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Contaminants in polar bears from the circumpolar Arctic

State of knowledge and further recommendations for monitoring and research – Action #42 of the Circumpolar Action Plan for polar bear conservation

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The Norwegian Polar Institute is Norway's central governmental institution for management-related research, mapping and environmental monitoring in the Arctic and the Antarctic. The Institute advises Norwegian authorities on matters concerning polar environmental management and is the official environmental management body for Norway's Antarctic territorial claims.
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Preface

The Norwegian Ministry of Climate and Environment has tasked the Norwegian Polar Institute with compiling a report that fulfils action #42 of the Circumpolar Action Plan for polar bear conservation (CAP) *"Compile the state of knowledge on (both global and local source) contaminants affecting polar bears and prey"*.

In this report, we give a short summary of the state of knowledge on current exposure, fate and potential health effects of contaminants in polar bears from the circumpolar Arctic. We identify needs for future monitoring and research and suggest approaches to implement the Circumpolar Action Plan for polar bear conservation actions concerning monitoring and research on contaminants and pollution. Finally, we provide recommendations following this in terms of polar bear management.

The report has been complied by Heli Routti from the Norwegian Polar Institute (NPI) in collaboration with Jon Aars (NPI), Todd C. Atwood (U.S. Geological Survey, USA), Bjørn Munro Jenssen (Norwegian University of Science and Technology, Norway), Melissa McKinney (McGill University, Canada), Robert J. Letcher (Environment and Climate Change Canada) and Christian Sonne (University of Aarhus, Denmark).

Forord

Klima- og miljødepartmentet har gitt Norsk Polarinstitutt i oppdrag å sette sammen en rapport på engelsk som svar på Action #42 av den Sirkumpolare handlingsplanen for isbjørn *"Compile the state of knowledge on (both global and local source) contaminants affecting polar bears and prey"*.

I denne rapporten gir vi en oppsummering av kunnskapsstatus med hensyn til eksponering, skjebne (spredning og nedbryting) og potensielle helseeffekter av miljøgifter i isbjørn i det sirkumpolare Arktis. Vi identifiserer behov for framtidig overvåking og forskning, og foreslår tiltak for å implementere overvåkning og forskning på miljøgifter gitt i den Sirkumpolare handlingsplanen for isbjørn. Til slutt gis anbefalinger for relevant oppfølging i forvaltningen av isbjørn.

Rapporten er sammenstilt av Heli Routti fra Norsk Polarinstitutt (NP) i samarbeid med Jon Aars (NP), Todd C. Atwood (U.S. Geological Survey, USA), Bjørn Munro Jenssen (Norges teknisk-naturvitenskapelige universitet), Melissa McKinney (McGill University, Canada), Robert J. Letcher (Environment and Climate Change Canada) og Christian Sonne (University of Aarhus, Danmark).

Photo: J. Aars / NPI

1. Introduction

The polar bear *(Ursus maritimus)* is the Arctic species exposed to some of the highest levels of biomagnifying contaminants. These contaminants include halogenated organic compounds, which originate from industrial and agricultural activities, and mercury. After climate-driven loss and fragmentation of sea-ice habitat, contaminant exposure is considered to be one of the most significant threats to polar bears. Contaminants that polar bears are exposed to, originate mainly from long-range transport. Although local pollution sources also exist, their contribution to larger scale contamination in polar bears likely has been minor.

