Title: Monitoring Planetary and One Health in the Arctic.

Author: Christian Sonne, Aarhus University, Department of Ecoscience, Roskilde, Denmark (cs@eocs.au.dk).

Abstract: Exposure to industrial chemicals is of global concern together with climate change and zoonotic diseases causing risks for recurrent pandemics. These immune-toxic chemicals are long-range transported to the Arctic ecosystems providing a thermometer for the assessment and monitoring Planetary and One Health due to the extreme warming of the region and the local community's exposure to zoonotic diseases from subsistence hunting. These societies rely on the same marine food web as marine mammals, which requires a One Health approach to understand holistic ecosystem dynamics and environmental stressors' effects on ecosystem dynamics including top predators and humans. Among these Arctic stressors, mercury and PFAS in the marine ecosystems are among the highest worldwide posing significant risks of effects at immune systems and reproduction. Here I give an overview of the current knowledge on mercury and POPs in the Arctic in relation to global warming and zoonotic diseases, while discussing planetary health and future solutions.

Hunting and fishing have always been an important part of Arctic human existence in this harsh northern environment, and their intensity has increased with a growing Arctic human population bringing along more effective hunting methods, including larger and faster boats and fishing vessels, riffles and gillnets. Adding to these local stressors on Arctic ecosystems, anthropogenic pollution has become a ubiquitous problem that is particularly relevant in the Arctic environment. In addition to elevated Mercury (Hg), an array of anthropogenic chlorinated, brominated, and fluorinated persistent organic pollutants (POPs), all alien substances, have been introduced to the Arctic. More specifically, the 1850s marked the period of early industrialization and was associated with elevated Hg emissions [10], whereas the onset of the 1940s marked the onset of large-volume worldwide use of industrial chemicals and pesticides. POPs and Hg typically originate from industrial and household emissions at temperate regions and are transported via global atmospheric and oceanic pathways that result in deposition in the Arctic environment.

Arctic fish and wildlife rely on energy-rich fatty tissues as their main energy source in the harsh Arctic environment. Fatty tissues typically host various natural lipophilic compounds, such as specific vitamins (A and D) and endogenous steroid hormones transported by portal and periphery blood supply among others. However, most POPs and methyl-Hg, the bioavailable chemical from of Hg, are highly lipophilic as well and are therefore readily stored in lipid-rich tissues. Additional low excretion of these compounds results in a net intake of POPs and Hg over time, referred to as bioaccumulation, and is moreover transferred from prey to predator along the food chain resulting in biomagnification. As a result, apex predators such as polar bears, Arctic fox (*Vulpes lagopus*), seal spp., whale spp. and seabird spp., are exposed to the highest concentrations occurring the Arctic environment, already a major sink for POPs and Hg as described above. Finally, indigenous northerners and their dogs are ultimate sinks due to their traditional consumption of the aforementioned wildlife. Newer perfluorinated compounds (poly- and perfluoralkyl substances (PFASs)), in particular perfluorooctane sulfonate (PFOS) and other long-chained poly- and perfluorocarboxylic acid (PFCAs) are proteinophilic and also biomagnify due to high resistance to biological degradation.

Long-range transported pollutants have been extensively monitored in the Arctic due to the high exposure of Inuit populations, resulting from their consumption of a marine diet consisting especially of apex marine predators high in contaminants. Such biomonitoring activities have shown that, among these POPs, polychlorinated biphenyls (PCBs) continue to dominate and are of the greatest exposure concern, despite their ban decades ago. However, other high-concentration POPs, amongst which organochlorine pesticides (OCPs), brominated flame retardants (BFRs), PFASs, and Hg can also be found at concentrations that raise concerns for the health of top predators and humans.

POPs and Hg pose a health threat to Arctic top predators and humans because the compounds and their biotransformation metabolites have structural similarities to endogenous compounds. These anthropogenic compounds have been classified as endocrine disruptors or cellular toxicants acting via non-endocrine pathways, and thus negatively affect immune and neuro-endocrine functioning, growth and development, reproduction and general fitness. Since the compounds potentially target different organ-tissues, the dietary exposure causes chronic and combined stress manifested through several health effects at the organism level.

There is evidence that high exposure poses a great risk to neonatal individuals during critical periods of development. Seasonal cycles of energy requirements for fasting, breeding, lactation, and migration lead to increased intake or catabolism of adipose tissue causing pulsed exposure to bioavailable contaminants circulating in the blood. In polar bears, for example, up to 70% of the total organochlorine body burden is transported from mother to offspring during lactation, resulting in cub adipose tissue concentrations that are approximately three times higher than those in their mothers. A female polar bears' very first cubs are believed to be especially vulnerable since high contaminant exposure can affect normal development and growth. In a meta-study, it has recently been modelled that chlorinated and brominated POPs, singularly or collectively, were far better predictors of declines in population densities in 14 polar bear subpopulations than were human population density, harvest rate and sea ice extention. Indeed, circumarctic polar bear subpopulations are under influence of immunological, reproductive and carcinogenic consequences from POP exposure. From a population conservation point of view, contaminants that reduce pregnancy, fecundity and survival in both males and females are among the most important to monitor in different Arctic subpopulations of polar bears, as well as other top predators and northerners relying on the same food web.

