. 2005), strongly indicating that POPs are acting as endocrine disruptors in these birds.

In glaucous gulls from Bjørnøya, a significant relationship was found between levels of POPs and asymmetric wingfeathers. The effects were stronger for HCB than PCB and DDE (Bustnes et al. 2002). Asymmetric wingfeathers are an indication of stress and the observation of asymmetry may indicate that gulls with elevated POP concentrations are under increased stress during moulting.

12.1.2 Cytochrome P450 activity

In glaucous gull liver samples (Henriksen et al. 2000), a weak positive association was found between hepatic 7-ethoxyresorufin-O-dethylase (EROD) activity and PCB-levels. This may indicate enzyme induction by PCBs, but the EROD activities were low compared to other studies on fish-eating birds. Microsomal testosterone hydroxylase activity was only observed at the 6β-position and could not be related to levels of POPs. The low P450 associated enzyme activities in glaucous gulls suggests that they have a low capacity for metabolizing POPs, which may contribute to the high accumulation of POPs in this species.

In a laboratory study of glaucous gull chicks on Svalbard, a significantly higher level of CYP 1A enzymes was found in the liver in males from a group that were feed a diet of POPs (a natural diet they receive in the wild) compared to a group of males which were feed clean food (hen egg with little or no POPs) (Østby et al. 2005). Evaluation of blood POP levels demonstrated that the chicks fed a natural diet had higher POPs than the clean diet and there was also a positive correlation between blood POP levels and CYP 1A enzyme induction.

When making comparison of the TEQ value in glaucous gulls and several arctic seabird species (little auk, Brünnichs guillemot, kittiwake and black guillemot) the EROD levels were higher in little auk and lower in Brünnichs guillemot, kittiwake and black guillemot compared to glaucous gulls (Borgå et al. 2005b). Since the TEQ values in arctic seabirds were 100-200 times lower than the LOEL for CYP induction in common tern, it is assumed that most birds are below threshold levels for biological effects (Borgå et al. 2005b).

12.1.3 Effects on the hormone system

In male glaucous gulls from Bjørnøya a significant negative correlation was found between the PCB and HCB levels, and thyroxin (T4) levels and T4- to T3-ratios in the blood (Fig. 3). HCB, oxychlordane and PCB 118, 114 and 105 were the contaminants that had the strongest correlation to the decrease of the T4/T3-ratios in these glaucous gulls. The levels of T4 and T4/T3-ratio were lower in glaucous gulls from the colony that had highest levels of POPs when compared to the colony with low POP levels