The Circumpolar Action Plan for polar bear conservation (CAP) was developed in 2015 by the polar bear Range States in recognition of the need to collectively address emerging threats, such as loss of sea ice habitat, contaminants, diseases and parasites, human-caused mortality, mineral and energy resource exploration and development, shipping, and tourism-related activities, to the long-term persistence of polar bears (Range States, 2015). The CAP aims to strengthen international cooperation to conserve polar bears across their range through implementation of a 10-year initiative. One (#42) of the CAP's 62 actions is to "Compile the state of knowledge on (both global and local source) contaminants that affect polar bears and prey". Specific requirements are to (1) present and evaluate the current state of knowledge, (2) give recommendations on management priorities informed on the current state of knowledge, (3) identify broad needs for future monitoring and research, and (4) suggest specific approaches to implement CAP actions #43-46, all concerning monitoring and research on contaminants and pollution (Range States, 2015). A comprehensive review entitled "State of knowledge on current exposure, fate and potential health effects of contaminants in polar bears from the circumpolar Arctic" was recently published by Routti et al. (2019) to address the first question of the action #42. In the present report, we respond to the remainder of action #42. We summarize the findings presented in the before-mentioned review, identify needs for future monitoring and research, and suggest approaches to implement CAP actions concerning monitoring and research on contaminants and pollution. Finally, we provide recommendations with respect to CAP actions that should be prioritized to better inform polar bear management.

The suggestions and recommendations in the report are intended to inform polar bear management in the Range States in matters of contaminants and pollution, and to guide decisions on monitoring and research on this subject, according to the needs of each country or subpopulation. The report is a starting point for implementing the set of further actions on contaminants and pollution in the CAP.

2. Summary of the state of knowledge on current exposure, fate and potential health effects of contaminants in polar bears from the circumpolar Arctic

The recent summary of current exposure, fate and potential health effects of contaminants in polar bears from the circumpolar Arctic (Routti et al., 2019) suggests that legacy persistent organic pollutants (POPs) are still the main compounds, which polar bears accumulate and are exposed to. These are dominated by polychlorinated biphenyls (PCBs), chlordanes and perfluorooctane sulfonic acid (PFOS), followed by other perfluoroalkyl acids (e.g. carboxylic acids, PFCAs), organochlorine pesticides and polybrominated diphenyl ether (PBDE) flame retardants. Among emerging compounds, polychlorinated naphthalenes and chlorinated paraffins have been reported at concentrations intermediate to PCBs and

PBDEs. For most legacy POPs that have been banned for decades in most parts of the world, concentrations initially declined in polar bears, but recently POPs such as PCBs, PFOS and DDE have remained at relatively constant levels. Recent studies suggest increased concentrations of newer POPs such as PFCAs in certain subpopulations.

Current contaminants levels vary widely between subpopulations and among compounds. Concentrations of PCBs in the Kara Sea and East Greenland subpopulations were found to be approximately twice those in the Hudson Bay and Barents Sea subpopulations, whereas considerably lower concentrations were found in the Chukchi Sea and the southern Beaufort Sea. Concentrations of chlordanes were higher in polar bears from Hudson Bay and the southern Beaufort Sea compared to the other subpopulations. Concentrations of β-HCH were higher in East Greenland, Hudson Bay and Chukchi Sea polar bears than in other subpopulations, whereas HCB concentrations tended to be more uniform. Concentrations of *p,p*'-DDE tended to be highest in the Kara Sea, southern Beaufort Sea and East Greenland subpopulations. ΣPBDE concentrations were highest in southern Hudson Bay, followed by Barents Sea, East Greenland and western Hudson Bay polar bears. Comparison of PFOS and PFCA concentrations between the southern and western Hudson Bay, East Greenland and Barents Sea subpopulations indicated that PFOS concentrations were several times higher in Barents Sea polar bears than in the other areas. The subpopulation trends were similar, although less pronounced, for ΣPFCAs. Concentrations of Hg were several times higher in East Greenland compared to all other studied subpopulations.

Numerous studies have investigated potential adverse health effects of contaminants in polar bears using different approaches (Routti et al. 2019), but our understanding of population level risks and effects of contaminants in polar bears is still very limited. Correlative field studies, supported by *In vitro* studies, suggest that contaminant exposures alter circulating levels of thyroid hormones as well as lipid metabolism in polar bears. In addition, the immune systems of polar bears are potentially affected by specific contaminants based on correlative field studies, *in vitro* studies and risk assessment approaches. Furthermore, both correlative field studies as well *in vitro* studies have suggested that neurochemistry is altered by contaminant exposure.

