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Review

Persistent organic pollutants in Arctic animals in the Barents Sea area and at Svalbard: Levels and effects

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Abstract: At Svalbard and in the Barents Sea area, high levels of persistent organic pollutants (POPs) have been found in glaucous gull (*Larus hyperboreus*), arctic fox (*Alopex lagopus*) and polar bear (*Ursus maritimus*). Studies of the possible toxic effects on the hormone-, vitamin-, enzyme-, immune- and reproduction system have been conducted during the last 5–10 years. Data obtained both from laboratory and field studies indicate that the present POP levels have an influence on biochemical-, physiological- and immunological parameters in glaucous gull and polar bear. In these two species, studies are currently being conducted in order to relate POP levels to biological/toxic effects both on individuals and populations.

1. Introduction

A thorough review of the levels and effect of the persistent organic pollutants (POPs) in Arctic animals is beyond the scope of a single symposium lecture. In this paper we will try to outline what is known about the levels and effects of POPs in marine mammals and seabirds, which are living in the Barents Sea area and at Svalbard. For a more complete review of these issues we refer the reader to the Arctic Monitoring and Assessment Programme report (AMAP, 1998) and to the reviews by Muir *et al.* (1992, 1999), Thomas *et al.* (1992), MacDonald and Bewers (1996), Bard (1999), and Skaare *et al.* (2000).

The AMAP report (1998) lists and documents several threats to the Arctic ecosystem from long-range transported contaminants, in particularly from POPs. Most POPs that are found in the Arctic comes from distant industrial and agricultural sources. They accumulate in biotic lipids and biomagnify in food chains (Ottar, 1981; Muir *et al.*, 1992). Consequently the highest POP levels in Arctic marine food chains have been found in top predators such as glaucous gull (*Larus hyperboreus*)(Bogan and Bourne, 1972; Gabrielsen *et al.*, 1995), arctic fox (*Alopex lagopus*) (Wang-Andersen *et al.*, 1993) and polar bear (*Ursus maritimus*) (Bernhoft *et al.*, 1997). The finding of high POP levels in tissues and blood of these species raises questions if these levels are high enough to be associated with possible biological effects on individuals and populations.

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In the first part of this paper we will briefly present our knowledge of POPs in Arctic mammals and seabirds. At the last part, we will present data obtained on the biological effects in polar bear and glaucous gull, and data on temporal trends of POPs in Arctic seabirds and marine mammals.

2. Persistent organic pollutants

Environmental contaminants include both industrial chemicals, such as polychlorinated biphenyl (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 1960's and the start of 1970's (Blus, 1995; Voldner and Li, 1995). Substances like PBBs and PBDEs are still being produced globally at an estimated 150000 tons a year (Sellstrøm and Jansson, 1995). The brominated compounds are being heavily used in electronic equipment such as computers and TV sets, which means that the production and release into the environment is expected to increase in the years to come.

The presence of anthropogenic chlorinated contaminants in the Arctic, especially in the marine environment, have been documented in the literature since the 1970's (AMAP, 1998). In Arctic marine organisms, the first case of POPs (DDT, PCB and toxaphene residues) was reported in the 1970's in Arctic seals (Holden, 1972). In the Arctic area, high levels of POPs were documented in glaucous gulls from Bjørnøya (Bear Island) in the early 1970's (Bourne and Bogan, 1972; Bogan and Bourne, 1972). In polar bears, POPs were also documented in Canada at the beginning of the 1970's (Bowes and Jonkel, 1975). The concern about levels of pollutants in the Arctic increased with the comprehensive surveys performed in the 1980's and 90's (AMAP, 1998).

The production and use of most chlorinated compounds listed above were stopped in Europe and North America in the 1980's and 1990's. Some pesticides (such as DDT and toxaphenes) are still being produced and used in Asia, Africa, South America and in some eastern European countries (AMAP, 1998).

