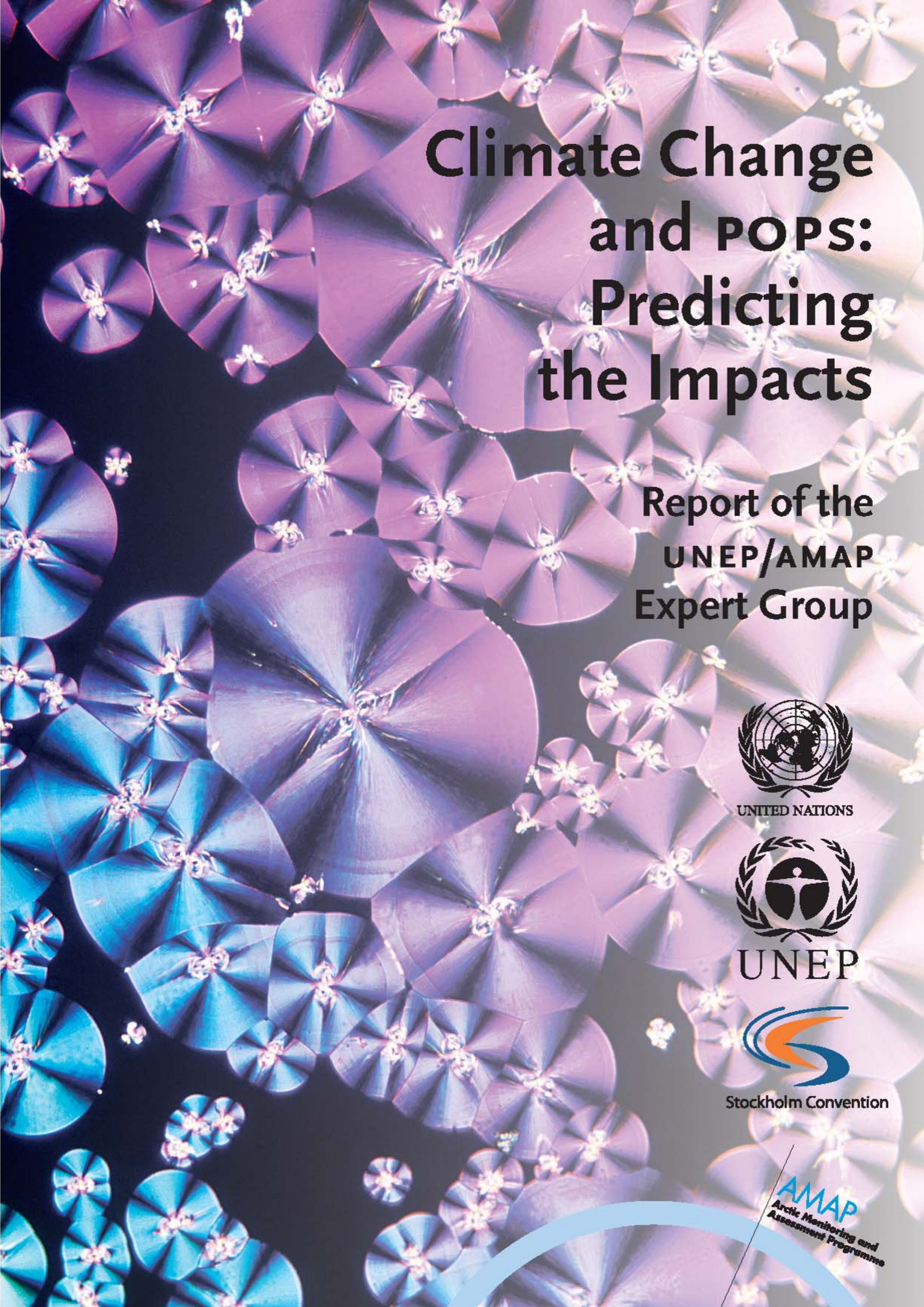

Climate Change and POPS: Predicting the Impacts

Report of the UNEP/AMAP Expert Group

UNITED NATIONS

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Cover. Polarized light micrograph of the insecticide DDT.

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Preface

The potential for climate change to increase the planet's vulnerability to persistent organic pollutants is of major concern, multiplying the risks posed by global environmental change. Climate change alone presents serious threats to society and the environment, and in conjunction with other environmental stressors, increased risks and higher vulnerability of human populations and ecosystems are foreseen. While the level of scientific understanding associated with each component is relatively well-defined, assessment of the coupled dynamics of multiple environmental stressors and processes is associated with higher uncertainties and knowledge gaps.

In this perspective, science holds the key not just to advancing our understanding of these complex problems, but also to improving our ability to reduce the risks they pose to the world. Finding appropriate solutions to address today's complex, intertwined environmental issues requires strong scientific support and advice.

To support informed decision making, the Secretariat of the Stockholm Convention, in collaboration with the Arctic Council's Arctic Monitoring and Assessment Programme (AMAP) invited a number of distinguished experts to review the most recent scientific findings on climate change effects on persistent organic pollutants within a global perspective. This cooperation ensured that the study benefited from the extensive assessment experience and ongoing scientific investigations of this issue in the Arctic region.

Significant climate-induced changes are foreseen in relation to future releases of persistent organic pollutants into the environment, their long-range transport and environmental fate, and to human and environmental exposure, subsequently leading to higher health risks both for human populations and the environment.

The findings and conclusions of this systematic and authoritative study offer the opportunity to the Parties to the Stockholm Convention to work more effectively towards meeting the objective of the Convention to protect human health and the environment from persistent organic pollutants, by considering aspects of coupled dynamics between climate processes and persistent organic pollutants.

Donald Cooper
Executive Secretary of the Stockholm Convention

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This technical document was shared with and reviewed by the members of the Global Coordination Group for the Global Monitoring Plan for Persistent Organic Pollutants. The document represents the technical basis of the report on policy recommendations submitted to the fifth meeting of the Conference of the Parties to the Stockholm Convention, 25-29 April, 2011.

Executive Summary

The first global monitoring report under the Global Monitoring Plan (GMP) was released in 2009 and recognized the importance of climate effects on persistent organic pollutants (POPs). It also stressed the need to consider possible climate effects when interpreting temporal trend data for POPs in GMP core media (i.e., human tissues and air). The present work is based on the mandate given to the Global Coordination Group (GCG) by the Conference of the Parties to the Stockholm Convention at its fourth meeting (Decision SC-4/31) to assess climate influences on the levels of POPs measured in the environment and in humans and the relevance of how these influences may interfere with present and future evaluations of the effectiveness of the measures undertaken through the Stockholm Convention.

The report highlights key scientific findings related to the complex relationships between climate change and abatement of POPs. It provides an overall view of POPs releases into the environment, long-range transport and environmental fate, and human and environmental exposure in a changing climate, as well as potential coupled effects of climate and POPs on human health and the environment. The report also addresses the synergies between climate change mitigation policies and actions to eliminate and manage POPs, and provides recommendations based on the current state of science.

Climate change may affect primary emissions to air of POPs by changing their rate of mobilization from materials or stockpiles, or by altering use patterns. This could result in an increase in primary emissions that could offset some of the efforts undertaken to reduce emissions of POPs under the Stockholm Convention. Higher temperatures will also increase secondary emissions of POPs to air by shifting the partitioning of POPs between air and soil, and between air and water. Releases from environmental reservoirs such as soil, water and ice will also increase due to these increasing temperatures. The effect of temperature on emissions of semi-volatile POPs is probably the most important effect and stronger than any other effect of climate change on the environmental cycling of POPs. The expected increase in the incidence of vector-borne disease associated with climate change, such as malaria, may lead to enhanced demand for and release of DDT (dichlorodiphenyltrichloroethane) in some regions.

There are several main factors related directly to climate change which have previously influenced and will continue to influence the environmental fate of POPs, including their long-range transport. These include: the strength of secondary re-volatilization sources; wind fields and wind speed; precipitation rates; ocean currents; melting of polar ice caps and mountain glaciers; higher frequency of extreme events; degradation and transformation; partitioning; and, biotic transport.

Climate change is expected to modulate the impact resulting from exposure of humans and wildlife to POPs. However, the lack of understanding of climate change effects on food web structures and dynamics means that it is not currently possible to make reliable predictions of the extent of these impacts. Nor is it possible to determine if the effects will be felt up or down the food chain, i.e., whether top of the food chain species are most affected, causing a ripple down effect to lower trophic level species, or whether changes in lower trophic level species will lead to disturbances in the viability of higher trophic level species.

Climate change, including increasing climate variability, will also affect biodiversity, and ecosystem composition, function, and vulnerability. Toxicity and toxico-kinetics of POPs could be altered as a direct result of changes in temperature. Climate change will also alter salinity, ocean acidification, eutrophication, water oxygen levels, and the nutritional status of species and their adaptability. These changes, either alone or in combination, could enhance the toxic effects of POPs on wildlife, increase disease risks, and increase species vulnerability.

Persistent organic pollutants are known to have negative health effects on humans, such as cardiovascular disease, immunosuppression, metabolic disorders, cancer, and neurobehavioral, endocrine and reproductive effects. If climate change results in an increase in exposure to POPs, this would increase the risks related to their harmful effects. The combined effect of several climate-related factors – for example, excessive heat or cold, population migration related to temperature change and loss of arable land, increased exposure to insect vectors of disease, and changes in the availability and quality of traditional/local food – could also aggravate the effects of POPs exposure on human populations. Socio-economic factors such as education and general health status can also contribute to human vulnerability to POPs.

Implementation of various climate change mitigation options targeted to reduce carbon dioxide emissions, such as improvement of energy efficiency in power stations, replacement of fossil fuels by renewable sources, and improvement of combustion, industrial and transportation technologies, is likely to have a positive impact on the reduction of releases of unintentionally produced POPs (i.e., mainly polychlorinated dibenzo-*p*-dioxins / polychlorinated dibenzofurans, hexachlorobenzene, polychlorinated biphenyls). These measures could also reduce the emissions of several non-POPs contaminants of concern (e.g., nitrogen and sulfur oxides and other gases, particulates, mercury and other metals). There are, however, some potential negative impacts that need to be taken into account when considering mitigation options. For example, increased use of biomass fuel could increase emissions of unintentionally produced POPs.

This report identifies several key areas where knowledge gaps exist and provides recommendations to address these gaps.

Chapter 1. Introduction

Katarina Magulova and Ana Priceputu

The Stockholm Convention on Persistent Organic Pollutants aims to protect human health and the environment from the negative effects of POPs, by restricting and ultimately eliminating their production, use, release and unsafe disposal. These are chemical substances that have toxic properties, resist degradation in the environment, bioaccumulate through food chains and are transported long distances through moving air masses, water currents and migratory species, within and across international boundaries. The Stockholm Convention was adopted on 22 May 2001 and entered into force on 17 May 2004. It initially listed twelve chemicals (shown in bold font in footnotes 1-3 below). In general, these 'legacy' POPs were first produced and/or used several decades ago, their persistence, bioaccumulative properties and potential for long-range transport are well studied, and they have been globally banned or restricted since 2004. In 2009, nine more substances were added to the Convention (chemicals with an asterisk in footnotes 1-3). The 21 POPs belong to three groups:

- pesticides used in agricultural applications, for fungus control or for insect control[1]
- industrial chemicals used in various applications[2]
- chemicals generated unintentionally as a result of incomplete combustion and/or chemical reactions[3].

Some of the chemicals fit into more than one of these three general categories, for example, hexachlorobenzene (HCB), pentachlorobenzene (PeCB), polychlorinated biphenyls (PCBs) (see footnotes 1-3). While some chemicals are grouped together in the elimination or control Annexes of the Convention, for example, penta- and tetrabrominated diphenyl ethers represent one listing for elimination of commercial pentabrominated diphenyl ether (see footnote 2).

The provisions of the Stockholm Convention are aimed to address health and environmental concerns at the global level, while focusing on effects resulting from local or regional exposures to POPs. Specific attention is placed on the impacts of POPs upon the most vulnerable human population groups, such as in the Arctic. These include the fetus, newborns, children and women of reproductive age. The Convention also emphasizes the strengthening of national capacities for the management of chemicals in developing regions, including through transfer of technology, the provision of financial and technical assistance, and the promotion of cooperation and information exchange among the Parties to the Convention.

Article 11 of the Stockholm Convention encourages Parties to undertake research, development, monitoring and cooperation activities on POPs, as well as on their alternatives and 'candidate' POPs (candidate chemicals under review by the POPs Review Committee), including aspects related to sources and releases into the environment, levels and trends, transport, fate and transformation, and effects on human health and the environment.

Article 16 of the Stockholm Convention calls for the Conference of the Parties to evaluate periodically whether the Convention is an effective tool in achieving the objective of protecting

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1 **aldrin, chlordane,** chlordecone*, **dichlorodiphenyltrichloroethane (DDT), dieldrin, endrin, heptachlor, hexachlorobenzene (HCB)**, gamma-hexachlorocyclohexane (γ-HCH, lindane)* and by-products of lindane [alpha-hexachlorocyclohexane (α-HCH)* and beta-hexachlorocyclohexane (β-HCH)*], **mirex, toxaphene**.

2 tetra- and pentabromodiphenyl ethers (PBDEs)*, hexa- and heptabromodiphenyl ethers (PBDEs)*, hexabromobiphenyl*, perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOS-F)*, pentachlorobenzene (PeCB)*, **polychlorinated biphenyls (PCBs)**.

3 **hexachlorobenzene (HCB)**, pentachlorobenzene (PeCB)*, **polychlorinated biphenyls (PCBs)** and **polychlorinated dibenzo-*p*-dioxins (PCDDs)** and **dibenzofurans (PCDFs)**.

DDT spraying in Namibia

human health and the environment; this evaluation is based on several types of information, one of which is comparable and consistent monitoring data on the presence of POPs in the environment and in humans. The Global Monitoring Plan (GMP) for POPs, which has been put in place under the Convention, is a key component of the effectiveness evaluation and provides a harmonized framework to identify changes in levels of POPs over time, as well as information on their regional and global environmental transport.

Because the release, distribution and degradation of POPs are highly dependent on environmental conditions, climate change and increasing climate variability have the potential to affect POPs contamination via changes in emission sources, transport processes and pathways, and routes of degradation. Climate variation may also lead to exposure to chemicals through different sources, processes and mechanisms. This will have implications for the effectiveness evaluation of the Stockholm Convention, as the measured levels of POPs will include a climate-induced component.

The first global monitoring report under the GMP released in 2009 recognized the importance of climate effects on POPs and stressed the need to consider possible climate effects when interpreting temporal trend data for POPs in GMP core media (i.e., human tissues and air). The report concluded that consideration of the effects of climate on the transport and partitioning of POPs had the potential to improve significantly the interpretation of measurements of POPs in environmental media in future evaluations. It also concluded that further studies should be encouraged to assess climate influences on levels of POPs in environmental media.

Furthermore, Decision SC-4/31 on the GMP establishing the terms of reference of the Regional Organization Groups and the Global Coordination Group, encourages further assessment of long-range transport of POPs while considering the effect of climate and meteorology on the observed trends in levels of POPs. The present work is based on the mandate given to the Global Coordination Group to assess climate influences on the levels of POPs measured in the environment and in humans.