Based on the review (Routti et al. 2019), the authors recommended that high quality studies using different approaches should be conducted to improve our limited understanding of effects of pollutants in polar bears. Future field studies investigating effects of contaminants should use a large number of samples, and take into account possible confounding factors (breeding status, feeding/fasting status, age, body condition, infections, and environmental factors where possible). *In vitro* methods specific to polar bears were recommended to complement field studies and to give species-specific information for toxicity of contaminants. Finally, the authors suggest investigations to determine if cumulative effects of contaminants, pathogen exposure and environmental change have adverse effects on polar bear population vital rates.

3. Needs within future monitoring and research

Needs within future monitoring and research partly reflect actions 43-46 of CAP (see below). Thus, needs and suggestions for monitoring and research for the following themes are discussed in section 4: 4.1 impact of contaminants on polar bear life history characteristics, demographics and reproduction, 4.2 spatial and temporal trends of contaminants and the influence of climate change, 4.3 causal relationships between multiple contaminants and physiological and pathological changes and 4.4. monitoring emerging compounds as well as non-target chemical screening in polar bears.

Additionally, we suggest that future correlative research on contaminant-related effects should also include environmental omics (genomics, proteomics and metabolomics), as done by a few recent studies (Morris et al., 2019; Tartu et al., 2017b), in addition to physiological parameters analysed traditionally (hormones, enzymes, vitamins, immune variables). Future studies should also incorporate analysis of effects at multiple levels of organization, i.e., from molecular and cellular to individual and population. Responses at omics level should be linked to ecologically relevant physiological responses, which again should be linked to population level responses A further step would be systems toxicology discussed in detail in the section 4.3.

Future research should also focus on potential impacts of oil spills on polar bears. Oil and gas development in the Arctic is likely to increase in scale and scope in the future, and Arctic seas are increasingly used as shipping routes. Both activities increase the potential for oil spills in polar bear habitat. Experimental studies from the 1980s have shown that direct exposure to oil is highly detrimental for polar bears (Engelhardt, 1983; Hurst and Øritsland, 1982; Hurst et al., 1991). In addition, the consequences of an oil spill that would directly expose bears to oil have been modelled, but the consequences of exposures to industrial solvents or consuming oil-contaminated prey are poorly known (Amstrup et al., 1989; Wilson et al., 2018).

4. Suggested approaches to implement CAP actions concerning monitoring and research on contaminants and pollution

4.1. CAP action 43. Examine the impact of contaminants and pollution on polar bear life history characteristics

Six studies have attempted to assess effects of contaminants on polar bear reproduction (Dietz et al., 2018; Dietz et al., 2015; Pavlova et al., 2016a; Pavlova et al., 2016b; Sonne et al., 2009). These studies have estimated the rate of embryo and teratotoxicity, percentage of abnormal sperm, stillbirth and offspring death for polar bears based on information about contaminant concentrations in polar bears and critical doses for experimental animals or humans. For example, potential relationships between PCB exposure and pregnancy rates of female polar bears have been modelled based on mouse studies that found associations between PCB exposure, sperm quality, and fertility (Pavlova et al., 2016b). Similarly, the rate of abortion and cub survival were estimated for East Greenland polar bears based on mink studies and subsequently used to model polar bear population growth (Pavlova et al., 2016a). The outcomes of these studies are challenging to interpret since the models are based on numerous poorly known assumptions for polar bears. These assumptions concern polar bear sensitivity to toxic effects compared to experimental animals, additivity of contaminant effects, partitioning of contaminants in the animal's body, and demography and behavior.

Studies that consider the potential for adverse effects of contaminants on population vital rates would be highly relevant for management. Optimally, the relationships between contaminants and vital rates would be assessed together with other stressors such as environmental change and pathogen exposure. A matrix projection model as well as an individual-based model that reflect polar bear life cycle has been recently developed and applied to explain vital rates of polar bears (Cubaynes et al., unpublished; Regehr et al., 2018; Regehr et al., 2017). These models allow the incorporation of environmental parameters such as environmental contaminants, and one could use them to examine the statistical impact of contaminants and pollution on polar bear life history characteristics. However, it should be kept in mind that interpretation of the results might be challenging due to confounding factors that are likely present. Additionally, as models increase in complexity, so do the computational requirements which may require access to advanced computing systems (i.e., supercomputers).

