Effects of anthropogenic endocrine disrupters on responses and adaptations to climate change*

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Abstract

The effects of global change on biodiversity and ecosystem functioning encompass multiple complex dynamic processes, and climate change and exposure to endocrine disrupting chemicals (EDCs) are currently regarded as two of the most worrying anthropogenic threats to biodiversity and ecosystems. Various persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs), dichlorodiphenyldichloroethylene (DDE), hexachlorobenzene (HCB) and oxychlordan, have been documented to affect hormone homeostasis and function in laboratory and wildlife species. The most pronounced effects have been reported on the thyroid hormone system, but effects have also been reported on sex steroid hormones and cortisol. Behavioural and morphological effects of POPs in marine mammals and seabirds are consistent with endocrine disruption. Since different endocrine systems are important for producing adequate physiological and behavioural responses to environmental stress, EDCs may interfere with the adaptations to climate change. Such interacting effects can be expected to be related to adaptive responses regulated by the thyroid, sex steroid and glucocorticosteroid systems. There is concern for the possible effects that EDCs may impose on the ability of animals to adapt to environmental alterations caused by climate change.

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Introduction

Because of structural similarities with endogenous hormones, many anthropogenic (man-made) chemicals have the ability to mimic or block the effects of endogenous hormones. Together with substances which may interfere with hormone metabolism, these chemicals may disrupt the normal actions of endogenous hormones and have thus become known as endocrine disrupting chemicals
(EDCs) (1). Examples of environmental pollutants with endocrine disrupting properties are certain pesticides, phthalates, alkylphenolic compounds, polychlorinated biphenyls (PCBs), polychlorinated dioxins and furans (PCDD/Fs), bisphenol A, polybrominated diphenylethers (PBDEs), tetrabromobisphenol A (TBBPA), and some heavy metals including lead, mercury, and cadmium (2,3).

Among the the environmental pollutants that are of most concern with respect to their potency to act as EDCs, are some persistent organic pollutants (POPs). POPs are chemicals that are resistant to physical, chemical and biochemical degradation and therefore remain available for uptake and bioaccumulation for a long period of time. POPs are also semi-volatile and are transported via the atmospheric even to remote areas in the polar regions. Furthermore, POPs are hydrophobic (albeit to differing degrees depending on their individual structures) and are therefore easily taken up by animals and bioaccumulated in fatty tissues. Hence, POPs are present even in endemic Arctic species, such as polar bears (*Ursus maritimus*) (4), glaucous gulls (*Larus hyperboreus*) (5), walrus (*Odobenus rosmarus*) (6), ring seals (*Phoca vitulina*), bearded seals (*Erignathus barbatus*) (7) and beluga whales (*Delphinapterus leucas*) (8).

Recently, polybrominated diphenylethers (PBDEs) and perfluorooctane sulfonate (PFOS) have also been reported in Arctic marine mammals and seabirds (9-12). The concentrations of some of these compounds, such as PBDEs show an increasing trend in Arctic marine mammals (10). Thus, even though there is evidence that levels of classic POPs such as PCBs are decreasing or have levelled off, such as reported in polar bears from the Svalbard and Barents Sea region (13), it is likely that the total exposure of Arctic biota to POPs will increase during the next decade.

It should also be noted that many animals, and in particular mammals and birds, have the ability to biotransform many POPs into more polar metabolites via the hepatic cytochrome P450 enzyme system or other phase I or II reactions. Paradoxically, many of the metabolites formed during the phase I or phase II metabolism have larger endocrine disrupting properties than their parent compounds (14). Thus, a well-developed detoxification system is not a guarantee against endocrine disrupting effects of POPs.

Recently, climate change has been recognised as another significant threat against Arctic biodiversity and ecosystem functioning. The Earth’s climate has warmed by approximately 0.6 C over the past 100 years, and since 1976, the rate has been greater than at any other time during the last 1000 years (15). Although there is a debate about what are causative factors with respect to the climate change issue, there is clear evidence of the ecological impacts of recent climate change, from polar terrestrial to tropical marine environments (16-20). There appears to be regional variations in climate change. For instance, as a consequence of decreased diurnal temperature ranges, in mid and high latitude regions there has been a 10% decrease in snow cover and ice extent since the late 1960s (15). General circulation models predict that climate changes will be greatest at high latitudes (21).
Since the bioaccumulation of many POPs is particularly high in marine endothermic animals (birds and mammals) (22), and since some of these animals also have the ability to biotransform POPs into metabolites that may have even larger endocrine disruptive capacities than their parent compounds, there are well-founded reasons for being concerned about their effects on the hormonal balance and function of these animals.