The Arctic Council's Arctic Monitoring and Assessment Programme (AMAP) has conducted a number of activities in recent years documenting the linkages between climate change and environmental transport and fate of contaminants, including POPs. It has also produced several assessments of POPs in the Arctic, most recently in 2010 (see www.amap.no), the results of which contribute to the work under Article 16 of the Stockholm Convention and the further development of the GMP. AMAP is mandated to support the development and implementation of international agreements that will reduce environmental contamination and effects in the Arctic region. The Secretariat of the Stockholm Convention and AMAP jointly implemented a strategy to prepare this technical background document in order to provide consistent information to both the Conference of the Parties to the Stockholm Convention and to the Arctic Council.

This technical report draws on other recent and ongoing studies that aim to assess climate change effects on POPs dynamics and toxicity, as well as on the wider scientific literature in order to provide a brief overall synthesis/review of the current state of knowledge at the global level, and especially with reference to the Stockholm Convention.

This technical report highlights key findings related to the complex relationships between climate change and POPs. It aims to provide an overall global view of POPs releases into the environment, long-range transport and environmental fate, and human and environmental exposure in a changing climate, as well as the potential for a coupling of the effects of climate and POPs on human health and the environment. It also addresses the synergies between the climate change and POPs policy agendas and provides policy messages based on the current state of science. This document identifies areas of uncertainty and existing gaps in information and knowledge.

An improved understanding of the influence of climate change on POPs dynamics, exposure and toxicity together with a better understanding of how these combine to affect ecosystem and human health will assist the scientific community and decision-makers in developing appropriate policy responses that may be addressed through the Stockholm Convention and regional and national strategies. Better management of POPs will benefit the global community and, in particular, sub-populations that are most at risk from exposure to POPs. The identification of gaps in information and knowledge described in this technical report may stimulate additional research to address these outstanding needs.

This report has eight chapters. Following this introduction, Chapter 2 provides information on how changes in climate have affected and may continue to affect releases of POPs (including existing inventories and stockpiles) and possible new uses of POPs in different industrial sectors. Chapter 3 addresses both generic and specific fate and transport processes for POPs, with an emphasis on re-releases of POPs from different environmental compartments such as the oceans, ice, and land masses. Chapter 4 investigates the potential for changes in exposure levels of the environment and human populations, while Chapter 5 discusses the health and ecotoxicological implications of the projected changes in exposure. Chapter 6 analyzes possible co-benefits of climate change mitigation activities and POPs emission reduction measures. Chapter 7 summarizes the main conclusions, while policy recommendations drawn from the scientific assessment are provided in Chapter 8.

Chapter 2. Release of POPs to the environment

Christian Bogdal and Martin Scheringer

2.1. Environmental releases from primary sources

Past and current uses of intentionally produced POPs lead to primary releases – also referred to as primary emissions – into the environment. That is, direct dispersion on soils and into air (pesticides), volatilization into air from initial applications (semi-volatile technical chemicals, e.g., PCBs and polybrominated diphenyl ethers (PBDEs)), and leaching into water from initial applications (water soluble technical chemicals, e.g., perfluorooctane sulfonate (PFOS) / perfluorooctane sulfonyl fluoride (PFOS-F)). Currently, DDT is the only POP pesticide that is produced and applied in appreciable amounts for malaria control, PFOS/PFOS-F are still used in a wide range of applications, and there are extensive amounts of PBDEs in products and stockpiles of obsolete formulations. Emissions into air of unintentionally generated POPs result from side-reactions in thermal and chemical processes (e.g., polychlorinated dibenzo-*p*-dioxins (PCDDs) / polychlorinated dibenzofurans, (PCDFs) generated by combustion). Although the majority of environmental POP sources are related to anthropogenic activities, some natural processes generating POPs in small amounts have been identified, such as PCDDs and PCDFs from forest fires (Hung et al., 2010).

The geographical occurrence of the release of POPs and their distribution in the environment is associated with their global production and usage pattern. Current releases of POPs used as pesticides are often related to their former applications in large agricultural areas (Li, 1999; von Waldow et al., 2010). Worldwide emissions of POPs formerly used as technical chemicals are highest in industrialized countries in the Northern Hemisphere. Factors representative of the economic status and the population density of a country, such as night-time light emissions and electric power consumption, have also been considered as representative of the use and associated emissions of technical chemicals (Breivik et al., 2002; Doll et al., 2006; von Waldow et al., 2010). During the past decades, practices and regulations for the use of hazardous chemicals have been improved both in industrialized and less industrialized nations. Today, production and associated releases of halogenated chemicals, as well as disposal and recycling of POP-containing applications (such as electronic equipment) are increasingly relocated to developing countries and countries with economies in transition. These countries often do not yet have available state-of-the art production technology, workers may lack the education required for production and use management, and frequently have insufficient regulations and/or enforcement regimes for these sectors, including self-regulation / voluntary regulation by industries (Weber et al., 2008a,b).

2.2. Impact of climate change on primary emissions

The objective of the Stockholm Convention is to "*…protect human health and the environment from persistent organic pollutants*". To meet this objective, the Convention eliminates or severely restricts the production and/or use of POPs. The Convention also manages releases by limiting sale, transportation and storage of POPs. However, the efforts undertaken through the Stockholm Convention may be undermined by climate change in several ways. Climate change may affect primary emissions of POPs by changing their rate of mobilization from materials or stockpiles, or by altering use patterns. Increasing ambient temperatures will directly lead to enhanced emissions of POPs that volatilize from existing POP-containing applications. The vapor pressure of chemicals increases exponentially with temperature, which shifts the partitioning between air and soil and between air and water. Thus, increasing temperatures enhance volatilization and, therefore, lead to increased emissions into air (Lamon et al., 2009). For semi-volatile chemicals, such as most POPs, the emissions by volatilization are particularly sensitive to a small modification of vapor pressure. The global average of surface temperatures has increased by about 0.74 °C in the period 1906 to

Bromine chemical fumes above a refinery at Sidom, Israel

2005. Eleven of the twelve warmest years occurred between 1995 and 2006. However, the warming has been neither steady nor the same in different seasons or at different locations. Seasonally, warming has been slightly greater in the Northern Hemisphere and especially in the Arctic.

Warming, particularly since the 1970s, has generally been greater over land than over the oceans. Additional warming occurs in cities and urban areas, often referred to as the 'urban heat island effect'. An increase in temperature of 1 °C, which is to be expected in the near future (IPCC, 2007), will result in an approximately 10% to 15% increase in the volatility of a typical semi-volatile POP (e.g., PCBs). Locally, temperatures may, however, increase by considerably more (IPCC, 2007). A 10 °C rise in ambient temperature will result in an approximate 3-fold increase in the volatility of a typical POP. Therefore, emissions of POPs present in open applications are expected to increase, such as PCBs used as plasticizers in paints and joint sealants, and PBDEs used as flame retardants.

The effect of temperature on primary emissions of POPs is probably the most important effect, stronger than many other effects of climate change on the environmental fate of POPs (see Chapter 3). In an experiment with a global environmental fate model that compared the effect of increasing temperature, changing wind fields, changing ocean currents, and changing precipitation on the global distribution of PCBs, higher concentrations of PCBs in air were obtained in all parts of the world (Lamon et al., 2009). This is mainly caused by stronger emissions from primary sources and, to a lesser extent, by increased re-volatilization from POP reservoirs in soils and seawater (see Chapter 3).

Further, increasing global temperatures are expected to intensify the propagation and spread of malaria and other vector-borne diseases in tropical countries so that larger areas than at present may need malaria control. The existing public health exemption on the use of DDT for combating malaria may lead to enhanced demand for DDT and, consequently, may lead to increasing emissions of DDT.

Owing to this effect of climate change on the demand for greater use of some POPs and increased volatilization of POPs from existing primary sources, the overall trend of future releases of POPs is likely to increase although the certainty of the predictions is limited. For some POPs, climate change-induced enhancement of emissions may reduce the expected effectiveness of the Stockholm Convention, resulting in releases decreasing less rapidly than targeted. For other POPs, such as DDT, continuing or even increasing demand and increasing volatilization may outweigh reduction efforts, possibly leading to stabilizing or even increasing overall releases of some POPs into the environment.

Once released into the environment from primary sources, POPs may be temporarily stored in environmental reservoirs, which can then turn into secondary sources of POPs. The impact of climate change on secondary sources of POPs is addressed in Chapter 3.

2.3. Conclusions

Climate change makes it difficult to predict the overall trend of future releases of POPs. Whereas the efforts undertaken under the Stockholm Convention are expected to reduce releases, climate change may counteract these efforts. Increasing global temperatures are likely to intensify propagation of vector-borne diseases such as malaria and, thus, enhance the demand for insecticides likely to include DDT. Also, emissions of POPs from remaining stocks (e.g., PCBs still present in buildings and electrical equipment) will increase with a warming climate because volatilization of chemicals increases exponentially with temperature.

Although the magnitude of these effects is unclear, some POPs may show a slowdown of emission reductions whereas other POPs may even have increasing emissions. Increasing demand and higher emissions from volatilization sources will influence both the projections and interpretation of future trends of environmental contamination by POPs.

The existing uncertainty associated with the expanded use and release of POPs points to the need for improved quantification and characterization of use patterns of POPs (e.g., DDT applied in malaria affected regions) and volatilization sources of POPs (e.g., PCBs storage sites and other POPs waste sites).

Chapter 3. Environmental fate and long-range transport of POPS

Christian Bogdal and Martin Scheringer

3.1. Large-scale distribution in the environment

After release, POPS are transported away from the source regions with moving air masses and, in the long term, also with ocean currents. Transport by ocean currents is particularly important for relatively water-soluble chemicals such as hexachlorocyclohexanes (HCHS) and perfluorinated acids (PFOS, perfluorooctanoic acid (PFOA)). Although the vapor pressure of most POPS is relatively low (below 1 Pa), it is sufficient to support significant mobilization by volatilization (see Chapter 2).

Both transport pathways (air and water) together carry POPS into all regions of the world, as has been extensively documented by measurements in various media in the Arctic and Antarctic (Muir et al., 1999; Macdonald et al., 2000; Weber and Goerke, 2003; Corsolini, 2009; Hung et al., 2010).

For chemicals transported by air, hemispheric distribution occurs within weeks or months, whereas inter-hemispheric mixing takes place on the time scale of years. The effectiveness of airborne transport of POPS is determined by the interplay between: transport (i.e., wind speed and direction); removal from air by degradation, which occurs mainly by reaction with OH radicals for chlorinated compounds and photolytic transformation for brominated chemicals; and removal from air by deposition, which includes dry and wet deposition of POPS in the gaseous phase and dry and wet deposition of POPS associated with atmospheric particles (aerosols). Wet and dry deposition of the particle-bound fraction of POPS is, on average, the fastest and most effective of the removal processes. Degradation for most POPS is relatively slow, particularly the reaction with OH radicals, which has half-lives of the order of days to weeks and even months or years. Given that the transport of POPS from industrial regions to remote areas like the Arctic takes days to weeks, some POPS will undergo degradation during 'transportation', while others will remain unaltered. POPS with relatively high vapor pressure such as lighter PCBS are mainly in the gas phase, whereas POPS with low vapor pressure, such as highly halogenated PCBS or PBDES are strongly associated with aerosol particles. Because of the high efficiency of the particle-associated deposition processes (washout with rain, gravitational settling), POPS with lower vapor pressure are removed more quickly and travel shorter distances (on average). This difference in removal efficiencies leads to the so-called 'global fractionation' effect, wherein more volatile POPS are prone to travelling longer distances in the environment than less volatile POPS.

The global distribution of POPS has been investigated by large-scale field studies, including analysis of large sets of samples of tree bark (Simonich and Hites, 1995), soil (Meijer et al., 2003), vegetation (Tremolada et al., 1996), butter (Kalantzi et al., 2001), air and precipitation (Jurado et al., 2004, 2005; Pozo et al., 2006), and biota (Solomon and Weiss, 2002; Hites, 2004; Carlson and Hites, 2005). For air sampling, both active and passive sampler approaches have been used and proved to be useful as complementary methods (Gouin et al., 2005).

The field studies indicate that volatile compounds such as HCB are almost evenly distributed within the Northern Hemisphere or even globally. In contrast, concentrations of less volatile compounds such as highly chlorinated PCBS show highest values in and around the populated regions of primary releases and are considerably lower – but clearly not zero – in more remote regions. Important questions in this context are: (1) whether primary sources still dominate the observed levels, global-scale distribution patterns, and time trends of POPS in the environment; and (2) what is the relative contribution from secondary sources (e.g., soils and oceans) through remobilization of POPS? Current evidence suggests that primary sources are still dominating, at least for PCBS (Gioia et al., 2006; Li et al., 2010; Schuster et al., 2010).

3.2. Impact of climate change on environmental fate and long-range transport

Higher temperatures increase the rate of volatilization of POPs from open sources. This factor, which is addressed in Chapter 2, mainly concerns primary emissions and may be a dominating effect of climate change on the environmental distribution of POPs. However, climate change will also affect the environmental fate of POPs once they have been emitted into the environment from primary sources. There are several main factors that are relevant for the environmental fate and long-range transport of POPs and that may be affected by climate change (see Figure 3.1). For the monitoring of POPs under the GMP, it will be important to take such factors into account. For example, increased re-volatilization from environmental reservoirs such as soil or glaciers (process 1 in Figure 3.1) will increase levels detected by monitoring programs. In the interpretation of these data and the development of control options under the Stockholm Convention, it will be important to understand the relative roles played by primary and secondary sources. Only then can conclusions on the effectiveness of measures to reduce emissions from primary sources be drawn.

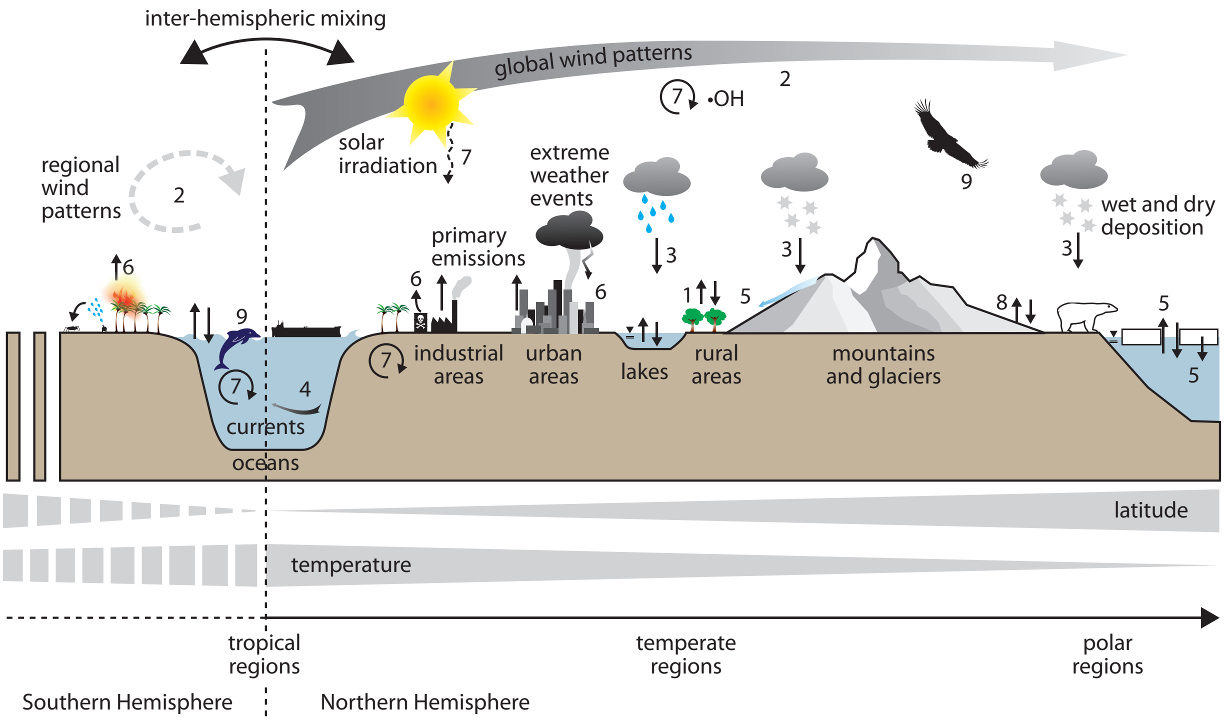

Figure 3.1. Conceptual representation of key factors influencing the environmental fate and transport of POPs under a climate change scenario. Numbers correspond to enumerated items in the text, including climate-change-induced modifications in (1) strength of secondary re-volatilization sources, (2) wind fields and wind speed, (3) precipitation, (4) ocean currents, (5) melting of polar ice caps and mountain glaciers, (6) frequency of extreme events, (7) degradation and transformation of POPs, (8) environmental partitioning of POPs, and (9) biotic transport of POPs. Note that the processes depicted for the Northern Hemisphere are the same in the Southern Hemisphere.