In this article we focus on PCB, DDT, toxaphenes and PBB/PBDE, since these contaminants dominate at higher trophic levels in the marine environment. For these contaminants we also have the best knowledge of distribution, levels and fate in the Arctic environment. So far, studies on effects of contaminants in arctic animals have mainly been focused on the possible effects of PCBs. In the cases where PCBs are suspected to cause adverse effects, it is difficult to exclude a contributing adverse influence from other contaminants.

2.1. PCB

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). There

are 209 possible PCBs (congeners), of which *ca.* 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 favor long range transport. With regard to the effect on wildlife, PCBs have been linked to reproductive and immunotoxic effects. In the Baltic sea PCB was linked to reproductive failure in ringed seal (*Phoca hispida*) and grey seal (*Halichoerus gryphus*) (Blomkvist *et al.*, 1992).

2.2. DDT

DDT and its metabolities (DDD and DDE) have been found in biota since 1940's. 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 spreading of diseases to humans by insects (*i.e.* malaria and typhus). DDT and related compounds are very persistent in the environment and their half-life in soil range from 10–15 years. DDT received a lot of publicity in the 1970's for its adverse effects on bird reproduction, causing eggshell thinning (Ratcliffe, 1967). DDT has also been linked with feminization and altered sex ratios of a western gull (*Larus occidentalis*) population of the coast of southern California and in herring gulls (*Larus argentatus*) in the Great Lakes (Fox, 1992).

2.3. Toxaphenes

Toxaphene is an insecticide, which was introduced in 1949. In the US it became the most widely used insecticide by 1975. It has been used on cotton, cereal grains, fruits, nuts, and vegetables, as well as to control ticks and mites in livestock (Fisher, 1999). Toxaphene is a complex mixture of many hundred of different compounds, chiefly chlorinated bornanes. Toxaphene is highly insoluble in water, comparably resistant to ultraviolet sunlight, and its half-life in soil is 10–15 years. Toxaphene is highly toxic to animals and humans. The list of effects of toxaphene in laboratory animals includes neurotoxicity, carcinogenicity and induction of hepatic biotransformation enzymes (De Geus *et al.*, 1999).

2.4. PBBs and PBDEs

Brominated flame retardants are used in high concentrations in electric equipment such as computers, television sets, in textiles, cars and other applications (De Boer *et al.*, 1998). Humans may absorb PBBs and PBDEs 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 easily in food chains. Both PBBs and PBDEs are listed as compounds that effect the regulation of thyroid and steroid hormones. High levels of PBDEs have been found in seals and dolphins from the North Sea and the Atlantic (De Boer *et al.*, 1998).

2.5. Accumulation of POPs in marine animals

POPs originating in industrial and agriculture areas are mainly transported to the Arctic via winds, ocean currents and rivers (Barrie *et al.*, 1992). Once transported to the Arctic, low temperatures promote their condensation and deposition (Ottar, 1981; Wania and Mackay, 1993). Since POPs are lipophilic they are easily incorporated into food chains, especially in the marine environment. The substances are mainly incorporated into the

organisms fat (*bioaccumulation*) (Barrie *et al.*, 1992; MacDonald and Bewers, 1996). At lower trophic levels the uptake occurs both through the diet and direct partitioning from seawater to the body lipids (*bioconcentration*) (Walker *et al.*, 1996). At higher trophic levels the uptake occurs mainly through the diet, which results in increased concentrations of substances in the food chain (*biomagnification*) (Walker *et al.*, 1996; Barron *et al.*, 1995). Accordingly, we find the lowest POP levels in phytoplankton and zooplankton, while we find the highest levels in the top of the food chain.

2.6. POP levels in Arctic animals

There are large differences in POP levels in Arctic animals. These differences may be attributed to many factors such as exposure time, 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 the lipophilic compounds into the egg. In polar bears, considerable amounts of POPs are also transferred 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).

Mapping the levels of anthropogenic pollutants in the Arctic has shown that the problem is mainly related to the marine ecosystem. POP levels in terrestrial species (all herbivorous) such as the Svalbard reindeer (*Rangifer tarandus platyrhynchus*), Svalbard ptarmigan (*Lagopus mutus hyperboreus*), geese (barnacle geese (*Branta leucopsis*), and pink footed geese (*Anser brachyrhynchus*)) are close to background levels (AMAP, 1998).