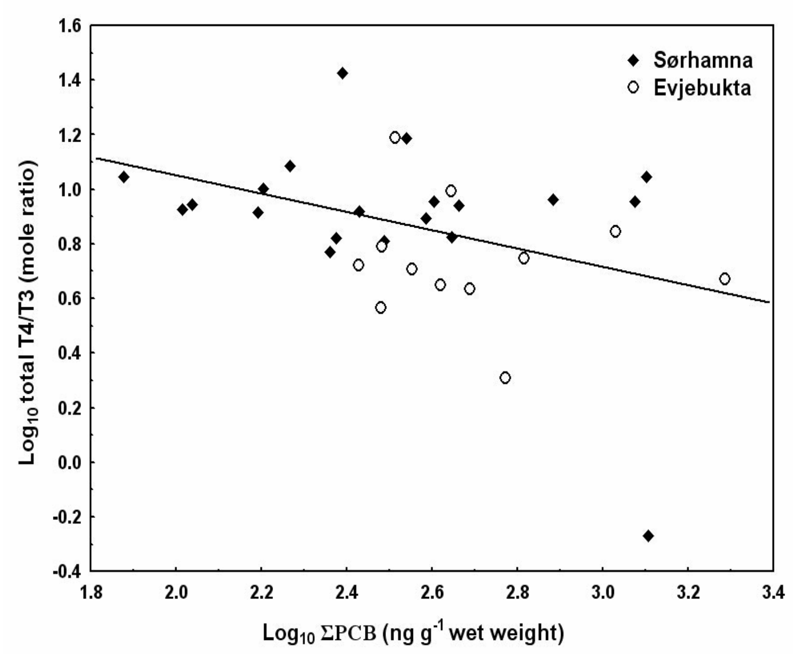

Fig. 3. Relationship between the total T4:T3 (thyroxin:triiodothyronine) ratios ($\log_{10}$ mole ratio) and blood levels of $\sum$ PCB ($\log_{10}$ ng/g wet wt), corrected for extractable plasma fat (%) and day of capture, for male glaucous gulls (n = 32) breeding in two colonies (Evjebukta and Sørhamna) at Bjørnøya (Norwegian Arctic) ($r = -0.40$, $p = 0.031$) (ng g^{-1} w.w.: nanograms per gram wet weight) (Verreault et al. 2004).

(Verreault et al. 2004).

12.1.4 Effects on the vitamin system

Many POPs, in particular 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and dioxin-like PCBs, can interfere with vitamin A homeostasis in experimental animals (Zile 1992). Vitamin A is mainly stored as retinyl palmitate in lipid droplets of liver stellate cells (Blomhoff 1994). In herring gulls from colonies in eastern Canada, liver retinoid concentrations were inversely related to TCDD-concentrations in eggs from the same colonies (Spear et al. 1986; Anonymous 1991). In the sample of forty glaucous gulls from Bjørnøya, no significant relationships were found between liver retinoid concentrations and PCB levels (Henriksen et al. 2000). The hepatic vitamin A stores in glaucous gulls from Bjørnøya were larger than in herring gulls from contaminated locations in North America

(Anonymous 1991) suggesting that the present contaminant levels do not influence vitamin A in gulls from Svalbard.

12.1.5 Genotoxic effects

In a laboratory study of glaucous gull chicks from Svalbard, a significant increase in levels of DNA-adducts (a measure of genetic mutations) was found in the group receiving a diet of POPs compared to a clean group. However, no clear relationship was found between levels of DNA adducts and POPs between the exposed and clean group (Østbye et al. 2005). The small sample size of birds included in this study may be one reason for the lack of statistical significance.

The frequency of chromosome abbreviation in lymphocytes was also higher in the POP-exposed group, when compared with the clean group. Although, no correlation was found for frequency of chromosome abbreviation and concentration of some of the POPs analyzed (Krøkje et al. 2005), suggesting that the present contaminant levels have genotoxic effects in gulls from Svalbard.

12.1.6 Effects on the immune system

Suppressed immune function has been associated with exposure to POPs in herring gulls from the contaminated Great Lakes area (Grasman et al. 1996). If establishment and/or survival of intestinal macroparasites are limited by host immune function, we would expect increased parasite intensities in animals with high organochlorine burdens, such as the glaucous gull. In a sample of 40 glaucous gulls from Bjørnøya in the western Barents Sea, numbers of intestinal macroparasites were compared with hepatic levels of selected POPs (Fig. 4) (Sagerup et al. 2000). After controlling for nutritional condition, no single parasite species was significantly associated with concentrations of PCBs or chlorinated pesticides. However, the intensity of all nematodes grouped together was positively correlated with all the 14 POPs measured, and significantly with 10 of them. The strongest correlations were with p,p'-DDT, Mirex, sum PCB, and PCB congeners 28, 118, 153, 138, 170, and 180. Although correlative, no immunological data were collected. However, these results suggest that POPs might affect immune function in the glaucous gull.

In glaucous gull from Bjørnøya a correlation was found between blood levels of POPs and increased levels of white blood cells. Females with high levels of HCB and oxychlordane have less possibility to initiate immune responses than glaucous gulls with low levels of these contaminants (Bustnes et al. 2004).