Effects of climate change on factors governing the environmental fate of POPs include:

1. **The strength of secondary re-volatilization sources.** The process of increasing volatilization with increasing temperature mainly affects releases of POPs from primary sources; however POPs can also re-volatilize from secondary sources. Environmental reservoirs (e.g., surface water, soils, vegetation, permafrost, snow and ice) that have been loaded with POPs initially emitted from primary sources can become secondary sources of POPs. Land use changes (e.g., agricultural land

Swimming Polar Bear, Svalbard

use in the Arctic region) will change vegetation cover, affect environmental reservoirs, and, in turn, modify secondary emissions of POPs. Deposition of POPs from the atmosphere into foliage and subsequent formation of long-term soil reservoirs (Wania and McLachlan, 2001) may be affected by climate-change-induced modification of land use. For instance, increased proportions of leaf-bearing plants in Arctic regions may promote this 'forest pump effect' from atmosphere to soil.

2. **Wind fields and wind speed.** POPs migration through the atmosphere is driven by winds and, therefore, higher wind speeds lead to faster and more effective transport of POPs. Consequently, higher levels of POPs are expected in regions downwind of relevant primary and secondary sources. That is, northeast of Europe in Siberia and the Arctic; southeast of mainland Asia in the tropical Pacific Ocean; and in northern Canada and Greenland. Model projections of future climate change scenarios suggest higher POPs concentrations in air in regions downwind of their primary sources (see Chapter 2). In the context of decadal or longer time-scale climate change, changes in the magnitude and direction of global winds as a consequence of climate change are more difficult to assess because such changes are not readily measurable. Rather, the evidence for linkages between POPs circulation and changing wind fields has come from relationships between POPs transport and wind flows or atmospheric circulation associated with inter-annual time-scale climate variation, notably the North Atlantic Oscillation (NAO), the El Niño-Southern Oscillation (ENSO), and the Arctic Oscillation (AO) in the Northern Hemisphere (Ma et al., 2004a; Macdonald et al., 2005; MacLeod et al., 2005; Becker et al., 2008). Anomalous changes in these atmospheric circulation modes alter the intensity and position of major meridional or longitudinal wind streams in the Northern Hemispheric atmosphere. This might enhance the meridional or poleward atmospheric transport. Some of these climate variations (e.g., NAO) also exhibit inter-decadal changes that have been linked to global warming (Hoerling et al., 2001). The association between POPs levels in the atmosphere and these climate variations (e.g., NAO) are likely to contain a signature of the effect of decadal or longer time-scale climate change on long-range atmospheric transport of POPs (Gao et al., 2010). Climate change induced desertification might also lead to greater distribution of POPs through dust transport associated with changing wind fields.

3. **Precipitation.** Precipitation is most likely to be important at the regional scale: in regions with increased precipitation, deposition of POPs from air to surface media will increase; in regions with and during times of low or no precipitation, airborne POPs will be transported more effectively. Precipitation projections in climate change differ considerably around the globe, indicating both decreasing (e.g., 20% reduction from mean) and increasing (e.g., 40% increase from mean) trends

Calving Iceberg,
Disko Bay, Greenland

as reported by the Intergovernmental Panel on Climate Change (IPCC, 2007). A main impact of the changes in precipitation on POPs concentrations is caused by changes in wet deposition. Another factor is the effect of changing precipitation on soil moisture and microbial communities in the soil that biodegrade POPs.

4. **Ocean currents.** Modifications of ocean currents possibly occurring under climate change will also affect the transport of POPs. It is mainly the environmental fate of more water-soluble chemicals, such as perfluorinated acids, that will be affected by modifications of ocean currents (Pavlov, 2007; Pavlov and Pavlova, 2008; Yamashita et al., 2008).

5. **Melting of polar ice caps and mountain glaciers.** Ocean ice melting will result in air-water exchange of POPs in large areas of the Arctic oceans when they are no longer ice covered. Melting ice leads also to release of POPs trapped in ice in polar and alpine glaciers, as well as to a loss of permafrost, enabling air-soil exchange of POPs. For example, during the past five years the levels of HCB at the Zeppelin station (Ny-Ålesund, Spitsbergen, Norway) have been increasing (Hung et al., 2010). To date, such an increase in HCB concentration has only been observed at the Zeppelin station; no similar trends are reported from any other atmospheric monitoring sites (Hung et al., 2010). The increasing HCB levels may be explained by increased evaporation of HCB from the open ocean (including during the Arctic winter) along the western coast of Spitsbergen (Svalbard, Norway), which has been ice-free during in the period 2004 to 2009. Similarly for α-hexachlorocyclohexane (α-HCH), it is expected that the central Arctic Ocean, which currently is considered over-saturated with α-HCH compared to the air (Jantunen et al., 2008; Hansen et al., 2009), will serve as a direct source when the ice cap disappears on a seasonal basis (as predicted in various climate change scenarios). Mobilization of POPs from mountain glacier ice has already been observed (Blais et al., 2001; Bogdal et al., 2009). It is also widely expected that sea ice melting will facilitate more ship traffic and oil and gas exploration, which will probably cause increased direct or indirect releases of POPs (ACIA, 2005; Macdonald et al., 2005). Tourism and the size of resident populations may also increase in the Arctic as the climate in this region moderates, leading to increased POP releases to air, water and soils.

6. **Frequency of extreme events.** More frequent extreme weather events such as heat waves, storms, floods and forest fires are projected to occur as a result of global warming (IPCC, 2007). Extreme weather events have a documented impact on the remobilization and subsequent bioavailability of POPs. It has been shown that concentrations of certain POPs, shortly after hurricanes and

storms, were elevated several fold locally in soils, sediments and runoff waters (Burgoa and Wauchope, 1995; Presley et al., 2005). Also, flooding events, which occur frequently in temperate regions of Europe, the Americas, Asia and Africa, may significantly contribute to re-emission and redistribution of POPs formerly stored in sediment and agricultural soils. Recent studies investigating the effects of flooding events on long-term remobilization of legacy POPs illustrate the potential of these events for reactivating formerly deposited pollutants (Wilken et al., 1994; Holoubek et al., 2007; Pulkrabova et al., 2008; Weber et al., 2008a).

7. **Degradation and transformation.** Higher temperatures will probably lead to increased degradation of POPs; this is probably most relevant to reservoirs of POPs in soils, vegetation and seawater. However, it is not clear to what extent the capacity of microorganisms to degrade POPs will increase with increasing temperature and whether microorganisms will experience thermal stress under warming climate. In air, stronger irradiation in regions with less cloud cover and rain leads to higher photolytic irradiation and higher concentration of OH radicals in air, which increases the degradation of airborne chemicals. In addition, degradation of POPs often includes formation of transformation products that are structurally similar to the parent compound and may also be similarly toxic and persistent. An example is DDE (dichlorodiphenyldichloroethylene), a highly persistent transformation product of DDT (Schenker et al., 2007). Although the effect of temperature on transformation and degradation of POPs is expected to be less important than the effect of temperature on promoting primary and secondary emissions of POPs (see Chapter 2 and Lamon et al., 2009), the effect of temperature on transformation and degradation as the climate changes is very uncertain.

8. **Partitioning.** Climate change can affect partitioning of POPs between available phases in environmental compartments in different ways. A key factor is the increase in the vapor pressure of POPs with increasing temperature. This affects partitioning both between bulk phases (air vs. surface media such as soil, water and vegetation) and between the gaseous and particle-bound phases in air. As a result, stronger emissions from primary and secondary sources and a shift towards higher gaseous fractions in air may be observed. All of these factors make POPs more available for long-range transport. The amount of particulate matter in environmental compartments may also be increased by climate change and affect the mobility of particle-associated POPs. In the atmosphere, temperature increase may enhance the formation of secondary atmospheric particulate matter by accelerating chemical reactions (Forster et al., 2007). Moreover, a higher temperature of surface water may increase primary production leading to increased particulate organic matter (Macdonald et al., 2005; Carrie et al., 2010). The melting of sea-ice cover is likely to further enhance primary productivity as a result of the improved light regime. Such changes would enable a larger fraction of the POPs to be associated with particulate matter in air and water. Intuitively, the atmospheric transport of POPs to remote regions may be reduced due to temporary or permanent deposition to surfaces. However, more association of POPs with particulate matter may also result in decreased photodegradation during transit to remote regions and thus increase the long-range transport potential of POPs (Scheringer, 1997; Macdonald et al., 2005). Additionally, modified wind fields and higher wind speeds are expected to promote atmospheric transport of airborne particles and associated POPs and might, therefore, counteract increased deposition of POPs. Increased particulate organic matter in surface waters would lead to a reduction of freely dissolved water concentrations and increased transfers to benthic sediments with implications for long-range water transport.

9. **Biotic transport.** Altered migration patterns of contaminated species (e.g., fish and seabirds) may cause future transport of POPs to previously uncontaminated regions (Macdonald et al., 2005; Blais et al., 2007). Some recent studies have suggested that, next to atmospheric and oceanic transport, biotic transport of bioaccumulative contaminants (e.g., from guano of Arctic and Antarctic seabirds and death of migrating sockeye salmon) may be of relevance (Bard, 1999; Krümmel et al., 2003; Blais et al., 2005, 2007; Geisz et al., 2008).

In addition to the factors discussed above, there are additional elements of climate change that are likely to affect the environmental fate of POPs. One is increasing soil erosion, which increases mobilization of POPs present in soils and their transfer to rivers, lakes and oceans (ACIA, 2005).

Another element is changes in the salinity of the seawater. Salinity is predicted to increase in several regions of the world's oceans and to decrease in others (IPCC, 2007). Changes in salinity change the solubility of POPs in water and, thereby, also air-water partitioning (POPs are less soluble in water if salinity is higher). Influences of salinity changes on the toxic effects of POPs are addressed in section 5.2.3.

There are several important gaps in current understanding of the impacts of climate change on the environmental fate and transport of POPs. First, for all POPs there is a transition from a regime that is dominated by primary sources to a regime where secondary sources dominate the environmental distribution, levels and trends (Nizzetto et al., 2010). Primary sources are still dominant for PCBs, whereas secondary sources have already been observed for HCB and HCHs (see item 1 above). It is currently not known how climate change will affect the rate of this transition from primary to secondary sources for different POPs and in which way the capacity of important environmental reservoirs (ocean water and soils in temperate and polar regions) that accommodate POPs will change. A second field with major uncertainties is the reaction of microorganisms in soils to changing temperature and soil humidity and how this will affect the capacity of soils for biodegradation of POPs. Finally, as with all aspects of climate change, it is generally more difficult to predict changes in the fate of POPs on regional scales that might be caused by changes in land-use, soil composition, and extent of precipitation and irrigation. Most importantly, changes in transport and fate of POPs as a result of climate change will have direct consequences for exposure of wildlife and humans to POPs (see Chapter 4).

3.3. Conclusions

The environmental fate of POPs at the global, regional and local scale will be affected by numerous factors related to climate change. The main effects of climate change on the fate of POPs indicated by the current scientific knowledge include:

1. Increased mobilization of POPs from environmental reservoirs (e.g., soils, glaciers, the Arctic Ocean) by increased temperature, extreme weather events such as flooding, and increased erosion.
2. Increased airborne transport to locations downwind of main emission areas because of higher wind speeds (mainly relevant on the regional scale).
3. Enhanced degradation of POPs (under the assumption that higher temperature leads to higher degradation capacity of microorganisms), but also increased formation of potentially POP-like transformation products.
4. Changes in deposition patterns due to changing precipitation patterns (spatially and temporally), mainly relevant on the local to regional scale.

The most important research needs associated with climate change and the fate of POPs include:

1. Better characterization of primary and secondary sources of POPs (this is highly relevant for the prediction of future levels and trends and for the interpretation of monitoring data).
2. Better understanding of the molecular fate of POPs and especially the reaction of microorganisms in soil and water to POPs and climate change and, in particular, higher temperature (i.e., will metabolic activity and thereby the capacity to degrade POPs increase with rising temperature or will thermal stress reduce the capacity of microorganisms to degrade chemicals).
3. Identification of transformation products of POPs that may be formed in relevant amounts under the conditions of climate change and their impacts or potential impacts on the health of ecosystems and human populations.

The key policy recommendation is that political and financial support be provided for long-term POP monitoring programs in all regions of the world.

Chapter 4. Impact of climate change on exposure to POPs for wildlife and humans

Ian T. Cousins, Deguo Kong and Robin Vestergren

4.1. Introduction

Drawing on previously published studies, including model forecasts, this chapter aims to determine if, and the extent to which, exposure to wildlife and humans will alter as a result of climate change. The geographical scope of this chapter is global, although climate change effects may be more pronounced on regional scales. The Arctic is an area particularly sensitive to climate change and many examples in the chapter are taken from this region. The issues covered in this chapter are important because they affect the trends in human exposure levels, and one of the two core media of the GMP under the Stockholm Convention is human tissues. The purpose of the GMP is to monitor spatial and temporal changes in POPs levels in core media to determine the effectiveness of regional and global control measures for POPs. It is important to be able to attribute the relative weight of different processes in explaining changes in concentration in core media as a result of (i) climate change; (ii) control measures recommended by the Stockholm Convention; or (iii) other factors such as accidents, war or technological breakthroughs, so that correct conclusions are drawn when conducting an effectiveness evaluation of the Convention and evaluating the need for new management strategies to control POPs.

Chapter 3 contains information on how climate change is expected to alter concentrations in environmental exposure media (e.g., air, water, soils, sediments and vegetation). That discussion will not be repeated here, but it is worth emphasizing that changes in POPs transport and fate as a result of climate change will have direct consequences for exposure of wildlife and humans to POPs. Because human and wildlife exposure to most POPs is through environmental media, a predicted change in external POP concentrations will cause an associated change in internal concentrations in wildlife species and human populations.