In general the POP levels in most marine species from the Barents Sea area are low when compared to the Baltic and the North Sea. High POP levels and possibilities of biological effects are mainly associated with species at the top of the food chains: the glaucous gull, the arctic fox and the polar bear. In glaucous gulls, the PCB levels are within the levels that cause reduced hatching success in wild and captive birds (AMAP, 1998). For polar bear and arctic fox, the PCB levels are within the levels that cause effects on reproduction in laboratory mammals (AMAP, 1998).

2.7. POP levels in marine food chains

In most marine species investigated at lower trophic levels in the Barents Sea area, the POP levels are low compared to species at lower trophic levels from the sub-arctic and temperate areas (0.01–0.2 ppm, lipid weigth concentrations) (Borgå *et al.*, 2001). For example, in copepods (*Calanus* spp.), euphausiids (*Thysanoessa* spp.) and amphipods (*Parathemisto libellula*) the POP levels are similar to the levels found in the Canadian Arctic (Muir *et al.*, 1999). In fish species, such as polar cod (*Boreogadus saida*) and cod (*Gadus morhua*), the POP levels are low when compared to the levels found in cod from the North- and Norwegian Seas (AMAP, 1998). The POP content in seawater, phyto- and zooplankton is dominated by HCH and HCB. In zooplankton, polar cod and cod from the Barents Sea, pattern of Chlordanes, DDTs and HCHs was dominated by compounds from the technical mixtures. This is similar to the POP pattern found in the Bering Sea and north Pacific (Tanabe *et al.*, 1984; Kawai *et al.*, 1988; Hargrave *et al.*, 1992; Ray *et al.*, 1999). The patterns found in zooplankton and fish may indicate that these species have a low ability to metabolize POPs (Borgå *et al.*, 2001). The low POP levels found in species at

lower trophic level are mainly explained by their position in the food web, their lipid content, their relatively short life span, as well as their migration routes.

2.8. Seabirds

Seabird species living in the Arctic are contaminated by the same POPs as seabirds living in the south (AMAP, 1998). The POP levels in seabirds are mainly determined by their feeding habits. 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 ppm)(Savinova *et al.*, 1995). However, in fish-eating species such as kittiwakes (*Rissa tridactyla*), common and Brunnich's guillemots (*Uria aalge* and *Uria lomvia*) and puffins (*Fratercula arctica*) the POP levels are somewhat higher (1.0–5.0 ppm) than in common eider and in little auk. The highest POP levels (1.0 to 40 ppm) are found in herring gull, glaucous gull, great black-backed gull (*Larus marinus*) and the great skua (*Stercorarius skua*)(Savinova, Skaare and Gabrielsen, unpublished). The POP levels in these gull species are 5–10 times higher than the other seabird species in the same area. In seabirds, the PCB is the major POP in all species, followed by DDT, Chlordane, HCB and HCH (Savinova *et al.*, 1995; Borgå *et al.*, 2001). The high POP levels in gulls reflects 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 (Savinova, Skaare and Gabrielsen, unpublished).

2.9. 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- and the Baltic Sea. The PCB levels in ringed seal, harp seal (*Phoca groenlandica*), bearded seal (*Erignathus barbatus*) and Atlantic walrus (*Odobenus rosmarus*) are an average of 1.0–5.0 ppm (AMAP, 1998). The PCB levels in blubber of harp seal from the East Ice (Russian area) was three times higher (3.0 ppm) 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). A recent geographical trend study of PCB and DDT in ringed seal blubber have shown higher levels – in samples from the Yenisey Gulf in the Russian Arctic, Svalbard and east Greenland when compared to west Greenland and the Canadian Arctic (Muir *et al.*, 2000). The highest levels of toxaphene have been found in harp seal collected east of Svalbard (Wolkers *et al.*, 2000). The levels of the toxaphene congeners Tox 26 and Tox 50 in harp seals collected east of Svalbard were 20 times higher than in ringed seal samples west of Svalbard (Wolkers *et al.*, 1998) and four times higher than in seals from the Canadian Arctic (Zhu and Nordstrom, 1993). The POP levels in seals are mainly determined by their feeding habits. The PCB levels in bearded seal and walrus, which are feeding on benthic organisms, is lower than in ringed - and harp seals, which mainly feed on fish and amphipods.