4.2. CAP action 44. Where appropriate, monitor contaminants and pollution to determine temporal and spatial trends, modes of transmission etc.

Temporal trends of organohalogen contaminants are currently monitored in East Greenland, the Barents Sea, and, western and southern Hudson Bay subpopulations (Figure 1). The time series are based on almost yearly sampling from East Greenland and Barents Sea polar bears since early the 1980s and 1990s, respectively (Dietz et al., 2013a; Dietz et al., 2013b; Lippold et al., 2019; Rigét et al., 2013; Routti et al., 2017). Samples from western Hudson Bay polar bears have been collected at intervals over the period of 1991 to 2007 (McKinney et al., 2010). Yearly sampling for and analysis of a broad suite of legacy and newer contaminants have also been ongoing in southern Hudson Bay since 2007 and up to 2018 (Morris et al. unpublished; Letcher et al. unpublished). Additionally, temporal trends of Hg concentrations have been monitored in hair samples from East Greenland polar bears, collected since pre-industrial times (Dietz et al., 2011; Dietz et al., 2006). Hg trends have also been studied in Barents Sea polar bears during the time period 1997-2016 (Braune et al., 2011; Routti et al., 2019), whereas the monitoring in the southern Beaufort Sea has been going on since 2004 (McKinney et al., 2017). Spatial trends of contaminants have been studied at 7-8 years intervals (Routti et al., 2019). Most studies focus on subpopulations from North America, Greenland and the Barents Sea, whereas published information from the Russian Arctic is scarcer.

We therefore suggest continuing temporal monitoring of OHCs and Hg in areas where the monitoring is already ongoing. Long-term time series are needed since contaminant concentrations tend to have a high year-to-year variation. It is of high importance to base trend studies on frequently collected samples, because it is difficult to get a large number of samples during one sampling season, and statistical power i.e. time-series' ability to detect trends increases with a number of time points included in the analyses (for further discussion see Rigét et al., 2019; Rigét et al., 2011). To reduce year-to-year or within-year variation, sampling design (season, age, sex) should be standardized. In addition, whenever possible standard morphometric parameters (e.g., mass, girth, body length) to calculate a body condition index should be recorded, as concentrations of lipophilic compounds and Hg are related to body condition (McKinney et al., 2017; Tartu et al., 2017a). With regards to spatial trends, we recommend continuing such investigations at approximately seven- to ten-year intervals. It will be important to include samples from the Russian Arctic in all circumpolar assessments (where data up until recent have been scarce). As for temporal trends, sampling design as well as analytical methods should be standardized.

Climate change is likely to affect various individual characteristics of polar bears such as body condition, feeding habits, and movement and activity patterns, which may in turn also affect contaminant concentrations (McKinney et al., 2009; Olsen et al., 2003; Tartu et al., 2018; Tartu et al., 2017a). To understand how potential climate related changes in individual characteristics affect temporal and spatial trends of contaminants, information about body condition, diet proxies (e.g. stable isotopes and fatty acids) and movement and/or activity patterns should be incorporated into contaminant trend studies (Figure 2).

Climate change may also affect the modes and rates of long-range transport, partitioning of contaminants in the physical environment, and uptake and biomagnification of contaminants in Arctic food webs.

Understanding the impacts of climate-related changes in the exposures of polar bears to contaminants will require parallel studies of temporal and spatial trends of contaminants in physical compartments and food webs of polar bear habitats (Figure 2). In addition, comparison of temporal trends among sub-populations would help to understand the roles of emissions versus other factors that may affect trends.