Polar Bears at Garbage Dump, Churchill, Canada

This chapter builds on Chapter 3 by addressing the potential climate change effects on exposure to POPs that are not associated with changes in external environmental exposure concentrations. It is divided into three parts: the possible effects of climate change on wildlife exposure; the possible effects of climate change on human exposure; and a section highlighting data gaps and recommendations for future research. Table 4.1 summarizes the climate-induced impacts on wildlife and human exposure and, where possible, provides an indication of whether exposure of wildlife and humans are likely to increase or decrease as a result of the specified climate-induced impact. It is important to remember, however, that concentrations of most regulated POPs are expected to fall as a result of emission reduction measures. However, this may not continue to be the case in the future for all POPs if climate change leads to greater primary and secondary releases (see Chapter 3). Consequently, when it is concluded that exposure will increase or decrease as a result of climate change, the change is only relative to exposure that would have occurred without the climate change effect. Health effects resulting from POP exposure are not included here as these are addressed in Chapter 5.

Table 4.1 Climate-induced impacts on the POPs exposure of wildlife and humans.

Climate change-induced impact		Impacts on POP exposure		Source
		In wildlife	In humans	
Altered external environmental exposure		+/-	+/-	See Chapter 4
Change in food web structure	Bottom-up (aquatic)	+/-	+/-	Macdonald et al., 2003, 2005
	Bottom-up (terrestrial)	+/-	+/-	Macdonald et al., 2005
	Top-down (aquatic and terrestrial)	+/-	+/-	Macdonald et al., 2003, 2005
	Earlier arrival of migrant species	+/-	+/-	Walther et al., 2002
	Arrival of invasive species	+/-	+/-	Occhipinti-Ambrogi, 2007; Moore, 2008; Moore and Huntington, 2008
Increased internal uptake		+	+	Lydy et al., 1999; Buchwalter et al., 2003
Increased metabolism		-	-	Maruya et al., 2005; Buckman et al., 2007; Paterson et al., 2007
Increased remobilization due to starvation		+		Cherry et al., 2009
Changing growth rates in organisms		+/-		Peltonen et al., 2007
Increased time spent indoors or in urban areas			+	Jaward et al., 2004; Bohlin et al., 2008; Schecter et al., 2009
Increased usage of DDT for malaria control			+	Ritter et al., 2011
Waste site leakage due to permafrost thawing and rising sea levels			+	Gilman et al., 2009a
Human diet changes caused by food being supplied from different geographical locations			+/-	

+ Indicates increase; - indicates decrease; an empty cell indicates no information.

4.2. Exposure of wildlife

Bioaccumulation is the phenomenon by which chemicals reach higher concentrations in biota relative to the media in which they dwell. For example, POPs such as PCBs can reach concentrations in a high trophic level fish that are many hundred thousand times the concentrations that are present in the water in which that fish swims and may be a thousand times higher than the levels found in a mid-trophic level fish that it consumes. The bioaccumulation processes for POPs in aquatic and terrestrial wildlife species are complex (Gobas and Morrison, 2000; Mackay and Fraser, 2000) and the complexity of the processes offers the opportunity for climate change to act in subtle ways (Macdonald et al., 2005). Biomagnification is made up of two processes termed bioconcentration and bioaccumulation. Bioconcentration is partitioning of a substance from the external exposure medium into the tissues of the organism. For hydrophobic/lipophilic compounds it is the partitioning from environmental media into lipids that primarily causes the high concentrations observed in wildlife. Bioaccumulation, especially dietary accumulation is the cause of additional accumulation in organisms of the next trophic level resulting in an increase in chemical concentration up the food chain and across the upper food web (i.e., biomagnification). Modeling tools are available and have been used to predict bioaccumulation for specific POPs in wildlife (Clark et al., 1990; Thomann et al., 1992; Gobas et al., 1993; Campfens and Mackay, 1997). In principle, these models can also be used to predict how bioaccumulation will alter as a result of climate change. It is necessary to understand how trophic structure and POP processes within organisms are likely to change as a result of climate change processes in order to understand how biomagnification of POPs in food webs may change.

4.2.1. Changes to food web or trophic structure

Changes in food web structure may have important consequences for the biomagnifications of POPs in food webs. These changes may occur via numerous processes. At the simplest level, trophic structure changes can occur in two fundamentally different ways, either from the 'bottom-up', or from the 'top-down'.

In aquatic systems, bottom-up controlled changes are, for example, changes in primary or secondary productivity, which occur as a result of changes in stratification, nutrient supply, light intensity or ice cover, that lead to large-scale consequences for higher trophic level organisms. It is known, for example, that marine phytoplankton (primary producers) affect the abundance and diversity of marine organisms, drive marine ecosystem functioning and set the upper limits for fishery yields (Ryther and Yentsch, 1957; Behrenfeld et al., 2006; Henson et al., 2010). Climate change is likely to impact on phytoplankton abundance, but whether it will decrease or increase abundance in specific regions is challenging to predict. Long-term monitoring studies of phytoplankton abundance using satellite remote sensing have reported both increases and decreases in phytoplankton abundance (Gregg and Conkright, 2002; Antoine et al., 2005; Gregg et al., 2005; Behrenfeld et al., 2006). These observed changes in phytoplankton abundance vary spatially between ocean regions and also display large inter-annual and decadal-scale temporal variability. Changes in primary and secondary production will have a major effect on the production of organisms at higher trophic levels, but the complexity of the trophic systems leading from primary production to higher trophic level organisms (e.g., fish) makes it difficult to establish predictive relationships (Richardson and Schoeman, 2004). Nevertheless, as suggested by Macdonald et al. (2003), it is conceivable that bottom-up changes in trophic structure could result in organisms being pushed higher or lower in their effective trophic levels and result in exposures to POPs being altered by a factor of 5 to 10 in either direction. Studies which attempt to determine how changes in primary production could affect POPs exposure to wildlife in aquatic food webs have been reported by Borgå et al. (2010) and Carrie et al. (2010). Borgå et al. (2010) used a POP food web model to conclude that increased temperature coupled with increased particulate organic matter (POM) in water would cause a reduction of the bioaccumulation potential of POPs in the Arctic marine pelagic food chain. The decreased bioaccumulation (or exposure) potential of POPs in their study is primarily controlled by the reduction in the bioavailable fraction of POPs. The assumption of higher POM causes a decrease in the freely dissolved fraction of POPs (which is the fraction assumed to be bioavailable) as these compounds strongly associate with POM.

Although the study reported by Borgå et al. (2010) illustrates how a food web model can be used to estimate the consequences of climate change on POP exposure, it is considered that the effects of climate change on phytoplankton abundance and on food web structure are currently too poorly understood to do this with any degree of confidence in the model predictions. For example, contrary to the assumptions of Borgå et al. (2010), a recent study (Boyce et al., 2010) measured a decrease in primary productivity in the Arctic Ocean over the past century. The observed decrease in primary productivity was associated with limited nutrient supply caused by the increased stratification of the surface ocean. The way that primary productivity will react to climate change is expected to be highly regionally specific. Some regions of the Arctic may have increased primary productivity as a result of climate change (due to decreased ice cover and increased warmth and sunlight) whereas others may show decreases due to limited nutrient supply. How food webs will react to these changes is uncertain; some food webs may experience decreased exposure to POPs as suggested by Borgå et al. (2010), while others may experience increased exposure to POPs as suggested by Carrie et al. (2010). In the study reported by Carrie et al. (2010) it is suggested that the increasing levels of contaminants observed in an Arctic benthic fish (burbot, *Lota lota*) were linked to increased primary production and related sedimentation resulting from climate change. The authors postulated that rising temperatures and reduced ice cover will lead to increased exposure of high trophic level Arctic freshwater biota to contaminants. Their reasoning is that greater amounts of algal organic matter are found in lakes and thus can contribute to organic matter-bound POPs which may deposit to sediments and increase the exposure of local aquatic biota such as burbot. Carrie et al. (2010) and Borgå et al. (2010) both started with the same premise that primary production will increase as a result of rising temperatures; however, they come to opposite conclusions regarding the effect increased primary production will have on POPs exposure of different organisms. The two studies together would suggest that increased primary productivity will decrease POPs exposure to pelagic organisms, but increase exposure to benthic feeding organisms. The present authors judge these findings to be uncertain, due to the paucity of studies, and recommend further investigation.

In terrestrial systems, bottom-up controlled changes in trophic structure could result from climate change effects on vegetation abundance (biomass and diversity). In the Arctic, for example, organisms at the top of the food web that can adapt to habitat changes (e.g., Arctic foxes, grizzly bears and some birds), may switch between terrestrial and aquatic food webs, which could largely alter their exposure to POPs (Macdonald et al., 2005). A shift from aquatic to terrestrial food webs would be likely to cause a decrease in POPs exposure for these organisms, although the magnitude of the decline would be POP specific (Brook and Richardson, 2002; Kelly et al., 2004). For water-soluble POPs such as perfluorooctane sulfonate (PFOS), higher temperatures may increase plant uptake by transpiration, although these changes may be offset by the effects of increased carbon dioxide that could reduce the activity of plant stomata and reduce plant transpiration. Bioavailability of POPs in soils (i.e., a higher proportion may be in the dissolved phase in soil-water) may increase with the predicted decline in soil organic carbon content (Bellamy et al., 2005).

Top-down controlled change occurs when the populations near the top of the food web are in some way altered. A well-known example of top-down controlled change in the Arctic food web is the widespread loss of ice cover, an important habitat for many Arctic species including bears, seals, walrus and Arctic cod (Macdonald et al., 2005). Top-down control in food webs limits the number of species at lower trophic levels through predation. Loss of predator species will have important consequences for species abundance at lower trophic levels and thus for POP biomagnification. The current shift towards an earlier spring break-up of sea ice in western Hudson Bay has resulted in polar bears shifting to a more pelagic diet. This not only changes the bioaccumulation of POPs in polar bears (McKinney et al., 2009), but may also have important long-term top-down controlled effects on food web structure. These changes in top-down control may feed back to cause further changes in POP bioaccumulation. Another special case of top-down change can occur as a result of human activity. An increase in habitat loss due to increased human occupancy, and decline in species diversity due to increased hunting and fishing, may result in alteration of the food web structure and subsequently change the exposure to POPs (Bard, 1999; Macdonald et al., 2003, 2005).

A behavioral (phenological) change with consequences for food web structure and POPs exposure is the timing of spring activities such as the earlier arrival of migrant birds and earlier breeding of carnivorous animals. For example, birds arriving earlier may be pushed higher or lower than their original trophic level. Altered migration pathways of migratory species (whales, fish, birds) as well as acting as vectors for POPs (see Chapter 3) can also affect food web structure. Invasions of new species or extensions of habitat ranges of existing species fostered by climate change also have the potential to alter food web structure. Climate change may also facilitate so-called 'regime shifts', defined as rapid reorganizations of ecosystems from one relatively stable state to another and are often related to changes in the climate system. For example, it is thought that a regime shift occurred in the North Sea and Baltic Sea in the late 1980s with fairly abrupt changes in sea surface temperature and wind field (Schrum, 2001), which has been linked to changes in the aquatic ecosystem with negative consequences for cod recruitment in both seas (Brander, 2010).

Temporal trends in contaminant levels in biota may be altered by dietary changes and this could lead to incorrect conclusions being drawn when evaluating POP management strategies (e.g., emission reduction). For example, if a species is forced to start feeding at a higher trophic level then temporal trends may not continue downward as expected, even if emissions have been reduced. Conversely, incorrect conclusions may be reached about effectiveness of management strategies if a species starts feeding at a lower trophic level and a sharp downward time trend in contaminant levels is observed. Experimental evidence for how dietary changes influence temporal trends in PCBs has been reported by Hebert et al. (1997).

In a study by McKinney et al. (2010), it has been proposed that temporal changes in contaminant patterns in the tissues of top predators can be used to determine dietary changes that may result from climate change. Adipose tissue was sampled from the western Hudson Bay subpopulation of polar bears at intervals from 1991 to 2007 to examine temporal changes in contaminant patterns of PCB and organochlorine pesticides. The authors examined the influence of year (i.e., aging or 'weathering' of the contaminant pattern), dietary tracers (carbon stable isotope ratios, fatty acid patterns), and biological (age/sex) group on congener/metabolite profiles. It was observed that patterns of PCBs, chlordanes, and PBDEs were correlated with dietary tracers and biological group, but only PCB and chlordane patterns were correlated with year. It is concluded that contaminant pattern trends may be useful in distinguishing the possible role of ecological/dietary changes on contaminant burdens from expected dynamics due to atmospheric sources and weathering.

4.2.2. Changes to POP processes within organisms

It is recognized that a warmer climate will affect the toxicokinetics of POPs within poikilothermic (cold-blooded) organisms such as invertebrates, fishes, amphibians and reptiles by directly enhancing the internal uptake in gills and the intestines (Lydy et al., 1999; Buchwalter et al., 2003) and metabolism (Maruya et al., 2005; Buckman et al., 2007; Paterson et al., 2007). Increased metabolism due to higher temperatures is only expected to be of minor importance in modulating exposure and effects for most POPs, which are by definition not susceptible to degradation processes. Where it does occur, enhanced metabolism could lead to an increased exposure to toxic metabolites due to biotransformation of POPs (Maruya et al., 2005; Buckman et al., 2007; Paterson et al., 2007).

Some top predators may undergo periods of enforced fasting related to climate change (Cherry et al., 2009). A well known example is the polar bears in Hudson Bay which are unable to hunt seals during the spring due to the changes in the spring ice-climate which affects food availability. Longer periods of starvation due to changes in ice cover would lead to higher internal exposure of POPs released from fat reserves.

Changes in growth rates in organisms can affect the bioaccumulation of POPs and can lead to incorrect conclusions being drawn when evaluating POP management strategies. For example, extremely large changes have occurred in the growth of Baltic herring (*Clupea harengus membras*) over the past few decades due to changes in plankton abundance (Peltonen et al., 2007). Although there is no evidence that climate change has caused these changes in herring growth rates, it is not inconceivable that climate change could cause similar effects. Some populations of Baltic herring have much lower growth rates than previously observed, which may be one of the reasons why levels of POPs in Baltic herring have not declined in recent years (Peltonen et al., 2007) despite reductions in POPs loadings to the Baltic Sea.

Mother and baby protected by mosquito net, Kenya

4.3. Exposure of human populations

Humans are exposed to chemical pollutants through ingestion of food, drinking water and dust, and to a lesser extent, through inhalation of ambient and indoor air and particulates. Most POPs are hydrophobic and lipophilic and have low vapor pressure, thus diet dominates background human exposure. This dietary exposure will be affected by any climate-related changes in the structure of relevant food webs. The controlling influence of food web structure on human exposure is supported by a recent study which concluded that food web structure is far more important than other environmental characteristics (e.g., temperature, precipitation) for determining the potential human exposure of chemicals (Undeman et al., 2010). Ritter et al. (2009) have developed a model for estimating multi-individual human time trends for levels of pollutants after they have been banned.

In addition to the dietary background exposure, some human populations are exposed to higher levels of POPs due to proximity to point sources (manufacturing or waste sites) or due to occupational exposure. For a few POPs present in commercial products, such as brominated flame retardants and perfluorinated compounds (Bohlin et al., 2008; Schecter et al., 2009) exposure via indoor air and dust has been identified as being important for low background exposures in human populations, and of more importance for children living close to floor surfaces (Wilford et al., 2005; Lorber, 2008; Johnson-Restrepo and Kannan, 2009). In developing countries, where houses are sometimes sprayed for control of disease-carrying insects, indoor human exposure to DDT via inhalation is important (Singh et al., 1992; Ritter et al., 2011), although non-POP alternatives to DDT may be used in the future.