The thyroid hormone, sex hormone and glucocorticosteriod systems seem to be among the most vulnerable endocrine systems with respect to disruption by EDCs in endothermic animals. Important functions of THs are the regulation of metabolic processes, growth and differentiation of tissues, including the regulation of neuronal proliferation, cell migration and differentiation of the developing animal (23). Hypothyroidism may also affect behaviour and reduce cognitive and learning abilities, affect motor coordination and cause menstrual dysfunction and anovulation and infertility (24).

Sex steroid hormones are essential for reproduction, but do also play an important role in sexual behavior. Glucocorticosteroids are involved in a range of physiological processes, including reproduction, behavior and adaptation to stress (25).

These three endocrine systems are important for animals to produce adequate physiological and behavioural responses to environmental changes. There are therefore good reasons for being particularly worried about the possibilities that EDCs may affect endocrine processes involved in adaptations to climate change in animals.

Because the climate change is predicted to be greatest at high latitudes (21), there should be special concern for the possible effects that EDCs may impose on the ability of Arctic marine mammals and seabirds to adapt to environmental alterations caused by climate change (26). The aim of the present paper is therefore to give a short review of the effects of EDCs in Arctic mammals and seabirds, and to assess the possible ecological outcome of interacting effects between climate change and endocrine disrupters.

**Endocrine disruption**

Chemical pollutants have the ability to disrupt endocrine function in animal groups ranging from planktonic invertebrates, amphibians and reptiles to birds and large carnivorous mammals (27-30). Although most of the endocrine disrupting properties of chemicals have been documented through experimental exposure of animals, there is an increasing number of studies where disruptions or alterations in reproductive activity, morphology or physiology have been reported in wildlife populations (28,30). The mechanisms by which the chemicals exert their endocrine disruptive effects have been described in many of the studies and reviews listed above, and will not be elucidated herein. In several recent studies and reviews the link between endocrine disruption, particularly of the thyroid system, and neurodevelopment and cognitive effects have received attention (23,31-33).
**Effects on thyroid hormones**

In captive harbour seals (*Phoca vitulina*), it has been shown that the response of fasting on plasma total triiodothyronine (TT3) were lowered in seals fed herring (*Clupea harengus*) from the Baltic Sea as compared to the control seals fed cleaner herring from the open waters of the Atlantic Ocean (34). In a similar feeding experiment, captive harbour seals given a diet of organochlorine (OC) contaminated fish had significantly lower plasma levels of total thyroxine (TT4), free thyroxine (FT4) and TT3 as compared to seals that were fed with less contaminated fish (35). Grey seal (*Halichoerus grypus*) pups from the highly polluted Baltic Sea have been shown to have lower plasma concentrations of TT3 and free triiodothyronine (FT3) compared to pups from the cleaner Norwegian Sea, whereas there was no difference in plasma concentrations of TT4 and FT4 between the two groups (36). Since blubber concentrations of OCs were significantly higher in the Baltic group as compared to Norwegian group, the results can be interpreted as a strong indication that plasma TT3 and FT3 concentrations may be susceptible to exposure to OCs in young phocids. Furthermore, stranded immature northern elephant seals (*Mirounga angustirostris*) with a skin disease had elevated serum levels of PCBs, dichlorodiphenyltrichloroethane (DDT) and DDE, and depressed levels of TT3 and TT4 as compared to healthy controls (37). In northern fur seal (*Callorhinus ursinus*) neonates TT4 was reported to correlate negatively with several PCB-congeners (38).

In ribbon seals (*Phoca fasicata*) from Japanese waters, TT3 levels were reported to decrease significantly with increased blubber concentrations of PCB-170 and -180, whereas no such relationship was found between blubber PCBs and FT3 (39). In Larga seals (*Phoca largha*), also from Japanese waters, plasma TT3 and FT3 correlated negatively with blubber PCB concentrations, whereas no such relationships were found between blubber PCB concentrations and TT4 and FT4 in neither Larga or ribbon seals (39).