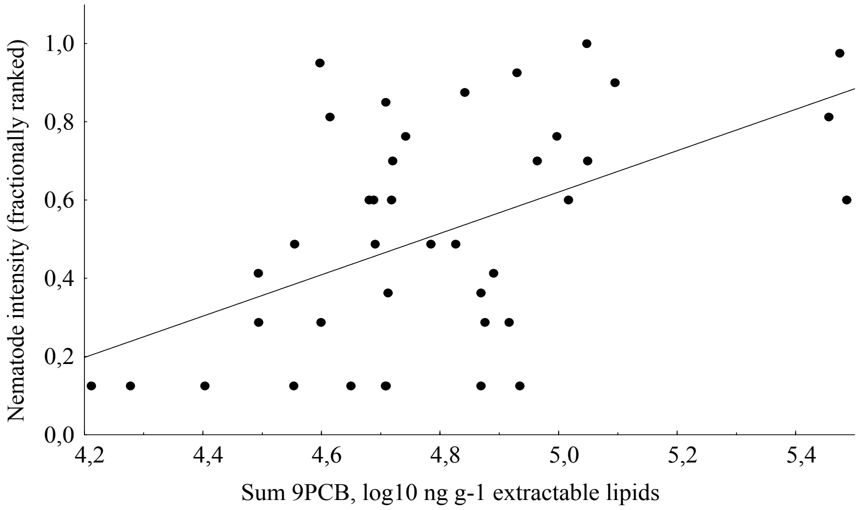

Fig. 4. Correlation between intestinal nematode infection intensity (fractionally ranked) and ∑ 9 PCB concentrations (log_{10} ng/g lipid weight, liver) in glaucous gulls from Bear Island (n = 40, R^2 = 0.26, P = 0.001) (Sagerup et al. 2000).

In a Svalbard laboratory study of glaucous gull chicks (56 days old chicks) fed a diet of POPs, a negative effect was found between POP levels in the diet and immunoglobulin (both IgG and IgM) concentrations when compared to a control group fed a clean diet (Larsen et al. 2004). The exposures of POPs through their diet appeared to cause a decrease in the immuno-competence and resistance of these chicks, which could impact their resistance to disease and infection.

12.2 Polar bears

In mink (*Mustela vison*), levels of 1230 ng/g (ww) of Aroclor 1254 in liver, was associated with impaired reproductive success (Platonow and Karstad 1973). Reduced growth and survival of mink kits were observed in female mink with 2000 ng/g (ww) Aroclor 1254 in liver tissue (Wren et al. 1987). An EC_{50} (effective concentration causing a response in 50 % of the treated organisms) in adult females for litter size was calculated to be 40 000 to 60 000 ng total PCB/g (lw) (approximately 1200 ng total PCB/g (ww) in muscle) and 2400 ng/g in muscle for kit survival (Leonards et al. 1995). Captive harbour seals (*Phoca vitulina*), exposed to PCBs via different fish diets, had reduced reproductive success at sum PCB levels of 25 000 ng/g (lw) in blood (Reijnders 1986). The EC_{50} for dioxin-like compounds was calculated to be 160 pg TEQ/g (ww) (5300-8000 pg/g (lw)) in mink muscle for litter size and 200 pg TEQ/g (ww) (6600-10000 pg/g (lw)) for kit survival (Leonards et al. 1995). Assessment based on subtle neurobehavioural effects in offspring of rhesus monkeys treated with PCBs and human mothers eating PCB contaminated fish, have resulted in an estimated LOAEL for effects on short term memory of 500-1000 ng/g (lw), and a NOAEL for effects on visual memory of 1000 ng/g (lw) in offspring or cord blood serum (Ahlborg et al. 1992). The LOAEL for immunosuppression is 21 000 ng sum PCB/g (lw) in rhesus monkeys (Tryphonas 1994).

In some polar bears from Svalbard, sum PCB concentrations are above the NOAEL and LOAEL levels for neurological-behavioural effects on their offspring, based on information studies of monkeys and humans and NOEL levels for kit survival in minks. The sum PCB in polar bears from Svalbard is also above NOEL and LOEL for reduced vitamin A in otters. Some individuals of polar bears above 3 years of age are above reported LOAEL levels for reduced immune function (based on information from monkeys). Some polar bears also have elevated levels of PCBs, which is correlated to low reproduction in seals and EC_{50} for reduced kit survival in mink (de Wit el at. 2004).

12.2.1 Reproductive effects

A negative effect on the reproduction and survival rate of young seals as result of PCB contamination has been shown in the Baltic (Olsson et al. 1992). Epi-zoological studies of polar bears indicate a reduced reproduction and survival of cubs at Svalbard compared to other arctic areas (Wiig 1995; Wiig et al. 1998), although the relationship between cub survival and POP levels has not been established. From laboratory studies on mammals, it is shown that high intake of PCB in a critical period may have an influence on the fetus and decrease in the survival of the offspring.