As a result of climate change, human populations in industrial regions could receive a higher proportion of their future exposure through inhalation of outdoor air given that the percentage of POPs partitioning to air in source regions where human populations reside are predicted to increase with increasing temperature (see Chapter 3). However, concentrations of most regulated POPs are falling as a result of emission reduction measures and this will probably continue to be the case into the foreseeable future. Nevertheless, it is not clear whether overall human exposure to these regulated POPs will decrease, because a greater fraction of POPs will be distributed to the atmosphere as climate changes. The relative proportions of indoor and outdoor exposure may also be influenced by climate change. In warm regions, humans may spend more time indoors as a result of warming (i.e., move to cooler air-conditioned environments), whereas in cooler regions humans may be inclined to spend more time outdoors. This could be important for overall human exposure to some POPs (e.g., PCBs, PBDEs, PFOS) where indoor air concentrations are one to two orders of magnitude higher than outdoor values (Bohlin et al., 2008).

The population shift from rural to urban environments in many countries may also change the exposure pathways of the general population, with a greater proportion of exposure coming from exposure to polluted urban air. This might be considered a secondary effect of climate change (climate-forced migration), although it should be noted that this is also social change related to the economy and may be only partially associated with climate. Urban air concentrations of some POPs are many times higher than rural concentrations (Jaward et al., 2004). In developing countries it is possible that higher temperatures will increase abundance and geographic distribution of malaria mosquitoes and thus the resulting increased use of DDT may lead to higher human exposure via inhalation (Singh et al., 1992).

As climate changes and permafrost thaws in the Arctic, current chemically polluted waste sites may begin to leak their contents into water systems and land with consequences for human exposure. Local food species could also become contaminated by substances from waste sites, leading to potential increases in human exposures depending on the types, amounts and seasonality of food use. Small islands, whether located in the tropics or at higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea-level rise, and extreme events. Sea-level rises resulting from climate change are expected to exacerbate inundation of contaminated lands and waste management sites, potentially increasing human exposure to POPs.

Social factors can also affect POPs exposure (Gilman et al., 2009a). Although the traditional/local foods of some Arctic populations are an excellent source of nutrients and energy and contribute to good social, spiritual and physical health, they are also the primary source of POPs exposure. Concern about contaminants, changing cultural values, and the lack of availability of traditionally-hunted species due to climate change, all play a role in influencing the types of traditional/local foods consumed, the frequency of their consumption, and the exposure of Arctic populations to POPs (Vaktskjold et al., 2009; Lougheed, 2010). It is possible that as a result of climate change, human populations that currently rely on traditional diets of local/country foods will move toward consumption of a more typical 'western' diet, high in carbohydrates. Although it is equally possible that with increasing drought and reducing grain yields, other human populations may need to rely more on subsistence/local foods. It is expected that climate change will have an impact on food production (Rosenzweig and Parry, 1994). Some regions may become largely infertile while others may be able to grow new crops previously unsuited to the climate. These changes in food production patterns may have consequences for POPs bioaccumulation and human exposure.

4.4. Conclusions

As climate change alters primary and secondary releases of POPs, levels and patterns of exposure in wildlife and humans will change. Climate change is already altering food web structures in some areas. This will be an added influence on the exposure of wildlife and humans to POPs.

There are large uncertainties concerning how climate change has affected ecosystems and food web structures in the past, and how these will be affected in the future. Due to insufficient baseline exposure information for POPs in many parts of the developing world and uncertain climate and ecosystem response predictions on a regional basis, it is not possible to estimate accurately the direction and extent of how climate change may impact POPs exposure for wildlife and humans. POPs exposure in wildlife could either increase or decrease as a result of climate change and the changes in exposure (relative to a scenario in which there were no climate change induced effects) could be an order of magnitude in either direction. Examining the temporal contaminant patterns in top predators is a promising method for studying the possible role of changes in ecology and diet.

Given the complexity of climate change effects on trophic structure, it is extremely challenging to develop accurate predictive models of ecosystem change and currently there are no suitable models available.

4.5. Data gaps and recommendations for future research

Currently, there are only a few long-term datasets which can be used for analyzing the climate-induced impacts on exposure to POPs in human cohorts and wildlife tissues (Chan, 1998; AMAP, 2002; Ma et al., 2004b; Hung et al., 2010; Rigét et al., 2010). It is important to have a good baseline dataset so that possible future changes can be observed. It is thus essential to continue existing monitoring programs of POPs in human cohorts and wildlife. It is also important to extend the monitoring to include newer POPs, as well as substances with POP-like characteristics, and to cover different regions of the world, especially the Arctic and Antarctic (which are particularly sensitive to climate change), the developing world (where certain POPs are still widely used), and those regions where little long-term monitoring currently exists.

Focus needs to be placed on stable long-term monitoring of the POPs listed under the Stockholm Convention and on concentrations in human milk and blood plasma, which are among the preferred media under the GMP. As well as monitoring POPs levels, it is also important to monitor social changes such as human dietary changes, in order to help determine the possible causes of changes in human exposure, and to monitor new sources of POPs, whether regulated or not, related to industrial activity or expanded uses of some POPs for disease vector control.

Research on how climate change is likely to affect the trophic structure of ecosystems is needed to support the development of predictive ecosystem-scale models. Although present predictions of food web changes are highly uncertain, sensitivity analysis of existing bioaccumulation models may present opportunities to pin-point key parameters for determining exposure to POPs. Ultimately, long-term ecological monitoring of plankton and other wildlife populations is needed to underpin the understanding of trophic relationships.

Bioaccumulation in food webs is not well understood for all POPs. It is important to improve predictive models of bioaccumulation to better understand the likely impacts of climate change with respect to levels in wildlife and humans. Models should be evaluated against measured data because it is important to have well-evaluated models of POPs exposure under current climate conditions before it is possible to model exposure under conditions of a changing climate. The more well-studied POPs (e.g., PCBs) are currently the best candidates for consideration in climate-change POP modeling exercises; however, POP models should be refined to model those POPs not previously studied (e.g., PFOS, which is not lipophilic and which behaves differently to the traditional legacy POPs).

Chapter 5. Impact of climate change on toxicological and ecotoxicological effects of POPs exposure

Andrew Gilman and Bjørn Munro Jenssen

5.1. Introduction

Persistent organic pollutant levels in global ecosystems are likely to change significantly over the next three decades due to changes in use and release patterns, a changing climate and climate variability (see Chapters 2 and 3). The changes in POPs levels will not be uniform and some regions may experience net reductions and some net increases. The relative changes will affect exposure of biota including human beings (see Chapter 4) even though the direction of change is uncertain and may impact health and wellbeing of all living populations (e.g., reproductive potential, neurological development, behavior, cancer and other diseases and adaptability).

Many of the legacy POPs have similar effects on biological systems. These legacy POPs include aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, HCB, mirex, PCBs, PCDDs, PCDFs and toxaphene; all 12 listed in the original Annex A, B and C of the Stockholm Convention (see footnotes 1 to 3 in Chapter 1). Most POPs possess endocrine disrupting properties (see section 5.2.9) and several are considered to be pro-carcinogens or co-carcinogens for mammals (see section 5.3.2); however, these POPs usually have different potencies and not all species respond in the same way to the same exposure of any given POP. In addition, several individual POPs, such as cyclodiene pesticides, PCBs, chlorinated dibenzo-*p*-dioxins, chlorinated dibenzofurans and chlorobornanes (which includes the technical product marketed as toxaphene) have hundreds of congeners in their individual families which can be metabolized at different rates and possess different toxic properties and potencies (see references in section 5.3). To add further to the complexity of an assessment of the effects of POPs on biota, including humans, is the reality that no environmental exposure to POPs is ever to a single chemical; environmental exposures are always to mixtures of POPs because they co-occur in the food chain (Gilman, 2003).

Exposure to pesticides can cause birds to lay eggs with thinned shells, reducing the chance of successful hatching

For most POPs, knowledge about their individual or combined toxicity is derived from controlled laboratory studies with fish, copepods, rats and mice. Occasionally test data are available for controlled studies with wildlife species in captivity. Even less commonly available are adverse health effects data for exposed wildlife or human populations (epidemiological studies).

The complexity of evaluating the effects of POPs on populations of animals or humans is huge because of the complexity of the individual POPs and their combined presence in the environment and also because of multiple confounders of effects. Confounders for animal populations are discussed in section 5.2; confounders for human populations which include lifestyle and cultural practices, socio-economic status, general health, diet and nutrition, education, genetic endowment, and others were discussed by Gilman et al. (2009a). Climate change and climate variability (e.g., additional heat stress, colder climates, more or less rainfall, food availability and quality, availability of services and shelter, movements of disease-bearing insect vectors) also act as factors which can influence the general health or exposure of animal and human populations.

This chapter examines very briefly the key adverse outcomes associated with POPs exposure and the influences that climate change may have on wildlife and human population health as a result of changes in exposures to POPs. The information on changes in exposure comes primarily from Chapter 4.

5.2. Environmental health impacts

5.2.1. Effects of POPs and climate change in the environment

Although it has long been recognized that temperature affects the toxicity and toxicokinetics of POPs in poikilothermic (cold-blooded) animals, such as invertebrates, fishes, amphibians and reptiles (Guthrie, 1950; Anderson and Peterson, 1969; Miller and Ogilvie, 1975; Powell and Fielder, 1982), it is not until recently that the consequences of climate change on the environmental toxicity of chemical pollutants has received attention (Jenssen, 2006; Schiedek et al., 2007; Noyes et al., 2009). Climate change may result in alterations of the environmental fate of chemicals as well as in a range of abiotic factors, such as salinity, pH and ultraviolet-radiation which have been shown to affect both uptake and toxicity of chemicals in poikilotherms (Huovinen et al., 2001; Wrona et al., 2006; Noyes et al., 2009; Kim et al., 2010). It is also acknowledged that climate change may have an impact on the effects of POPs in homeothermic (warm-blooded) animals (Jenssen, 2006; Noyes et al., 2009). Toxic POPs and other chemical pollutants may interfere with physiological and behavioral processes that are important for animals to acclimate and adapt to climate change (Zala and Penn, 2004; Jenssen, 2006; Noyes et al., 2009) and vice versa, climate change may modulate physiological processes in animals with consequences for chemical uptake, metabolism and toxicity in the organisms (Heugens et al., 2002; Noyes et al., 2009).

There is evidence that climate change, including increased climatic variability, can affect the biodiversity and thus ecosystem composition and functioning (Walther et al., 2002; Lovejoy and Hannah, 2005; Pörtner and Knust, 2007; Parker et al., 2008). Thus, climate change will cause alterations in trophic structures, food sources and migratory patterns, which will influence bioaccumulation and biomagnification of some POPs (Schiedek et al., 2007; Noyes et al., 2009) (see Chapter 4). Because of bioaccumulation, this is probably most important for top predators, in which different contaminant levels may either increase or decrease due to alterations in trophic structures. Climate change may also expose organisms to pathogens and disease vectors that they have not been previously encountered (Harvell et al., 2002), and POPs that cause immunosupression may make animals more sensitive to infectious disease agents (Acevedo-Whitehouse and Duffus, 2009). Furthermore, there is concern about effects arising from multiple stressors, including exposure to POPs and climate change, in environments where species are living at the edge of their physiological tolerance, such as in the Baltic Sea, or in polar and alpine regions (Schindler and Smol, 2006; Schiedek et al., 2007; Bustnes et al., 2008; Noyes et al., 2009).

Since molecular, cellular, physiological and behavioral processes in poikilotherms are highly influenced by temperature, climate change can modulate the effects of POPs on these processes. Furthermore, POPs can interact with physiological, behavioral and ecological adaptations to climate change, and thereby influence the ability of organisms, populations, communities and ecosystems to withstand and/or adapt adequately to climate change (Jenssen, 2006; Wingfield, 2008). Thus, climate change can enhance the sensitivity of organisms and ecosystems to POPs. In addition, POPs can modulate the vulnerability of organisms and ecosystems to climate change-induced variations of environmental factors. The major effects are summarized in Table 5.1.

Table 5.1 Climate change-induced ecotoxicological effects of POPs (modified from Noyes et al., 2009).

Climate change-induced effect	Relationships/interactions (for sources, see Noyes et al. (2009) and chapter text)
Increased temperature	↑ temperature = ↑ toxicity ↑ temperature = ↑ metabolic biotransformation and potentially altered metabolite profiles -Toxicant exposure may limit the capacity of species and populations to acclimate to altered temperatures -Pollutant-exposed animals at the edge of their physiological tolerance range may be especially sensitive to temperature increases
Altered environmental salinity	↑ salinity + POP exposure = ↓ osmoregulatory abilities
Decreased pH	↓ pH + POP exposure = ↑ toxicity and endocrine disruptive effects (?)
Increased UV-radiation	↑ UV-radiation + POPs = ↑ toxic effects on molecular, cellular end physiological processes in plants and animals (?)
Increased eutrophication	↑ eutrophication = ↑ toxic algal blooms -Algal toxins may interact with POPs
Hypoxia	↓ oxygen tension in water = ↑ increase in toxicity of POPs (?)
Altered ecosystems (and nutritional status)	- Altered POP sequestration and/or remobilization through shifts in food sources and starvation events - Shifts in disease vector range and severity coupled with toxicant exposure inhibiting immune responses may leave organisms more susceptible to disease - Low level exposures may impair organism acclimation to ecosystem alterations induced by climate change - Climate change induced changes in trophic food webs may alter POP bioaccumulation and biomagnification

↑ Indicates an increase; ↓ indicates a decrease; (?) indicates that the effects are not certain.

5.2.2. Effects of temperature on toxicity and toxicokinetics

Since poikilothermic animals are highly affected by ambient temperature, the toxicity of POPs can either be decreased or increased with increasing temperature (Noyes et al., 2009). In most cases, thermal stress potentiates chemical toxicity, and this appears to relate to temperature modulation of chemical uptake and to temperature-induced shifts in physiological and metabolic processes of the exposed organisms (Heugens et al., 2002; Noyes et al., 2009). For instance, the lethality of dieldrin to the freshwater darter (*Etheostoma nigrum*) and the toxicity of atrazine to catfish (*Ictalurus punctatus*) increased with increasing temperatures (Silbergeld, 1973; Gaunt and Barker, 2000). On the other hand, pyrethroids and DDT are generally more toxic at low temperature conditions (Narahashi, 2000). Exposure to sublethal concentrations of endosulfan caused significant reduction in the upper critical temperature tolerance of freshwater fish in Australia (Patra et al., 2007), a significant concern in view of climate change. Similarly, freshwater fish were able to survive higher concentrations of endosulfan at lower water temperatures (Capkin et al., 2006). A similar response was found with the eggs and larvae of the bollworm (*Earias vitella*); higher temperatures and higher humidity increased the toxicity of endosulfan (Satpute et al., 2007).

Temperature-dependent changes in metabolism can modulate the biotransformation of POPs by animals (Noyes et al., 2009). For example, in rainbow trout (*Oncorhynchus mykiss*), biotransformation of PCBs to the more toxic hydroxylated PCB metabolites is positively related to water temperature (Buckman et al., 2007). Since changes in ambient temperature will not alter the body temperature of homeothermic animals, changes in the environmental temperature will probably not directly influence toxicity and toxicokinetics in homeotherms. However, POPs may interfere with physiological adaptations to heat or cold stress in these animals.

The sensitivity of animals, particularly poikilotherms, seems to be dependent on the environments, or biomes, to which they have adapted. For six chemicals (among those the insecticide chlordane), tropical organisms tended to be more sensitive than their temperate counterparts (Kwok et al., 2007). However, for several other substances, especially metals and DDT, the opposite trend was noted (Daam and van der Brink, 2010).