Most seal species show large variations in POP levels in the blubber, which can be

related to food intake and seasonal variation in body mass. Usually, the lowest body mass (lowest blubber thickness and highest POP level) occurs after giving birth, during lactation or in the molting period. The usage of blubber throughout this period will release POPs, which can have toxic effects on the immune- and reproductive system of the seal pups. However, mapping of the contaminant levels in most seal species from the Barents Sea area show that the levels are well below the levels which cause biological effects on seals (AMAP, 1998).

2.10. Whales

The levels of POPs in different whale species are also reflected by their feeding habits. Beluga (*Delphinapterus leucas*), narwhale (*Mondon monoceros*) and harbour porpoise (*Phocoena phocoena*), which feed mainly on fish, have higher POP levels (5–6 ppm) in their blubber than the minke whale (*Balaenoptera acutorostrata*) (2–4 ppm), which feeds on krill and amphipod. The 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. This is mainly explained by their migration pattern. In minke whales the levels of POPs are higher on the coast of Lofoten Island in northern Norway when compared to the Svalbard area and the Kola area (Kleivane and Skaare, 1998).

In blubber samples of harbour porpoise from northern Norway, very high PCB levels (20–30 ppm) have been found. The levels of PCB and DDT are the highest measured in any whale species from the Arctic (AMAP, 1998). The reason for the high PCB levels in harbour porpoise from northern Norway is not fully understood. When compared to laboratory animals, the PCB levels in the blubber of the porpoise are high enough to have an effect on the immune system. High POP levels have also been found in beluga whales from the Gulf of St. Lawrence in Canada. Autopsy of stranded whales from this area did reveal cancer in the stomach and intestines (Martineau *et al.*, 1994). This was not found in animals from other areas. Such a finding is not described in dead whales found in Norwegian areas.

2.11. 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 ppm), 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, feed on carcasses of reindeer and terrestrial birds. When compared to POP levels in foxes from northern Europe and the Canadian Arctic, the levels in foxes from Svalbard are high (AMAP, 1998). The reason for this may be that foxes on Svalbard eat more marine species than foxes in Europe and in Canada.

The arctic fox shows seasonal variation in body weight and food intake throughout the year. In the late autumn (November), the fat content in arctic foxes is 20% of the body mass, while in late spring (June) the fat content is less than 6% of their body mass (Prestrud and Nilssen, 1992). Since PCBs are released during fat mobilization, there is reason to

believe that most of the PCBs in females are transported to the pups either when giving birth or transferred via milk. The POP levels in arctic fox at Svalbard are as high as in polar bear from Svalbard. It is reason to believe that the present POP levels, which are found in some individuals at Svalbard, are having an effect on the immune and reproduction system. At the present there are no studies going on to determine the effects of POPs on individuals or populations of arctic foxes from the Svalbard area.

2.12. Polar bears

Mapping of the contaminant levels in polar bear have shown high POP levels (5–80 ppm, average 25 ppm) in polar bears from east Greenland, Svalbard and Frans Josef Land (Russia), when compared to Alaska and Canada (Bernhoft *et al.*, 1997; Norstrom *et al.*, 1998; Andersen *et al.*, 2001). When compared to Alaska and Canada, the PCB levels are 2–6 times higher at Svalbard (Norstrom *et al.*, 1998; Bernoft *et al.*, 1997; AMAP, 1998). At Svalbard the PCB levels are 8–10 times higher than the levels found in ringed seal from the same area (Severinsen *et al.*, 2000). Polar bears feed mainly on the energy rich blubber layer of the seal (Stirling and McEwan, 1975), in which the POPs are accumulated, with the consequence that they are exposed to very high POP levels. During periods of reduced food intake in polar bears, stored lipids are released to meet the energy demands. During lipid mobilisation, however, the lipid-associated POPs are released to the blood resulting in POP exposure. At Svalbard the highest PCB levels are found in males, in which the levels increase with age (Bernhoft *et al.*, 1997).