In Canada it was found that polar bear mothers with high levels of POPs (in the milk) had a greater chance for loosing the cubs than mothers with low POP levels. Mothers, which lost their cubs, had levels of PCBs, which were 3 times higher than females that did not lose their cubs (Nordstrom 1999).

In polar bears from Svalbard, the age composition in the population was different from the Canadian population. Female polar bears, which were more than 16 years old, constituted 12.7 % at Svalbard compared to 40.3 % in Canada (Wiig et al. 1998; Derocher et al. 2003), signifying that POPs may have an influence on the polar bear population at Svalbard.

It has also been hypothesized that PCBs and other POPs may be involved in the relatively high incidence of female pseudohermaphroditism in polar bears from Svalbard (Wiig et al. 1998). In polar bears from Svalbard, pseudohermaphroditism was found in 3 % of the total amount of female polar bears caught (Wiig et al. 1998). In female polar bears from Canada and Alaska, no such malfunction has been found (Andrew Derocher, pers. com.). Because POPs cause endocrine disruption, high POP levels in polar bears at Svalbard may be one reason for the observed pseudohermaphroditism.

12.2.2 Cytochrome P450 activity

Many planar halogenated hydrocarbons (e.g., dioxin-like compounds, which include some of the PCBs) have a common pattern of toxic effects that is associated with affinity to the aryl hydrocarbon (Ah) receptor and induction of isoforms from the CYP1A subfamily (Poland and Knutson 1982). Preliminary results from 13 polar bears from Svalbard show a positive correlation ($P = 0.026$) between CYP1A and total PCB concentration in white blood cells (Skaare et al. 2000).

In male polar bears from Canada, CYP 1A1 levels were correlated to mono-*ortho* and non-*ortho* substituted PCBs. CYP 2B was correlated to the concentration of chlordanes (mainly oxychlordane and nonachlor) and total mono- and non-*ortho*-substituted PCBs (de Wit et al. 2004).

12.2.3 Effects on the hormone system

The thyroid hormones are important for regulating metabolism and heat production. For arctic species thyroid hormones are very important for their adaptations to a cold climate. In young animals, the thyroid hormones are also important for the growth and development of the central neural system. Hormone data from polar bears at Svalbard (high POP levels) and Canada (low POP levels) show that the levels of thyroid hormones (e.g., T4) are negatively correlated to PCBs (Skaare et al. 2001). In polar bears from Svalbard, high levels of POPs, were negatively correlated to thyroid hormone levels (total T4/free T4) with POPs explaining 30 % of the variation in these ratios (Skaare et al. 2001). The correlation was strongest for sum PCBs and HCB. In another study of polar bears from Svalbard, a negative correlation was found between sum PCBs and total (t) T4, free (f) T4, fT3, tT4/tT3, tT3/fT3 and fT4/fT3. More thyroid hormone variables from female polar bears were affected when compared to males (Braathen et al. 2004). This may indicate that female polar bears are more vulnerable to effects of PCB on thyroid hormones than males.

Testosterone is an important male hormone, which is involved in sexual development. In males of polar bears from Svalbard, a negative relationship was found between the levels of sum PCB/sum pesticides and testosterone levels. The sum of PCB and sum of pesticides explained 57 % of the variation in testosterone levels (Oskam et al. 2003).

In female polar bears with cubs from Svalbard, a positive relationship was found between sum PCB and the level of the sex hormone progesterone (Haave et al. 2003). This may indicate that the exposure of PCB might disturb the timing of ovulation (release of eggs) in female polar bears and thereby impacting the possibility for fertilization. No relationship was found between sum PCB and estrogen in female polar bears from Svalbard (Haave et al. 2003).

Cortisol is involved in the body metabolism and is released during stress in animals. In polar bears from Svalbard a negative relationship was found between POP levels and the level of cortisol in the blood. The sum PCB and sum pesticides explained 27 % of the variation in cortisol levels (Oskam et al. 2004). This may indicate that the exposure of PCB can disturb metabolism and the release of stress hormones.