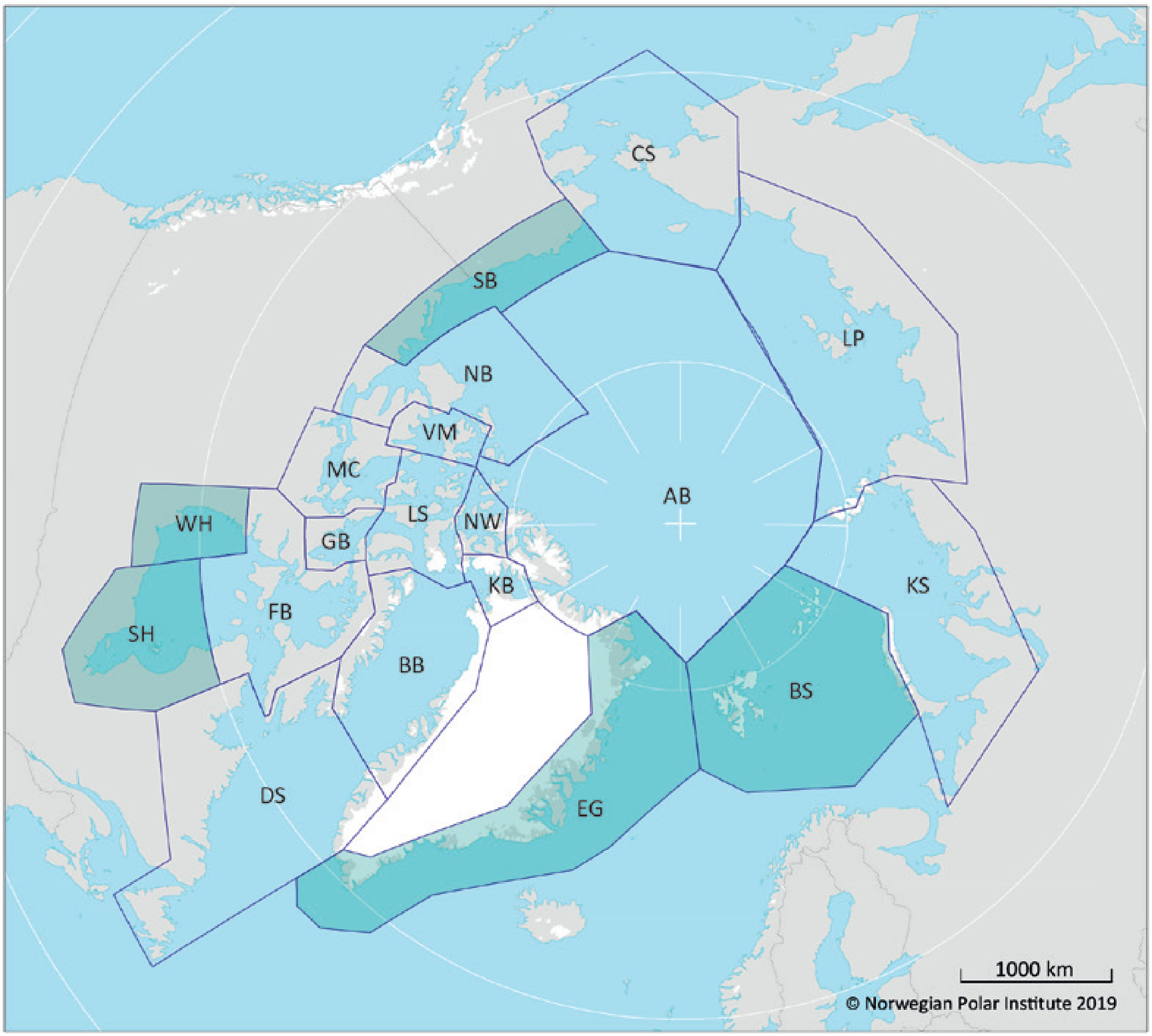

Figure 1. Subpopulations currently monitored for temporal trends in contaminants are shaded.