Several explanations have been presented for the high PCB levels in polar bears from Svalbard and Franz Josef Land. One explanation may be that the polar bear at Svalbard and Frans Josef Land is exposed to local contamination due to transport of ice (in which POPs are incorporated in the Kara Sea), which are melted in the eastern part of Svalbard (Alexander, 1995; Pfirman, 1995, 1997). Another explanation is that polar bears feed on harp seals which migrate from the White Sea to the northern Barents Sea during the winter/spring (Kleivane *et al.*, 2000). Higher PCB levels in harp seals from the east ice when compared to the west ice as well as higher POP levels in harp seal compared to ring seal and bearded seal from the Svalbard and Frans Josef Land area may explain the high levels found in polar bears.

In polar bear there are large differences in PCB/DDT levels. These differences in POP levels are mainly explained by their feeding habits, sex differences and seasonal changes in body mass. During lactation the females deliver a lipid rich milk (40% fat) with a high content of PCB/DDT to the cub. Due to the transfer of contaminants via milk, there is reason to believe that the polar bear cub is exposed to POPs in a sensitive period of rapid growth and development.

3. Effects of POPs on birds and marine mammals

POP exposure has been associated with a variety of disorders in birds and mammals. Effects on the immune system (De Swart *et al.*, 1996; Grasman *et al.*, 1996), the endocrine system (Brouwer *et al.*, 1986) and internal organs (Bergman *et al.*, 1992; Reijnders, 1994) have been described in both laboratory animals as well as in marine birds and mammals from contaminated areas.

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 residues of contaminants. Some biological responses (or *biomarkers of exposure*) are quite specifically related to contaminant exposure (*e.g.* cytochrome P450 enzyme activities or accumulation of highly carboxylated porphyrins), but are difficult to interpret in terms of consequences for the health of the individual, not to say the population (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. In the following, we will review associations that have been reported between biological parameters and contaminant levels in vertebrates from the Svalbard area.

3.1. Polar bears

The POP levels in polar bears from Svalbard are comparable to the levels found in Baltic ringed seals, which have a negative effect on the reproduction and survival rate of young seals (Olsson *et al.*, 1992). A low cub production at Svalbard compared to Alaska and Canada might indicate that the POPs are already affecting the cub production in this area (Wiig *et al.*, 1998). Furthermore, it has recently been hypothesized that PCB and other POPs may be involved in the relatively high incidence of female pseudohermaphroditism in polar bear from Svalbard (Wiig *et al.*, 1998).

Many planar halogenated hydrocarbons (that is, 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 cytochrome P4501A (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.*, 2000a).

Vitamin A homeostasis can be severely altered by exposure to POPs, and several vitamin A deficiency-like symptoms are associated with intoxication by polyhalogenated 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 fed fish from polluted waters, retinol and thyroid hormones in plasma was depressed, compared to seals fed fish from less polluted waters (Brouwer *et al.*, 1989). In polar bears from Svalbard, Skaare *et al.* (2000b) found a negative correlation between plasma retinol and PCB concentration ($r^2=0.11$, $P=0.003$). The ratio of total thyroxin to free thyroxin in plasma was also significantly negatively correlated to total PCB in plasma ($r^2=0.08$, $P=0.013$) (Skaare *et al.*, 2000b).