East Greenland polar bears, killer whales, narwhals and ringed, harp (*Pagophilus groenlandicus*) and hooded seals (*Cystophora cristata*) carry very high concentrations of POPs and Hg. Since Greenlanders in this region traditionally ingest significant quantities of adipose tissue from these species, they are among the Arctic people carrying the highest POP burdens. Such high exposure is likely to pose a health risk based on available literature on dioxin toxic equivalency factor (TEQ) and tolerable daily intake (TDI) guidelines [45, 46]. Human exposure to contaminants in Greenland has been evaluated from chemical analyses of prey species and food intake, showing that the TDI was exceeded for chlordane (CHL) by a factor of 3-6, while PCB exposure did not. However, none of these studies reported on polar bear and ringed seal blubber important to people's exposure in East Greenland, where POP loads are known to be four times larger than in west Greenland. It is recommended that Greenlanders reduce their exposure to PCBs and CHL by reducing their blubber intake. The Arctic Monitoring and Assessment Programme (AMAP) is therefore concerned about Arctic human health within a contaminant exposure context and their studies do support observations that Greenland hunters are particularly exposed to high PCB concentrations due to frequent ingestion of polar bear, killer whale, narwhal, and seal tissues. Studies from the Russian Arctic have shown that dioxin, furans, and PCB exposure of neo- and prenatal children exceeded TEQ TDI levels by up to 33 times in the year 2000. It has been shown that blood concentrations of PFASs including PFOS in male Inuits from East Greenland can be two to three times higher as compared to the Faroese population where local exposure has already been attributed with effects on the immune system.

Although certain PFASs have been associated with developmental and hormonal effects, immunotoxicity, and tumour growth in rodents, the impact of these compounds on human health appears to be inconclusive. Of the PCBs found in Greenlanders, the congeners CB-77, CB-126 and CB-169 attain a coplanar configuration similar to the very toxic dioxins and furans, and are in fact commonly found in Arctic wildlife. These coplanar PCB congeners are characteristically highly potent inducers of aryl hydrocarbon hydroxylase activity Furthermore, for Greenlanders, significant correlations were found between blood contaminant concentrations and calculated daily intake of POPs [52]. Hg exposure of Inuit people is also of great health concern and has been recognised as a neuro-endocrine and immune health problem in the societies of Faroe Islands, West Greenland (Avanersuaq, Thule) and Canada.

Arctic wildlife have received considerable focus as they, depending on the regional subpopulation, are threatened most dramatically by climate change due to observed and projected loss of sea ice, which has important implications for ice-associated hunters like polar bears. Modeling has shown that southernmost polar bear subpopulations in the Hudson Bay are at greatest risk, and will struggle to persist throughout this century. In fact, models have also predicted two-thirds of the world's polar bears could disappear if greenhouse gas emissions continue to increase as predicted. This has been linked to the occupation of large home range sizes and the requirement of higher energetic costs and thus higher feeding rates, which can lead to increasing blood PCB concentrations. In some regions, the decline of sea ice extent has resulted in changes in the presence of seal species that polar bears prey upon, and this has been shown to cause increased bioaccumulation of certain POPs as more contaminated prey are being consumed. Dietary shift towards feeding on plants, berries and caribou (*Rangifer tarandus*) and seabird eggs will most likely decrease and increase, respectively, the exposure to POPs. Furthermore, climate warming induced migration of warm water adapted fish species may act as bio-vectors increasing contaminant levels in marine Arctic ecosystems, ultimately causing increased bioaccumulation and biomagnification of these compounds to humans and other high trophic marine wildlife. A review on ecological impacts of global climate change on POP and Hg pathways and exposures in arctic marine ecosystems and documented that lower sea ice extent mediated dietary changes were associated with higher contaminant levels in some populations of polar bears, ringed seals, and thick-billed murres (*Uria lomvia*), but the influence of changing trophic interactions on POP levels and trends varied widely in both magnitude and direction.

Climate change not only threatens to alter contaminant dynamics by changing Arctic ecosystems, but these same factors influencing the presence and extent of different species in the Arctic will have implications for the introduction of novel infectious diseases to the region. Climate change has been deemed the most important factor in the emergence of infectious diseases, and nowhere else in the world is climate change occurring as fast as in the polar regions. A warming climate may profoundly affect disease dynamics in the Arctic by changing the species composition and northward invasion of disease vectors and transport of pathogens. In addation, increased survival of infected animals during milder winters may further increase the risk of pathogen reservoir in marine mammals including that of zoonosis. Moreover and as discussed above immunotoxic contaminants may increase disease-related mortality and morbidity of Arctic marine mammals.