There are reports of increasing levels of brominated flame retardants, such as PBDEs, in Arctic ring seals (10), and in grey seals there are indications that thyroid hormone levels may be affected by PBDEs (40).

The polar bear is the ultimate apex predator in the Arctic food chain. Even though the polar bear has a relatively well developed capacity of metabolising and excreting POPs (41), the polar bear accumulates relatively large amounts of some POPs because they feed almost exclusively on large amounts of seal blubber (42). During the last decades, Skaare and co-workers have conducted a series of studies related to accumulation and effects of POPs in polar bears from the Svalbard and the Barents Sea region. These studies have documented significant relationships between POPs and thyroid hormones and vitamin A (43). In a recent study these relationships were studied in more detail, and it was found that PCBs affected five thyroid hormone variables in females (TT4, FT4, FT3, TT3:FT3, TT4:TT3) but only two variables in males (FT3, FT4:FT3) (44). This indicates that female polar bears could be more susceptible to thyroid hormone related effects of POPs than are males. The actions of thyroid hormones are
mediated by nuclear thyroid hormone receptors that have their highest affinity for FT3 (45). It is therefore worth noting that in polar bears PCB was reported to affect T3 to a larger degree than T4 (44).

The glaucous gull is another top predator in the Arctic food web, and high levels of POPs have been reported in this species (5,46). Verreault et al. (47) reported significant negative relationships between plasma levels of hexachlorobenzene (HCB) and oxychlordane and plasma concentrations of FT4 and TT4 in adult breeding glaucous gull males from Bear Island (Bjørnøya) in the Barents Sea. Furthermore, negative correlations were found between several other OCs and the FT4:FT3 and TT4:TT3 ratios in males. No effects were found in females.

**Reproductive hormones and stress hormones**

In female polar bears plasma progesterone levels has been reported to be positively correlated with plasma concentrations of PCBs (48). In male polar bear both plasma concentrations of OC pesticides and PCBs contributed negatively to the plasma testosterone levels (49). Recently, relationships between blood levels of OCs and cortisol levels have also been documented in polar bears from Svalbard and the Barents Sea (50). The OC pesticides contributed negatively whereas PCBs contributed positively to the variation in plasma cortisol. The authors do however report that the overall contribution of the POPs to the cortisol levels was negative.

**Possible ecological effects of EDCs**

In a series of papers Bustnes and co-workers have focused on ecological effects of OCs in glaucous gulls from Bear Island. The proportion of time that adult glaucous gulls were absent from the nest when not incubating and the total number of absences, were both significantly related to blood concentrations of PCBs (51). The authors suggested that the effect could be due to that individuals with high blood concentrations of OCs need more time to gather food because of either endocrine disruption or neurological disorders. Furthermore, females with high blood levels of OCs, including HCB, oxychlordane, dichlorodiphenyl-dichloroethylene (DDE) and PCBs, were more likely to have non-viable eggs than females with low blood OC levels (52). Adult yearly survival rate was also reported to be significantly negatively related to blood concentrations of DDE, persistent PCBs and HCB, and especially to oxychlordane (52).

Bustnes and co-workers also reported a significant positive relationship between wing feather asymmetry (difference between the length of right and left wing feathers) and blood concentrations of two PCB congeners (CB-99 and -118), oxychlordane, DDE and especially HCB (53). Thyroid hormones are central in regulating the moultng and replacement of feathers (54,55), and as previously mentioned significant negative relationships between plasma concentrations of HCB and oxychlordan and thyroid hormones have been reported in glaucous gulls (47). Thus, there may be a link between the thyroid hormone
disruptive effects of HCB and oxychlordan and growth and development of the primary wing feathers following moulting.

There is a high aerodynamic cost of asymmetry (56), and Bustnes et al. (51) suggested that increased flight costs may be an important factor in explaining why birds with high blood concentrations of POPs spend more time on feeding trips than birds with low levels. Exposure to PCBs has been associated with cognitive and behavioral changes (57-59), and it has been suggested that the effects of PCBs on brain development may be attributable, at least in part, to their ability to affect the thyroid system (23,60). It is therefore tempting to speculate that thyroid hormone disruption caused by POPs may be the ultimate cause of this altered parental behavior. However, more research into linking endocrine disruption and behavioral and ecological alterations in free-living animals is needed before conclusions on this aspect can be drawn.