Many studies have demonstrated adverse effects of PCB and dioxin-like compounds 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. IgG levels indicate the ability of the bears to mount an immune response when re-exposed to a pathogen. In a sample of 52 polar bears from Svalbard, age- and sex-corrected level of IgG was negatively correlated with total PCB ($r^2=0.08$, $P=0.029$) and HCB ($r^2=0.13$, $P=$

0.005) (Bernhoft *et al.*, 2000). The PCB levels in the bears were within the range found to give immunotoxic effects in experimental animals (Bernhoft *et al.*, 2000). The association between POPs and IgG could indicate a contaminant-induced immunosuppression in Svalbard polar bears, with possible consequences for the susceptibility to infectious diseases.

3.2. Glaucous gulls

Possible biochemical effects of organochlorine contaminants in glaucous gulls were studied in a sample of forty adult individuals collected from colonies on Bjørnøya in the Barents Sea (Henriksen *et al.*, 2000a). Selected POPs, microsomal cytochrome P450 associated enzyme activities, highly carboxylated porphyrins (HCPs), retinol and retinyl palmitate, were quantified in liver samples.

As mentioned above, 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 the extent of TCDD-contamination 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.*, 2000a). The hepatic vitamin A stores in glaucous gulls from Bjørnøya were larger than in herring gulls from contaminated locations in North America (Anonymous, 1991).

Briefly, cytochrome P450 activities have two aspects. In the first place, induction of P450 enzymes can be recognised as a biochemical effect per se, with consequences for the metabolism of endogenous compounds. Secondly, the P450 activities give an indication of the organisms metabolic capacity, and the potential for formation of metabolites, which in some cases are toxic. 7-ethoxyresorufin *O*-deethylase (EROD) activity is catalysed by isoenzymes from the cytochrome P4501A (CYP1A) subfamily, which are induced by planar POPs with affinity for the aryl hydrocarbon (Ah) receptor (Poland and Knutson, 1982; Peakall, 1992). When hepatic microsomes are incubated with testosterone, the pattern of hydroxylated testosterone metabolites reflects the activities of a range of cytochrome P450 proteins (Paolini *et al.*, 1997). Alterations in testosterone hydroxylase activities may have consequences for the steroid hormone status, and thereby affect reproductive capacity. TCDD exposure at environmentally realistic levels increased 2β-, 6β-, and 15α-testosterone hydroxylation activities in captive female great blue herons (*Ardea herodias*) (Sanderson *et al.*, 1997). In the glaucous gull sample (Henriksen *et al.*, 2000a), a weak positive association was found between hepatic EROD activity and PCB-levels. This may indicate 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 the glaucous gull suggests that they have a low capacity for metabolising POPs, which may contribute to the high accumulation of POPs in this species.

Disturbances in the heme biosynthetic pathway can lead to elevated levels of highly carboxylated porphyrins (HCP) in the liver (Marks, 1985). In free-living birds, the only known cause of HCP elevation is exposure to POPs (Fox *et al.*, 1988; Kennedy *et al.*, 1998). In herring gulls from the Great Lakes, hepatic HCP levels were elevated, compared

to herring gulls from less polluted colonies (Fox *et al.*, 1988). Among forty glaucous gulls sampled on Bjørnøya (Henriksen *et al.*, 2000a), HCPs were only elevated (138 pmol g^{-1}) in a single sample. The remaining samples contained low levels of HCPs (< 30 pmol g^{-1}). It may not be a coincidence that the sample with elevated HCPs also had the highest levels of several POPs, including PCB-118, which is very porphyrinogenic in chicken embryo hepatocytes cultures (Lorenzen *et al.*, 1997). The findings of Kennedy *et al.* (1998) suggested that PCB-118 was an important contributor to porphyria in Great Lakes herring gulls. In these gulls, HCPs were consistently elevated whenever the liver level of PCB-118 exceeded 1.5 $\mu g\ g^{-1}$ wet weight (Kennedy *et al.*, 1998). In comparison, the PCB-118 level was 1.9 $\mu g\ g^{-1}$ wet weight in the single glaucous gull with elevated HCPs.

The weak association between EROD activity and PCB levels, and the low level of HCPs, suggest that these biochemical parameters were unaffected by OCs in most of the sampled gulls in the study by Henriksen *et al.* (2000a). Thus, the glaucous gulls seem not to be particularly sensitive towards Ah-receptor mediated effects.