4.3. CAP action 45. Investigate how contaminants interact in order to establish cause–effect relationships and assess the hazards from exposure to multiple contaminants

Cause–effect relationships for single or multiple contaminants can be studied using *in vitro* techniques or surrogate species. To understand cause–effect relationships between contaminant exposure and toxic effects in polar bears, molecular or cellular assays using sequences, molecules or cells from polar bears have been developed (Desforges et al., 2017; Gutleb et al., 2010; Lille-Langøy et al., 2015; Routti et al., 2016). Additionally, binding of contaminants to certain molecules has been studied using *in vitro* assays containing human molecules (Bytingsvik et al., 2013; Simon et al., 2011; Simon et al., 2013). The Greenland sledge dog has been used as a surrogate species for the polar bear: the dogs were experimentally exposed to minke whale blubber and the control group to pork fat and a number of effect parameters were investigated (Sonne et al., 2008a; Sonne et al., 2006; Sonne et al., 2007; Sonne et al., 2010; Sonne et al., 2008b). It may also be possible to use domesticated (farmed) arctic foxes as surrogates for studying effects in polar bears (Helgason et al., 2013; Sonne et al., 2017).

We recommend that future studies should develop and apply more *in vitro* methods to establish cause-and-effect relationships for various toxic outcomes of contaminants in polar bears (Figure 2). The methods should use sequences/molecules/cells from polar bears or from species known to have similar