5.2.3. Effects of salinity on toxicity

Climate change will cause shifts in precipitation and evaporation patterns, terrestrial freshwater run-off and ice melt and will thus cause alteration in the salinity of the sea (IPCC, 2007). Salinity can influence the chemical itself and its toxicity, and the physiology of organisms (Schiedek et al., 2007; Noyes et al., 2009). The bioavailability of organic compounds may also be altered in saltwater as compared to in freshwater (Noyes et al., 2009) (see Chapter 3). The increased toxicity observed at elevated salinity has been attributed to higher physiological costs for organisms to maintain osmoregulation, leading to a decline in fitness and elevated sensitivity to contaminants (Noyes et al., 2009). POPs may also alter osmoregulatory function in aquatic organisms (Schiedek et al., 2007; Noyes et al., 2009). Effects of altered salinity are most likely to affect toxicity in gill-breathing animals (invertebrates and fish) that need to osmoregulate. A study on the effects of combined temperature and salinity on the toxicity of common pesticides to the grass shrimp (*Palaemonetes pugio*), demonstrated that the responses were complex and depended on both the organism's life stage and the type of chemical contaminant (DeLorenzo et al., 2009). Amphibians and marine reptiles and birds, which also osmoregulate to excrete excess salt, are also likely to be vulnerable to the combined effects of POPs and salinity changes related to climate change.

5.2.4. Effects of pH on toxicity

Owing to the expected increased levels of carbon dioxide (CO_2) in the marine environment, ocean acidification is an expected outcome of climate change (Hoegh-Guldberg and Bruno, 2010). Observed accumulation of CO_2 in the surface seawater due to the increase of atmospheric CO_2 since pre-industrial times has probably already caused a decrease of almost 0.1 pH units (Haugan and Drange, 1996). Reductions of pH (and the following reductions in CO_2) in seawater may have consequences for marine life, especially shell-forming organisms and corals that rely on calcified structures (Marubini and Atkinson, 1999; Feely et al., 2004) and also deep-sea animals (Seibel and Walsh, 2003). It is well known that pH interacts with the toxicity of metals in aquatic organisms (Florence et al., 1992). However, there appear to be few reports on how pH affects the toxicity of POPs, and on how ocean acidity interacts with toxicity of POPs. Since no clear relationships between ocean acidification and POPs toxicity have been described so far, this issue merits further consideration.

5.2.5. Effects of UV-radiation on toxicity

Climate change can alter exposure of animals to UV-radiation. Exposure to UV-radiation can cause biomolecular, cellular and physiological alterations in exposed plants and animals (Wrona et al., 2006), a decline in fitness and elevated sensitivity to contaminants. In addition, UV-radiation can alter the chemical structure of toxicants, rendering them more toxic or less toxic to animals (Noyes et al., 2009; Huovinen et al., 2001). Indeed, synergistic interactions of UV-radiation and contaminants have been suggested to be a factor in population declines of amphibians (Blaustein et al., 2003). There is evidence that some non-persistent organic compounds may pose a greater risk to aquatic organisms when exposed to ultraviolet light (Macdonald et al., 2005); however, no evidence seems to be reported for POPs.

5.2.6. Effects of eutrophication on toxicity

Studies suggest that bioaccumulation and trophic transfer of sediment-associated contaminants will increase following fresh organic matter input, for example, after sedimentation of phytoplankton blooms (Granberg and Selck, 2007). Little is known about the effects of eutrophication on toxicity of POPs; however, toxins from phytoplankton blooms may interact with toxicants such as POPs.

5.2.7. Effects of pO_2 in water on toxicity

Factors such as eutrophication may cause lowered oxygen tension in aquatic systems. Higher water temperature also reduces the oxygen content in water. Worldwide, anoxic and hypoxic areas in aquatic systems have expanded over recent decades (Diaz and Rosenberg, 1995, 2001; Wu, 1999), and this trend probably will increase with climate change (Schiedek et al., 2007). Areas such as in Chile, Peru, California and Namibia are often affected by minimum oxygen zones (MOZ), in particular during water upwelling. It is anticipated that global warming will increase these minimum oxygen zones due to increased rainfall and temperature (Harley et al., 2006). In many coastal areas and estuaries, hypoxia is a common feature during low tides and usually the species have adapted successfully to cope with low oxygen conditions, switching to anaerobic energy production (Zebe and Schiedek, 1996).

There is little background information on the effects of low oxygen levels on toxicity of POPs. Exposure of animals to water containing less oxygen may increase overall 'stress' for that species; however there is little hard evidence for this assumption. Matson et al. (2008) have reported that in fish, hypoxic conditions may influence the toxicity of compounds whereas Brian et al. (2009) found that a combined exposure to hypoxia and endocrine disrupting contaminants caused no effects. Altered environmental oxygen levels can indirectly affect POPs toxicity in that they change ventilation and metabolic rates of gill-breathing animals.

5.2.8. Effects of nutritional status on toxicity

Climate change will cause alterations in trophic structures and, thus, alter the food composition of wildlife. Hence, the nutritional status of animals may become altered. For instance, polar bears may encounter long fasting periods due to changes in ice coverage and food availability (Cherry et al., 2009). The current shift towards an earlier spring break-up of the sea ice in western Hudson Bay, has resulted in a shift towards a more pelagic diet in polar bears and a resultant change in bioaccumulation of POPs (McKinney et al., 2009). It has been established that the nutritional status of organisms may influence the outcome of the toxic effects of POPs (Majkova et al., 2008).

Relationships between climate change, POPs accumulation and adverse responses of biota can be complex. For instance, Bustnes et al. (2008) examined the relationship between environmental conditions, organochlorine body burdens and fitness parameters of three marine bird colonies. They observed that food availability had a direct influence on body condition, and that body condition was related to organochlorine body burdens and reproductive fitness of the animals.

5.2.9. Effects of POPs on adaptation to climate change

To a certain extent, animals can respond to climate change by physiological and behavioral adaptations (Wingfield, 2008). However, toxic and endocrine disrupting POPs can interfere with physiological and behavioral processes (Colborn, 1995; Zala and Penn, 2004; Wingfield, 2008) that are important for organisms for acclimation and adaptation to climate change (Jenssen, 2006; Noyes et al., 2009). For instance, toxic chemicals impair the ability of animals to respond to changes in environmental temperature (Heugens et al., 2002; Noyes et al., 2009). Thus, toxic or endocrine effects may directly affect fecundity and/or survival, which can have a direct consequence on population size.

Of most concern are POPs that interfere with the reproductive system and with the thyroid system (Colborn et al., 1993; Jenssen, 2006). Several POPs have been documented to have harmful effects on reproductive organs and hormones, and to adversely affect fertility and fecundity in animals ranging from invertebrates to mammals (Vos et al., 2000). For instance, PCBs have been reported to affect reproductive hormones in polar bears (Haave et al., 2003; Oskam et al., 2003) and these effects have been linked to poor recruitment in polar bear populations exposed to high levels of POPs (Derocher et al., 2003). Thyroid hormones are important for temperature regulation, adaptation to fasting, for reproduction, growth and development, cognitive function, motor abilities and memory (Jenssen, 2006). There is plentiful evidence that POPs, or metabolites of POPs (e.g., hydroxylated PCBs), interfere with thyroid homeostasis and thyroid function in a wide range of species ranging from fish to birds and mammals (Letcher et al., 2010).

Persistent organic pollutants have also been shown to affect other endocrine systems, such as the corticoid system, which is related to stress responses (Letcher et al., 2010). Furthermore, endocrine disrupting POPs can interfere with behavior and thus disturb responses to climate change, such as migration, reproductive behavior and timing of reproduction (Zala and Penn, 2004; Wingfield, 2008).

Many POPs have been shown to be immunotoxic to fish and wildlife (Ross et al., 1996; Reynaud and Deschaux, 2006; Acevedo-Whitehouse and Duffus, 2009) and may affect the ability of animals to respond to a variety of pathogens and parasites. Examples from Canada provide a number of circumstances where chemicals and environmental variability are likely to have worked together to affect vulnerability of aquatic organisms (Couillard et al., 2008). Climate warming can increase disease risk both for terrestrial and marine biota (Harvell et al., 2002). Again, the impacts result from a combination of effects. POP exposure can also impair immunocompetence of animals (Noyes et al., 2009) and climate can alter transmission and infectivity of pathogens.

5.2.10. Predicted combined effects on ecosystems in different regions

There is concern that climate change will be particularly large in Arctic and Antarctic regions. POPs are transported to the polar regions from urbanized/industrialized areas via atmospheric and ocean transport. Although POPs levels generally are low in lower trophic levels in the polar regions, levels of some toxic and endocrine disrupting POPs are very high in some freshwater fishes and in top predators such as gulls, polar bears, and toothed whales (Letcher et al., 2010). Thus, the largest concern for interacting effects between climate change and POPs is for these higher trophic level species. However, it should also be noted that ecological effects can be manifested as a top-down stress that cascades down through the ecosystem, that is, effects on populations of higher trophic level species may affect populations of lower trophic level species (Schiedek et al., 2007).

Temperate areas are densely populated with large releases of POPs from households, industry, agriculture or old wastes/deposits. Ecosystems in these areas are also exposed to several other anthropogenic stressors, such as habitat loss and fragmentation, over-harvesting of fish and wildlife populations, and eutrophication. POPs can exert serious toxic or additional stress that can act in concert with climate change to push the species beyond their environmental tolerance limits, or reduce replenishment rates of harvested stocks or populations.

Tropical regions are characterized by high biodiversity. The numbers of individuals that constitute a species may, however, be low. In some tropical regions, the use of pesticides, such as DDT is also relatively high. Due to low genetic variability in such species, they may be susceptible to exposure to multiple anthropogenic stressors, such as climate change, habitat loss and fragmentation and pollution. It is likely that a combined exposure to these factors acts synergistically and increases extinction rates.

Freshwater environments are sinks for POPs. Climate change will cause temperature changes and may also affect hydrology, and water chemistry, including pH, conductivity and oxygen content, and eutrophication. Climate change can also influence precipitation and increase run-off of POPs and other substances, such as metals. Environmental changes linked to climate change may influence the toxicity of the substances, or the toxic and endocrine effects of POPs can interfere with the ability of species, populations and ecosystems to resist climate change.

Marine environments are considered to be the ultimate sink for POPs. This is the case, in particular, for areas close to urbanized areas. Marine ecosystems are also threatened by other anthropogenic factors such as over-fishing, petroleum-based activities, eutrophication and hypoxia, and recently also acidification due to increased marine carbon dioxide levels (pCO_2). POPs exposure is a serious additional toxic and endocrine disrupting stressor that can affect acclimation or adaptation to ocean temperature changes. Endocrine disrupting POPs can also reduce recruitment rates of heavily exploited stocks or populations. Due to biomagnification, top predators, such as marine mammals and seabirds, are most likely to be at greatest risk. A combination of increased disease risk caused by climate change (Harvell et al., 2002) and immunosuppressive effects of POPs (Acevedo-Whitehouse and Duffus, 2009) may have serious impacts at the population level.

5.3. Human health impacts

Estimating the effects of POPs on human beings is generally through animal studies which establish effect levels or no-effect levels measured in milligrams of contaminant exposure per kilogram of animal body weight per day of exposure (mg/kg-bw/d). Usually data are obtained for more than one species because it is clear that not all mammals respond the same way and to the same degree to a given toxicant. Body size, metabolic rate, and other factors affect how animal species respond. In order to understand the effects of a toxicant, most toxicology studies are designed to test one substance at a time. Most POPs have sufficient toxicity data to provide a range of 'effect' or 'no-effect' levels for a number of adverse health outcomes in laboratory species. A summary of the toxic effects of POPs is available through Hansen et al. (1998), Bonefeld-Jorgensen and Ayotte (2003), Dewailly and Weihe (2003) and Gilman et al. (2009b); detailed evaluations of individual POPs are available through the U.S. Agency for Toxic Substance and Disease Registries (ATSDR, 2010) and other international organizations (IPCS, 2010; EU, 2010).

'Effect' or 'no-effect' levels and uncertainty factors are used to set human exposure guidelines often referred to as 'tolerable daily intakes' (TDIs). TDIs are designed to include a margin of safety to protect human populations from the most dangerous adverse effects. For example, safety factors are applied to take account of species differences, severity of the effect observed, extrapolation from animal to human populations and usually consider the most sensitive members of the population (often considered to be the fetus, newborns, children and women of reproductive age). TDIs are often revised as new toxicology and epidemiology data become available. Some typical TDIs are provided in Table 5.2. These are only examples of the TDIs for some POPs and demonstrate the range in toxic potential for human populations exposed to 2,3,7,8-tetrachloro dibenzo-*p*-dioxin (2,3,7,8-TCDD) (highest toxicity shown) and DDT (lowest toxicity shown). There is a need to apply TDIs with caution as there may be the potential for synergistic, agonist or additive impacts as a result of the simultaneous exposure of human populations to a large number of POPs (i.e., legacy POPs, newly identified POPs, and chemicals with POP-like characteristics not yet listed under the Stockholm Convention), other less-persistent organic chemicals, gases, metals and particulates.

Table 5.2. Some Tolerable Daily Intake values set for human populations (adapted from Hansen et al., 1998).

Substance	TDI (μg/kg-bw)	Source
Dioxin (2,3,7,8-TCDD)	0.00001	World Health Organization
Mirex	0.07	Health Canada
Chlordane	0.05	Health Canada
Toxaphene	0.2	Health Canada
Total HCH	0.3	Health Canada
Total PCBs	1.0	Health Canada
γ-HCH (Lindane)	8.0	World Health Organization
DDT	20	World Health Organization

5.3.1. Effects of POPs on human populations

The Human Health Assessment Group of the Arctic Council's Arctic Monitoring and Assessment Programme (AMAP) has evaluated and described the major effects of several legacy POPs and some newly identified POPs on human populations (Hansen et al., 1998; Bonefeld-Jorgensen and Ayotte, 2003; Burkow and Weber, 2003; Dewailly and Weihe, 2003; Gilman et al, 2009b). Table 5.3 categorizes the most significant effects of some legacy POPs and some newly identified POPs, identifies the population subgroup primarily at risk, and provides an indication of the type of adverse outcome reported. Some of the effects reported have been observed in human populations following accidental poisoning situations (e.g., for dibenzo-*p*-dioxins, dibenzofurans, brominated biphenyls and chlorinated biphenyls) and others have been reported in populations exposed to POPs that have accumulated in the food chain. Since most of the data come from epidemiology studies there is less information on newly identified contaminants.

Table 5.3. Effects of concern of some POPs on specific sub-populations.