It has been reported that climatic warming may make birds breed earlier (61). Negative relationships between sea temperature and hatching date has been reported for several seabird species (62-64). On the other hand, Helberg et al. (65) reported significant positive relationships between blood concentrations of OCs, and in particular HCB and DDE and egglaying date in female black backed-gulls (Larus marinus). Thus, females with high burdens of OCs breed later than less contaminated individuals. Since both thyroid and sex hormones are important determinants for the timing of egglaying, it is possible that disruption of the thyroid and sex hormone balance caused by OCs could be linked to delayed egglaying. Based on the results from this study (65) it can be hypothesised that OCs may counteract the apparent adaptive response of seabirds to breed earlier as the environmental temperature rises due to climatic warming. In the Arctic the summer season is short, and a proper timing of breeding, moulting and migration is important for seabirds. Exposure to EDCs could disrupt the endocrine systems and mechanisms that regulate these events, leading to a sub-optimal timing in relation to the season.

In polar bears, learning and cognitive abilities are probably important factors for successful hunting. There is concern that disruption of the thyroid hormone balance caused by EDCs may effect neurodevelopment, and that this in turn may affect behavior and cognitive abilities of wildlife (66). Since maternal hypothyroidism is linked to disorders of the neurophysiological development in the offspring (67), cubs of polar bear females with lowered thyroid hormone levels due to exposure to anthropogenic chemicals may suffer from such disorders. It should, however, be noted that because information on normal baseline levels of thyroid hormones in polar bears is lacking, it is not known if the polar bear females with high PCB levels and low thyroid hormone levels (44) suffer from hypothyroidism. However, it can hypothesised that PCBs and other anthropogenic chemicals that affect thyroid hormone balance may disrupt behaviour and cognitive abilities in polar bears, and that this may have a negative effect on their hunting success and their abilities to cope with changes in prey distribution caused by climate change induced reductions of ice-coverage. In the case of a temporal and/or spatial change in the distribution of food caused by climate
change, an altered behavior caused by EDCs or an reduced ability to respond adequately to such major changes could hamper reproductive success and even survival rates of adult animals.

The increased levels of progesterone reported in polar bears (48) may disturb the normal reproductive cycle of the females and thus hinder successful mating. In male polar bear both plasma concentrations of OC pesticides and PCBs contributed negatively to the plasma testosterone levels (49), and it is thus possible that male reproductive performance may be affected by POPs.

Furthermore, it is possible also that the negative effects of POPs on plasma cortisol levels reported in polar bears from Svalbard and the Barents Sea (50) may interfere with physiological processes and render the polar bears less able to deal with other environmental stressors, such as those caused by climatic warming.

Ecological studies of the Svalbard population of polar bears have shown that there are indications of reproductive impairment of females, lower survival rates of cubs or increased mortality of reproductive females, and it has been suggested that these may be contaminant-related (68). Although it is difficult to prove any clear cause-effect relationships, it is possible that endocrine disrupting properties of many POPs could contribute to such population effects.

Many Arctic marine mammals undergo periods of fasting, mainly due to natural seasonal reductions in food availability, and thyroid hormones seem to play an important role in regulating these cycles. As previously reported in fasting harbour seals, EDCs may disrupt the thyroid hormone homeostasis (34), which possibly may lead to a sub-optimal timing of the fasting period.

Conclusions

Climate change is likely to pose additional stress to individuals, and since different endocrine systems are important for adequate physiological and behavioural responses to environmental stress, EDCs may interfere with the adaptations to the increased stress situation. Thus, when taking into consideration the long-range transport of EDCs into the Arctic ecosystem, the combination of EDCs and climate change may be a worst case scenario for Arctic mammals and seabirds. However, the knowledge of the responses of animals to multiple natural and anthropogenic stressors is at present time not sufficient to forecast the combined effects of these two stressors, and there is a clear need for more focus on the interacting effects of multiple stressors (natural or anthropogenic) on wildlife.

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