Female polar bears from Svalbard and the northern part of the Barents Sea, with and without cubs, had significantly higher progesterone levels than polar bears from other areas. However, no relationship was found between PCBs and progesterone levels within the Svalbard and Barents Sea bears (Haave et al. 2003).

Taken together, these findings strongly indicate that the present level of POPs may have an influence on the endocrine system on polar bears from Svalbard.

12.2.4 Effects on the vitamin system

Vitamin A homeostasis can be severely altered by exposure to POPs, and several vitamin A deficiency-like symptoms are associated with intoxication by poly-halogenated aromatic hydrocarbons (Zile 1992). Some PCB metabolites can disturb the formation of the protein complex responsible for retinol (vitamin A) and thyroxin transport (Brouwer et al. 1986). In harbour seals, which were fed fish from polluted waters, retinol and thyroid hormones in blood plasma were depressed, compared to seals fed fish from less polluted waters (Brouwer et al. 1989). In polar bears from Svalbard, the level of PCB, HCB and HCH was negatively correlated to the level of plasma retinol. POPs explained 12 % of the variation in retinol levels (Skaare et al. 2001). In another study from Svalbard, no relationship was found between the levels of PCB and retinol levels (Braathen et al. 2004).

When data from Svalbard (high POP levels) and Canada (low POP levels) were compiled and compared, a negative relationship was found between PCBs and retinol. A positive relationship was found between OH-PCBs and retinol levels (de Wit et al. 2004).

12.2.5 Effects on the immune system

Many studies have demonstrated adverse effects of PCBs and dioxin-like compound on the immune system of experimental animals (see *e.g.* review by Tryphonas 1994). In captive harbor seals fed fish highly contaminated with POPs, several measures of cell-mediated and humoral immune function were depressed compared to seals fed less contaminated fish (de Swart et al. 1996). Immunoglobulin G (IgG) is the most abundant class of antibodies in mammals, and consequently an essential part of the humoral immune system. In a sample of 52 polar bears from Svalbard, age- and sex-corrected levels of IgG were negatively correlated with sum PCB and HCB (Bernhoft et al. 2000). The PCB levels in bears were within in the range found to give immunotoxic effects in experimental animals (Bernhoft et al. 2000). In a subsequent study from Svalbard, which included more animals, the same negative relationship was found between IgG and PCBs. The sum PCB and sum pesticides explained 53 % of the variation in IgG levels (Lie et al. 2004). In polar bears from Svalbard, the ability to produce anti-bodies against flu- and rheo-virus and tetanus toxid after vaccination is 40-60 % explained of the sum PCB and sum of pesticides (Lie et al. 2004). The ability to produce anti bodies against *Mannheimia haemolytica* (earlier *Pasteurella* sp.) is 59 % explained by sum PCB and sum of pesticides (Lie et al. 2004). The lymphocyte function after *in vitro* stimulation by mitogens (PHA, Con A, PWM, LPS and PPD) and antigens (tetanus toxsoid and KLH) is 45-72 % explained by sum PCB and sum of pesticides (Lie et al. 2005). The association between POPs and IgG could indicate a contaminant-induced immunosuppression in Svalbard polar bears, with possible consequences for susceptibility to infectious diseases. This may indicate that the present contaminant levels may affect the health and the status for the polar bear at Svalbard.

13. Conclusion

The levels of POPs in the arctic environment are generally lower than found in more temperate regions. The present article shows that, while the levels of some POPs are decreasing (e.g., PCBs and DDTs), the levels of other

POPs (brominated flame retardants and fluorinated) are increasing in the arctic animals. The main reason for this increase is the increase in the global production and use of these contaminants. The POP levels found in polar bears and glaucous gulls from these areas exceed the effect thresholds as demonstrated by laboratory and field studies, which indicate present POP level influence behavioural-, biochemical-, physiological- and immunological parameters. Today there is enough evidence to suggest that the contaminant levels affect the health of polar bears and glaucous gulls from Svalbard and Bjørnøya. Further monitoring and research is needed to get a better understanding of the relationship between POP exposure and biological effects in arctic animals.

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