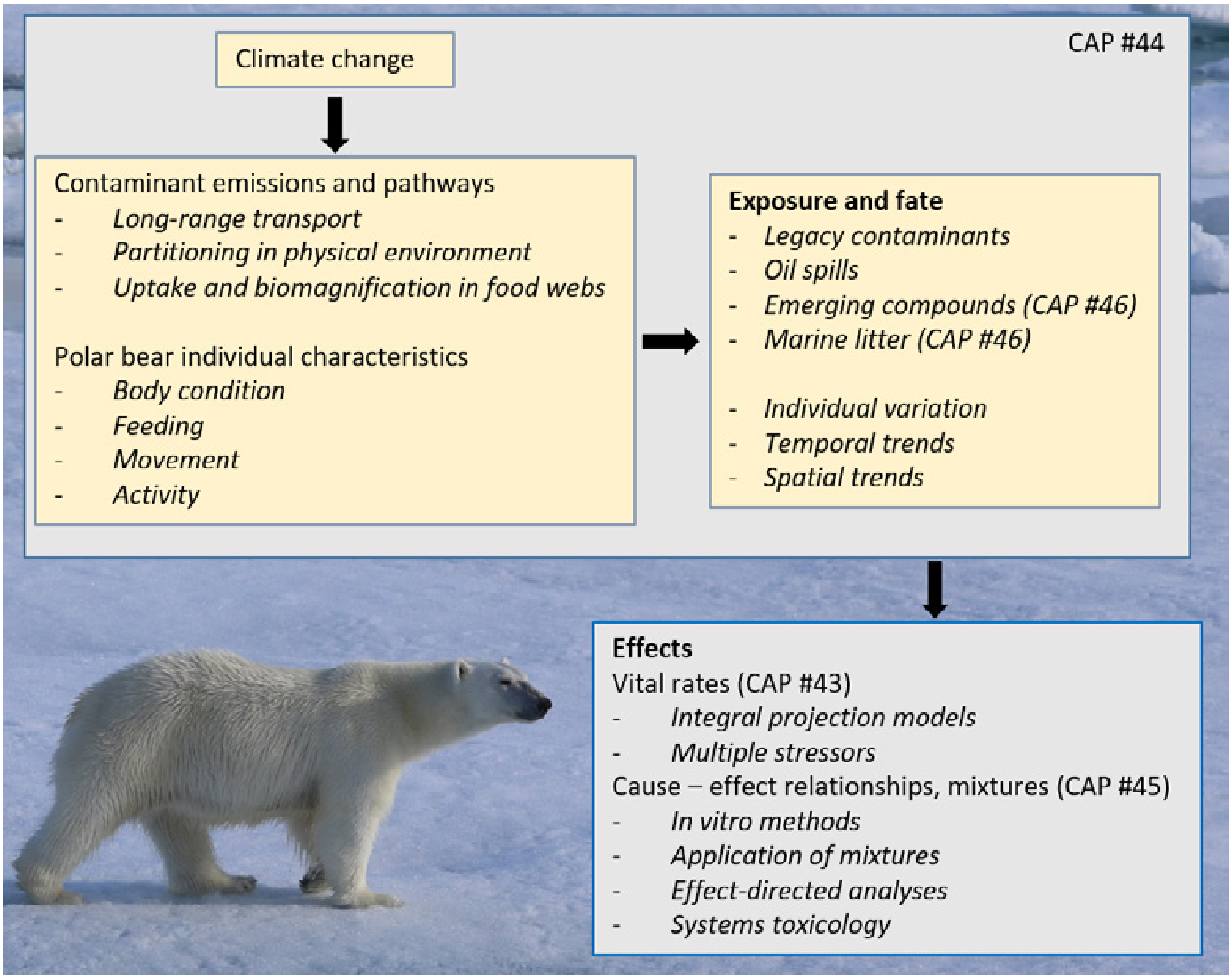

Figure 2. Summary of the suggested approaches to implement CAP actions concerning monitoring and research on contaminants and pollution.

molecules. Stem cells can be obtained from biopsies (Routti et al., 2016), and it is theoretically possible to differentiate them to different cell types (Fink et al., 2011). Because the polar bear genomic sequence is available (Liu et al., 2014; Miller et al., 2012), it is possible to find out whether molecular assays developed for other species can be directly extrapolated to polar bears. There are also recently developed sequence alignment tools that can be used to predict susceptibility to toxic compounds across species (LaLone et al., 2018).

To simulate the real-world situation, it is of particular interest to apply mixtures in *in vitro* experiments (Figure 2). Both extracted and synthetic mixtures should be used in parallel. We also recommend applying effect-directed analyses in polar bear research. In this approach, toxic properties of tissue extracts are tested using bioassays and further fractioned and the chemical composition of fractions is characterized in order to find toxic compounds in complex mixtures (Brack, 2003; Brack et al., 2016; Simon et al., 2013).

To asses a causal chain between molecular events and adverse outcomes we recommend to apply an approach called Systems Toxicology (Figure 2) (Sturla et al., 2014). The approach lies on the premise that changes at the genomic, proteomic and metabolomic levels interact with morphological and functional changes from the cellular to the organismal level (Sturla et al., 2014). Detailed mechanistic knowledge of toxicity is used to build mathematical models to predict adverse outcomes in a quantitative manner. Endpoints of particular interest to be studied are endocrine disruption, contaminant effects on immune system and disease susceptibility, contaminant effects in polar bear cubs and trans-generational effects of contaminants in polar bears.

4.4. CAP action 46. Periodically monitor for the presence of new contaminants/ pollutants (i.e., those not previously detected in polar bear samples)

Emerging contaminants are currently monitored in the Barents Sea, East Greenland and Hudson Bay subpopulations of polar bears. We recommend to continue the monitoring for the presence of new contaminants using both non-targeted and targeted analyses (Figure 2). However, this should be concomitant with the continued monitoring of legacy POPs such as PCBs. The presence of compounds identified by non-target analyses should be confirmed by target analyses. We also recommend following temporal trends of current-use compounds detected in polar bears. Along with increasing attention towards marine litter, potential exposure to micro and nanoplastics in gastro-intestinal tracts, and the latter in tissues, should be monitored in harvested polar bears. Methods to monitor exposure to micro and nanoplastics using less-invasive techniques should also be developed. Analysis of concentrations of plastic-related compounds (bound to plastic particles or plastic additives) in polar bear tissues is also recommended to evaluate the exposure to microplastics.

Recommendations in priorities of CAP actions

All the CAP actions are important to follow up. Most of the recommendations given for CAP actions 44 and 46 are already part of national monitoring activities. We thus recommend that if funding is available through Range States or other sources, CAP actions 43 and 45 should be prioritized.

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