Population health effect	Legacy POPs likely to be involved in causing the effect	Sub-population at risk	Source
Cancer	DDT, toxaphene, 2,3,7,8-TCDD, mirex, HCH, PCBs, HCB	Primarily adult (breast cancer; prostate and testicular cancer); Some cancers reported in children	IARC, 1987 (and updates); Prins, 2008;
	Chlordecone	Possible association with prostate cancer	Multigner et al., 2010
Reproductive effects	PCBs, some dibenzodioxins and dibenzofurans	Fetus (live births); Newborns (genital and other birth defects); Women of childbearing age (fecundity)	Gilman et al., 2009b
	PentaBDE		Harley et al., 2010
Growth retardation	PCBs, some dibenzodioxins and dibenzofurans	Fetus, newborns and children (length, body weight, head circumference of newborns)	Dewailly and Weihe, 2003
Neurological impairment	PCBs, some dibenzodioxins and dibenzofurans (cognition, attention span)	Fetus and children (cognition, attention span, memory)	Gilman et al., 2009b
		Adults (Parkinson's disease and Alzheimer's disease)	Landrigan et al., 2005; Weisskopf et al., 2010
Altered behavioural development	PCBs, some dibenzodioxins, PentaBDE	Children, into adulthood (attention deficit disorders, learning disabilities)	Herbsterman et al, 2010; Roze et al., 2009
Immune system suppression	PCBs, some dibenzodioxins and dibenzofurans	Newborns, children (increased ear infections, colds and disease resistance) Adults (immunosuppression)	Gilman et al., 2009b
Cardiovascular effects	PCBs	Children and adults (blood pressure and heart rate variability)	Dewailly and Weihe, 2003; Gilman et al., 2009b
Effects on the thyroid	PCBs, PFOS and PBDES	Perimenopausal women (hypothyroidism)	Gilman et al., 2009b; Sowers et al., 2003; Canaris et al., 2000
Metabolic disorders	PCBs, POPs in general	Adult males and females (diabetes and obesity)	Longnecker and Daniels, 2001; Longnecker et al., 2001; Rylander et al., 2005; Vasiliu et al., 2006
Bone disease	PCBs, dioxin, and HCH	Adult females and males (osteomalacea, osteoporosis)	Alveblom et al., 2003; Côté et al., 2006

Some of the effects listed in Table 5.3 are caused by long-term exposure to POPS (e.g., DDT and cancer), others may be associated with shorter term exposures (e.g., 2,3,7,8-TCDD and some dioxin-like PCB congeners, PBDES, and PFOS during specific windows of time during pregnancy). While some effects are now being discussed in the elderly exposed for decades (Masoro and Schwartz, 2001; Adler, 2003; Hood, 2003), most scientific focus has been on in utero exposures and childhood exposures (Gilman et al., 2009b).

Children and the developing fetus are more susceptible to POPS for several reasons:

- developing physiology opens windows of vulnerability at critical developmental stages and may also affect the absorption, metabolism and elimination of POPS
- immune system development is suppressed by several POPS at a time when microbiological challenges specific to some diets and living conditions are highest
- unique early life exposure pathways exist such as trans-placental transfer of POPS, consumption of breast milk containing POPS, 'close-to-ground' exposures of infants and hand-to-mouth behaviors of children
- exposures are comparatively greater than those of adults because children eat, drink and breathe more in proportion to their body weight.

Children are also more at risk because they are unable to manage or control their exposure to POPS or other environmental substances and environmental conditions related to climate change. Furthermore, children living in poverty have a higher burden of environmentally attributable disease, related in part to poor nutrition, poor or crowded housing, less education, less access to health care, poorer quality local environments and less than adequate nurture (Wigle, 2003; CPCHE, 2005; WHO, 2005).

A major mechanism thought to be responsible for many of the effects ascribed to POPS is endocrine modulation. It is very likely that many of the endocrine related effects reported in epidemiology studies of children and adults result from concurrent exposures to several POPS in mixture.

The legacy POPS and most of the newly listed chlorinated and brominated POPS are all highly lipophilic and biomagnify in the food chain. As a result, human exposure to most POPS in the environment is primarily through fatty foods and especially from marine, freshwater and land-based species at the top of the food chain (see chapters on diets and levels of POPS in AMAP, 2003 and 2009; Undeman et al., 2010). For most POPS, this lipophilicity places subsistence consumers (those who consume species at the top of the food chain) at the greatest risk of exposure and effects. In Arctic countries, this has been referred to as the 'Arctic Dilemma', that is, the highly nutritious subsistence diets are also the primary source of exposure to POPS. Subsistence consumers near polluted industrial sites or dumps where POPS may have been produced, stored or land-filled are also likely to be exposed for long periods of time and at greater risk than the average population (Gilman et al., 2009a). Individuals who consume foods from regulated suppliers (grocery stores, meat and dairy products from inspected domestic animals) tend to have lower POPS levels than subsistence consumers because most 'store bought' foods come from very short food chains (Van Oostdam and Donaldson, 2009).

Breast milk is the major source of exposure to lipophilic POPS for most infants. However, breast milk also provides significant benefits to newborns including excellent nutrition, a secure and safe food supply, development of a healthy immune system, nurture and parent-child bonding. Public health authorities are generally unanimous that the benefits of breast feeding outweigh the risks associated with POPS exposure (Gilman, 2003; Odland et al., 2009).

Exposures to most POPS via drinking and bathing water and by air are generally considered to be far less than through food. However, for one newly identified POP which is not lipophilic (i.e., PFOS), the major route of exposure is from surface contamination of foods and water as a result of water transport and from direct contact with products (see Chapter 2). Additionally, indoor sources of some POPS used as flame retardants (e.g., PBDES) and stain prevention (e.g., PFOS) related products may become more significant for human populations spending more time in climate controlled buildings due to increases or decreases in ambient temperatures related to climate change (see section 4.3).

Attention also needs to be placed on the potential for accelerated degradation of POPs as a result of increased temperatures and bacterial proliferation in regions which become warmer and wetter. While more rapid degradation of POPs may be a benefit, some POPs metabolites and degradation products can possess significant toxicity (e.g., hydroxylated-PCBs) for mammals, including humans (Gilman et al., 2009b).

5.3.2. Probable changes in onset and severity of effects due to climate change factors

Gilman (2003) provided qualitative estimates of declines in several legacy POPs (and resulting reductions in human exposures in Arctic populations); however, climate change and climate variability were not considered as factors. While there is a worldwide tendency toward decreasing levels of legacy pollutants such as PCBs and DDT, several newly listed POPs and chemicals with POP-like characteristics are being reported in the scientific literature (i.e., in ecosystem compartments and in tissue of biota and humans). These chemicals include brominated flame retardants such as PBDEs, some surface active compounds such as PFOS and PFOA, short-chained chlorinated paraffins (SCCPs) and other chlorobornanes (AMAP, 2009). Levels of some of these newly listed POPs are not decreasing and, for a few, levels are still increasing in human tissues (Van Oostdam and Donaldson, 2009).

Chapter 3 identifies a number of factors which will influence redistribution of POPs globally as climates change and become more variable. Chapter 4 indicates that for human populations, some generic exposures may increase, but that overall POPs levels will continue to decline globally as a result of emissions reduction initiatives such as the Stockholm Convention. Key factors which may increase exposures include greater use of persistent pesticides such as DDT to control parasitic disease vectors in wetter regions, redistribution of POPs waste in areas inundated with rain or seawater, greater partitioning of some POPs in industrial-urban areas into breathing zone air and greater exposure to some POPs as a result of greater time spent indoors away from ambient heat or cold.

Toxic effects related to POPs likely to be observed as a specific result of climate change and climate variability are difficult to predict with precision. Certainly, understanding the effects will be complicated by simultaneous multi-contaminant exposures and other confounding factors related to sustaining good health (Gilman et al., 2009a). Taking these realities into account, the enhanced effects of POPs associated with climate change may include the following:

- Some POPs (e.g., DDT) have very low acute toxicity for mammals including humans and as a result, increased use of DDT for insect vector control will not lead to any observable short-term increases in toxicity. However, greater use of DDT will lead to greater human exposure at the sites of application and in remote regions (as a result of long-range transport) and the effects of chronic exposure to high levels of accumulated DDE in tissue could include an increase in human cancers. Other effective and less persistent insect vector control agents (e.g., pyrethroids), when combined with community supported non-chemical pest management practices, have been shown to be effective in several countries (e.g., Mexico, some African states) and can significantly reduce reliance on DDT as a control agent.

- Flooded waste sites and waste sites affected by excessive runoff may lead to greater human exposure to a host of POPs. These POPs may enter the food chain or contaminate local potable water supplies. Greater exposure to POPs in general is likely to lead to moderately decreased birth weights and growth retardation of children, moderately increased neurobehavioral deficits, and other endocrine related effects as listed in Table 5.3.

- If some populations spend more time indoors to reduce their exposure to temperature extremes (heat or cold) related to climate change, human exposures may increase to more commonly found 'building POPs' such as flame retardants (e.g., PBDEs, hexabromocyclododecanes (HBCDs)) and anti-staining agents containing the PFOS moiety. Increased exposures to HBCDS may lead to greater toxicity as listed in Table 5.3; however, the effects of PBDES and PFOS on human health are still poorly understood. Long-term exposures to these substances have been associated with hypothyroidism in perimenopausal women.

- In regions where temperatures increase and there is less rainfall, levels of airborne particulates may increase. In urban areas with high motor vehicle density, outdoor burning and combustion based industries, chemical industries and electronic recycling activities, these particulates may contain POPS such as dioxins and furans, HCB, PBDES, PCBS, and pentachlorobenzene. Pulmonary exposures to POPS are not well studied; however, endocrine related effects may increase and be of significant concern for the developing fetus, newborns and children. Exposure to PCBS (and air pollution and some non-POPS contaminants such as mercury) can lead to cardiovascular disease in children and adults (see Table 5.3). Medications commonly used to treat chronic cardiovascular disease in seniors may exacerbate the effects of extreme heat associated with changing climate and climate variability (Flynn et al., 2005).

- Melting of the polar ice cap is likely to release HCH and HCB currently sequestered in the ice and seawater to the air column (see Chapter 3). Through deposition mechanisms, these POPS will enter the food chain and bioconcentrate and biomagnify. Arctic populations reliant on marine mammals in their diet may be exposed to higher concentrations of these POPS than currently reported. Greater exposure to HCH and HCB could lead to more cancer cases and possibly bone disease.

- As climates change, ocean currents will change, bringing increased pollution to some regions and lower levels of pollutants to other regions. These currents may deliver their pollutants to complex food chains with significant opportunity for bioaccumulation and biomagnification. As a result, human exposure to several POPS found in routinely harvested species of fish and marine mammals may increase as levels of these same POPS increase in these harvested species. Indigenous populations such as in the Arctic could be exposed to a large number of redistributed POPS from primary and secondary sources and could sustain an increase in a number of the POPS mixtures-related effects listed in Table 5.3.

- Changes in the availability or quality of food species normally eaten by subsistence consumers may lead to increased reliance upon more- or less-contaminated foods. POPS related effects are likely to occur in subsistence consumers with higher exposures.

- Populations most likely to be affected by climate-POPS related influences are those which are in the poorest health, have less access to health care, are less educated (especially about how to avoid exposures), crowded in dense urban-industrial areas, living in crowded housing and/or are more reliant on subsistence foods. In areas where POPS increase beyond their current levels, immunosuppression could also increase. For populations already compromised by poor general health and diet, suppression of the immune system could result in more frequent and longer lasting infections, especially for newborns. This is especially significant for regions where temperatures and moisture levels increase as a result of climate change because insect disease vectors and bacteria may both proliferate and spread into these areas.

5.4. Conclusions

Animal and human populations in the poorest health and exposed to increased levels of POPS are likely to be the most affected. It is not possible to predict with any certainty in which animal or human populations or regions the toxic effects of POPS will increase or decline as a result of climate change and climate variability effects. Greater knowledge of where temperatures and rainfall amounts will change and the current levels of individual POPS in biota and humans is essential for further meaningful evaluation.

Toxic and endocrine disrupting POPS can interfere with physiological and behavioral processes that are important for animals to acclimate and adapt to climate change. A combination of

Inuit children play on a pile of empty oil drums. Moriussaq, NW Greenland

increased disease risk caused by climate change and immunosuppressive effects of POPs may have serious impacts at the population level. Thus, toxic or endocrine effects may directly affect fecundity and/or survival, and therefore have a direct consequence on population size. Effects at the population level can be manifested as bottom-up or top-down stress in ecosystems, causing severe changes in biodiversity and ecosystem functioning.

Ecosystems in densely populated areas are exposed to several other anthropogenic stressors, such as habitat loss and fragmentation, over-harvesting of fish and wildlife populations and eutrophication. Thus, POPs can exert serious toxic or additional stress that can act in concert with climate change to push the species beyond their environmental tolerance limits, or reduce recruitment/replenishment rates of harvested stocks or populations.

In some tropical regions where insect disease vectors proliferate, the use of pesticides such as DDT may increase. Due to low genetic variability in many tropical species, these species may be susceptible to exposure to multiple anthropogenic stressors, such as climate change, habitat loss and fragmentation and pollution. It is likely that a combined exposure to these factors acts additively or synergistically and may increase extinction rates.

Marine and freshwater environments are considered to be the ultimate sink for POPs. This is particularly the case for ecosystems in close proximity to urbanized/industrialized areas. These ecosystems are also threatened by other anthropogenic factors such as over-fishing, petroleum-related activity, eutrophication and hypoxia, and recently also acidification. POPs exposure is a serious additional toxic and endocrine disrupting stressor that can affect acclimation or adaptation to ocean temperature changes. Endocrine disrupting POPs can also reduce recruitment/replenishment rates of heavily exploited stocks or populations when they are exposed to the additional stress of climate change.

In areas where levels of POPs in the environment increase as a result of redistribution and new primary and secondary source releases, human exposure will increase. POPs are known to have negative health effects on humans, such as cardiovascular disease, immunosuppression, metabolic disorders including diabetes, cancer, and neurobehavioral, endocrine and reproductive effects. Where climate change or climate variability result in an increase in exposure to POPs, risks to health will increase.

The combined effect of several direct and indirect climate-related factors – for example, excessive heat or cold, overcrowding associated with population migration, increased exposure to insect vectors of disease, and changes in the availability and quality of traditional/local food – could also modulate the effects of POPs exposure on human populations. Socio-economic factors such as education and general health status can also have an impact on human vulnerability to POPs. Indigenous peoples in general, and especially indigenous populations in the Arctic, experience many of these modulating factors and are highly vulnerable to the effects of climate change and POPs.

In general, POPs have their most significant effects on the developing fetus, on children, on women of reproductive age and, following lifetime exposures, on the elderly. It will be essential to follow both the trends in human exposure levels to POPs and the effects of these POPs in those subgroups most at risk and in regions where increases are taking place.

Without baseline data for current exposures, it will be impossible to measure changes in exposure to POPs and to undertake evaluations of the potential for an increase in harm to ecosystem or human health from climate related changes in POPs exposure.

5.5. Data/knowledge gaps

5.5.1. Environmental health

The following actions are needed to fill data gaps on environmental health:

- Identify and better understand the mechanisms underlying the interacting effects of climate change and POPs on all levels of ecosystems.
- Identify species and ecosystems most sensitive to the effects of climate change and POPs exposure.
- Develop and apply approaches for assessing combined ecological effects of multiple stressors (POPs, climate change, and other factors described in section 5.2.1).

5.5.2. Human health

The following actions are needed to fill data gaps on human health:

- Undertake more extensive and systematic monitoring of current levels of POPs in human tissues in populations located in the most significantly climate-affected areas is essential to create a baseline from which to measure change. Special focus should be placed on regions in Africa, the Indian sub-continent, South America and Asia, where little has been published on historical or recent levels of contaminants in human tissue (blood or breast milk).
- Undertake more studies of the effects of the newly identified POPs such as HBCDs, PBDEs, PFOS, SCCPs and other substances with POP-like characteristics, to understand how they may affect human populations, especially the very young (including the fetus) and the elderly (who may have been exposed for decades).
- Generate better predictions of the locations where climate change and climate variability are likely to be greatest and where impacts on POPs exposures are likely to be greatest, such as the Arctic.