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 is limited by host immunity, 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 (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 10 of the 14 POP concentrations measured. The strongest correlations were with p,p′-DDT, Mirex, total PCB, and PCB congeners 28, 118, 153, 138, 170, and 180. Although correlative and collected in the absence of immunological data, these data suggests that POPs might affect immune function in the glaucous gull.

Contamination by some POPs may result in behavioural impairments in birds (Peakall, 1996; McCarty and Secord, 1999). In a recent study by Bustnes *et al.* (2000) patterns of incubation and nest site attentiveness were examined in relation to PCB (polychlorinated biphenyls) loads, measured in blood, of 27 glaucous gulls from two different breeding areas at Bjørnøya. The levels of PCB in the blood samples ranged from 52 ppb to 1079 ppb (wet weight). PCBs were positively related to the proportion of time absent from the nest site, both overall and when not incubating, and to the number of absences, when controlling for a set of covariates (sex, breeding area ect.) known to influence behaviour. Bustnes *et al.* (2000) concluded that the increased absence from the nest site of glaucous gulls with high loads of PCB suggests that their reproductive motivation, possibly through endocrine disruption, or their ability to conduct some complex behaviour, were affected. PCB contamination could thus lead to increase energetic costs during incubation, and reduced reproductive output.

3.3. Harp seals

Testosterone hydroxylase activity was measured in harp seals by Wolkers *et al.* (2000). No correlation with PCBs were found, however, the CYP3A-like activity correlated significantly and strongly ($r^2=0.50$, $P<0.05$) with toxaphene residues. If the insecticide

toxaphene actually does affect this enzyme-activity in the harp seal liver, it means that the regulation of sex hormones could be disturbed.

4. Temporal trends in POPs in Arctic seabirds and marine mammals

Despite that several contaminants have been taken out of production and use in the 1970s and 1980s, we can see that it takes a long time before the POP levels decrease in seabirds and marine mammals in the northern Barents Sea area (AMAP, 1998). Trend studies of DDT and PCB levels in seabird eggs and marine mammals (seal and whales) from the Arctic and sub-Arctic show a clear reduction during the last 15-20 years (Barrett *et al.*, 1996; AMAP, 1998). For example, in 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, Fulmars and Kittiwakes (Braune and Donaldson, 2000). Such a decrease in PCB/DDT levels may indicate a reduction in production and use of organic pollutants. In marine mammals (seal and whales) the reduction in DDT and PCBs are not as strong as observed in seabirds. There is a lack of trend data from the Barents Sea area (except for polar bear). However, trend data from north west Canada show a strong decrease (5 times) in PCBs and a lower (3 times) decrease in DDT from 1972 to 1991 (AMAP, 1998). This is in contrast to data from seals and walruses from North-east Canada and Greenland which show no decrease in PCBs and DDT in a period of 15 years (AMAP, 1998). A reduction of PCBs and DDT was also found in Arctic foxes from Svalbard from 1970 up to present (E. Fuglei, pers. com). When it comes to the toxaphene and brominated compounds we do not have long trend data. However, it is reasonable to believe that there has been an increase in these contaminants in seabirds and marine mammals since the beginning of 1980s.

The most abundant PCB congener, PCB 153, decreased significantly in polar bear plasma from Svalbard during the 1990s (Henriksen *et al.*, 2000b). Temporal data with high resolution from high Arctic biota are sparse (Muir *et al.*, 1999). To our knowledge, the data from polar bears is the first detailed description of a temporal trend of PCB in high Arctic biota during the 1990s. The shape of the decline could suggest a levelling off in the latter part of the sampling period. Data from other marine mammals in the Canadian Arctic suggest a decline since the 1970s, but a levelling of during the 1980s and early 1990s (Muir *et al.*, 1999). Stabilisation of PCB concentrations has also been observed in Great Lakes herring gull eggs (Stow, 1995). Continued monitoring will be necessary to verify if the observed decline in the Norwegian Arctic is levelling off or not.

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