Chapter 6. Co-benefits of mitigation activities for climate change and POPs emission reduction

Jozef M. Pacyna, Kyrre Sundseth and Elisabeth G. Pacyna

6.1. Introduction

Greenhouse gases (GHGs) and selected unintentionally produced POPs are often emitted from the same sources and any mitigation option or integrated policy measures for reducing climate change impacts, particularly through reduction of carbon dioxide (CO_2) may change the levels of emissions and thus exposure to unintentionally produced POPs. However, in some situations reduction of CO_2 may lead to increased emissions of unintentionally produced POPs, requiring some trade-offs for policy makers. There are technologies and practices that require additional energy for their application (e.g., end-of-pipe techniques to reduce CO_2 emissions). In the case of waste incineration, modern techniques often aim at energy recovery and the net result could be a reduction of GHG emissions along with reductions of air emissions of unintentionally produced POPs from this source. On the other hand, this approach may result in an increase in total releases, for example, increased unintentionally produced POPs in fly ash. Finally, there are also measures to reduce unintentionally produced POPs which do not have any major effect on GHG emission reductions, such as elimination of open burning of wastes through application of modern incineration techniques (unless there is an energy recovery process in place). In general, the co-benefit cases occur in many more situations than the trade-offs situations and so the major focus in this chapter is on co-benefits rather than trade-offs.

Annex C of the Stockholm Convention lists 20 source categories having significant global impacts on the formation and release of unintentionally produced POPs to the environment. Apportionment of global CO_2 emissions by main categories on a global scale in 2006 is presented in Figure 6.1.

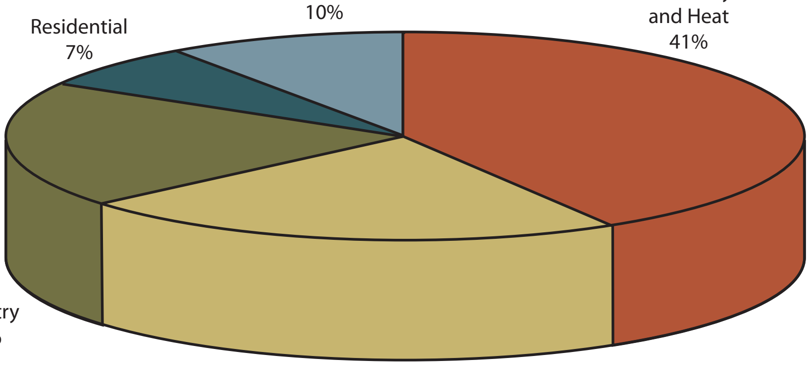

Figure 6.1 Global carbon dioxide emissions by sector in 2006 (OECD, 2008).

The largest CO_2 emissions are generated during combustion of fuels from stationary sources (67%) and transport (23%). Therefore, the co-benefit cases for CO_2 and unintentionally produced POPs emission reductions are most often found for these two groups of sources.

Among the 21 different POPs and POP groups listed in Annexes A, B and C of the Stockholm Convention and discussed in this report, several are emitted from the sources shown in Figure 6.1 in significant amounts, including PCDDs/PCDFs, HCB, and PCBs. There are also other POPs such as perfluorinated compounds (PFCs), organic pollutants such as polycyclic aromatic hydrocarbons (PAHs) and amines and black carbon (soot) which are not mentioned in Annex C to the Convention but need to be considered when discussing the co-benefits of climate change mitigation options.

A very comprehensive assessment of co-benefits and trade-offs between energy conservation and releases of unintentionally produced POPs has recently been prepared for the Global Environment Facility (GEF) by Bohmer et al. (2009). One of the major questions addressed in this assessment was whether implementation of best available techniques (BAT) and best environmental practices (BEP) in the context of the Stockholm Convention has synergistic effects on GHG emissions or whether there are trade-offs. This chapter has used the results of the assessment together with other data published in the open literature.

6.2. Technological and non-technological measures for emission reductions of greenhouse gases and unintentionally produced POPs

There are various technological measures presented within BAT and BEP lists which are directed towards improvement of combustion conditions, energy efficiency, energy recovery rates, and emission reductions (EEA, 2006; Nemet et al., 2010). These measures are designed for application in various industrial sectors and the transportation sector where both GHGs and unintentionally produced POPs can be released to the atmosphere. The following sectors are of particular importance in this context: combustion of fuels in utility burners for electricity and heat production, industrial and residential boilers (particularly those fuelled with wood and other biomass), waste incinerators, crematories, cement kilns, primary and secondary non-ferrous metal industries, pulp production, specific chemical production and motor fuel firing. The choice of specific technology would have a direct impact on releases of GHGs and unintentionally produced POPs.

Typically, high combustion temperatures designed to ensure complete combustion in various utility, industrial and residential boilers as well as motor engines minimize the formation of unintentionally produced POPs. Formation of unintentionally produced POPs during the combustion of fuels can be significantly reduced by optimizing combustion conditions with co-benefits for energy recovery and reduced GHG emissions. Maximized energy recovery significantly reduces the amount of fossil fuels needed to generate a given quantity of power and as such formation of unintentionally produced POPs (UNEP, 2005; Bohmer et al., 2009). As fuel is by far the largest portion of the overall operating costs for power generation facilities, both in terms of operating costs and GHG emissions, reduction of fuel consumption through efficiency improvement for lower fuel consumption per unit of power generated is the most promising approach to reduce simultaneously CO_2 and unintentionally produced POPs emissions.

In the case of transportation, diesel particulate filters in mobile engines can lead to up to a 90% reduction of Ah-binding compounds (e.g., dioxin-like compounds) as shown by Wenger et al. (2008).

Polychlorinated dibenzo-*p*-dioxins and dibenzofurans may also be formed during wood combustion via precursors such as phenols and lignin or via de-novo reactions in the presence of particulate carbon and elemental chlorine. High emission levels of unintentionally produced POPs can be expected from burning waste treated wood. Wood residues often contain various types of contaminants (copper arsenate, pentachlorophenol, creosote, preservatives, adhesives, resins, paint and other surface coatings). Stopping the practice of burning waste wood would significantly reduce unintentionally produced POPs emissions.

Wood and other biomass firing is also a large source of CO_2 (EEA, 2007) and these emissions can also be reduced through improved combustion efficiency. Combined heat and power (CHP)

Petrochemical plant, Scotland, UK

systems are the most important technical and economical measure to increase fuel efficiency (EC, 2006a,b). This measure will also contribute to reductions in unintentionally produced POPs emissions.

BAT and BEP for waste incineration include the implementation of primary measures, effective end-of-pipe techniques and appropriate treatment/disposal options for solid residues (especially for fly ash). Primary measures reduce both GHG and unintentionally produced POPs emissions through the prevention of unintentionally produced POPs formation or by providing the basis for high energy efficiency and reduced process demand for energy. In addition, the application of BAT and BEP helps to optimize the process by increasing the efficiency of end-of-pipe techniques over the lifetime of the plant (Bohmer et al., 2009).

Gasoline and especially diesel fuel combustion are known to emit PCDDs and PCDFs. In addition, in some regions of the world tetraalkyllead is still used as an anti-knock compound in gasoline. In addition to tetraalkyllead, both ethylene dichloride and ethylene dibromide have been used as engine scavengers. In the presence of chloride or bromide, fuel combustion processes favor the formation of unintentionally produced POPs. BAT and BEP for this source of CO_2 include prohibition of leaded gasoline, as well as installation of diesel oxidation catalysts, particulate filters and catalytic converters. Reduction of fuel consumption by vehicles and conversion of motor fleets to electric, solar, fuel cell or other alternative means of vehicle power is also recommended.

Amines are not considered within Annex C of the Stockholm Convention, although these compounds may be related to POPs as they are used in the development of various adsorbers for their application within the 'carbon capture and storage' (CCS) technologies. These technologies capture CO_2, POPs and other contaminants and then contribute to contamination of land and/or aquatic environments through the storage of captured contaminants. Amines, which are toxic to humans, are among these contaminants.

6.3. Mitigation options by implementation of environmental regulations and capacity building

Implementation of various environmental regulations also provides an opportunity to reduce GHGs and unintentionally produced POPs. This issue is of particular importance for waste disposal, which is a very important source of emissions of PCDDs and PCDFs. Open burning and accidental burning of wastes is an important source of GHG emissions on a global scale and one of the largest global sources of POPs. Prohibition of open burning of wastes through adequate domestic and regional regulations could result in significant reductions in emissions of GHGs and unintentionally produced POPs from this source.

There is a need to raise awareness, build capacity, transfer technology and provide technical awareness, particularly to developing countries on the issue of co-benefits that can be achieved from the reduction of GHGs and unintentionally produced POPs emissions at the same source or within the same source category. This will also result in simultaneous reductions of GHGs and unintentionally produced POPs emissions from several sources.

6.4. Conclusions

The effects of climate policies on unintentionally produced POPs and other air pollutant emissions mainly take place in a limited number of sectors: industrial, residential, and transportation. Climate policies are expected to have a positive effect on regional and local scale air pollution by reducing the creation and emissions of unintentionally produced POPs. Table 6.1 provides a qualitative assessment of unintentionally produced POPs co-benefits during the reduction of CO_2 emissions.

Table 6.1. A qualitative assessment of CO_2 emission reduction benefits for reduction options and co-benefits for unintentionally produced POPs reduction.

	CO_2 reduction option	CO_2 benefits	Co-benefits for unintentionally produced POPs reduction
1	Reduction from coal usage	Medium → Large	Medium
2	Reduction from industrial processes	Medium → Large	Medium → Large
3	Reduction from waste incineration	Small → Large	Large
4	Reduction from transportation	Small → Large	Medium → Large

Current literature indicates that air quality policies based on structural changes, such as improvement of energy efficiency in power stations, replacement of fossil fuels by renewable sources, and improvement of combustion processes in stationary and mobile sources, and industrial technologies, can provide greater climate and air pollution co-benefits than the traditional end-of-pipe technologies.

Mitigation through implementation of environmental regulations to arrest open burning of waste will also result in co-benefits of reducing GHGs and unintentionally produced POPs.

Enhanced collaboration and communication between key climate change and air pollution stakeholders (particularly for unintentionally produced POPs) would be essential to develop co-benefits strategies at international, national and local scales, which may include various environmental protection authorities and governmental departments, as well as industry and academia.

Chapter 7. **Conclusions**

The Expert Group as a whole

7.1. General trends

The Stockholm Convention includes important obligations to reduce or eliminate releases from intentional production and use and requires Parties to take measures to reduce the total releases of unintentionally produced POPs *"…with the goal of their continuing minimization and, where feasible, ultimate elimination"* (Article 5). Reductions in the manufacture, use and disposal of many of the original 12 POPs listed under Annexes A, B and C of the Stockholm Convention (i.e., the legacy POPs) have led to a general global decline in environmental concentrations. However, levels of some individual POPs, for example, DDT, HCH and HCB, commercial pentabromodiphenylether (c-PBDE), commercial octabromodiphenylether (c-OBDE) and PFOS may not be declining as rapidly or may even increase in regions most affected by climate change. For newly identified POPs, for which regulations are only now entering into force or for which restricted uses are permitted, levels are not likely to decline for several years and may increase in most climate change impacted regions.

7.2. POPs releases

Past and current manufacture, use and disposal of intentionally produced POPs lead to primary releases into the environment. Changes in overall trends of future releases of POPs are difficult to predict. Evidence suggests that climate change will affect primary emissions of POPs by changing their rate of mobilization from materials or stockpiles and their degradation rates due to higher ambient temperatures, or by altering use patterns or increasing demand for some POPs such as DDT for disease vector control. Therefore, the intended results of the Stockholm Convention could be affected by climate-related factors should they lead to greater use and releases of some POPs.

7.3. Environmental fate of POPs

After primary release, POPs circulate via environmental media until deposited in environmental reservoirs. Secondary releases are described as revolatilization and remobilization from these reservoirs. The secondary release of POPs is a confounding factor in the interpretation of monitoring data. There is considerable uncertainty whether primary or secondary releases will dominate on a regional basis.

The environmental fate of POPs will be affected by several factors related to climate change on a global, regional and local scale:

- remobilization (secondary releases) from environmental reservoirs due to increased temperature and/or extreme events such as flooding
- increased airborne transport to locations downwind of main emission areas because of higher wind speeds and stronger air circulation (mainly relevant on a regional scale with long-range transport in the range of hundreds to thousands of kilometres)
- enhanced degradation of POPs if microorganisms have higher degradation capacity, but also increased formation of potentially POP-like transformation products
- changes in atmospheric deposition patterns due to spatial and temporal changes in precipitation patterns, which are most relevant at the local and regional scale.

7.4. Exposure to POPS

As climate change alters primary and secondary releases of POPS, levels and patterns of exposure in wildlife and humans will also change. Climate change is already altering food web structure in some areas. This will be an added influence on the exposure of wildlife and humans to POPS. However, there are large uncertainties concerning how climate change will affect ecosystem and food web structure. Given the small amount of baseline exposure information for POPS in many parts of the developing world, uncertain predictions of regional changes in climate, and uncertain ecosystem response to these changes, it is currently not possible to evaluate accurately how climate change will impact exposure of animal and human populations to POPS.

7.5. Effects of POPS on biota

Overall, POPS are known to have direct adverse consequences on individuals of a species and can affect population size. Most significant are the endocrine disrupting effects of POPS, which may directly affect fecundity and/or survival, and thus have direct consequences on an individual basis as well as on population size. Endocrine disrupting POPS can also interfere with physiological and behavioral processes in animals, which are important for adaptation and response to climate change. For instance, POPS impair the ability of an animal to respond to changes in environmental temperature. Endocrine disrupting POPS can also reduce the replenishment of heavily exploited stocks or populations and the immunosuppressive effects of POPS may facilitate the spread of disease and have other negative impacts on populations. Attention should be paid to new information resulting from molecular and epigenetic studies which are examining impacts and outcomes of exposure of organisms and cells to changing concentrations of POPS.

Several climate-related factors will modulate the toxicity and toxicokinetics of POPS. These factors include salinity, ocean acidification, eutrophication, water oxygen levels, changes in the nutritional status of individuals/species, temperature change and the adaptability of individuals/species, and the proliferation of parasites and pathogens. These changes could enhance, either alone or in combination, the toxic effects of POPS and ultimately increase species vulnerability. Particular species with low genetic variability (as occur in some areas where DDT is applied) could face increased risk of extinction. Ecological effects of climate-related changes and POPS toxicity can be manifested as a top-down or bottom-up stress that cascades through the ecosystem.

In addition to POPS and climate-related impacts, ecosystems are also exposed to several other anthropogenic stressors such as habitat loss and fragmentation, over-harvesting of fish and wildlife populations, eutrophication, petroleum-related activities, as well as urban and agricultural discharges. The combination of some or all of these factors can push species beyond their environmental tolerance limits and significantly reduce the rate of replenishment of harvested stocks or populations.

7.6. Human health effects of POPS

Persistent organic pollutants are well known for their adverse effects on individuals and human populations. The extent of the effects is dependent on the amount, timing and duration of exposure. Those at most risk from the effects of increased exposure to POPS include the developing fetus (e.g., growth retardation, impaired neurological development), children (e.g., cardiovascular disease, immunosuppression, metabolic disorders, neuro-behavioral impairment) and women of reproductive age (e.g., endocrine and reproductive effects). Recent data suggest that the elderly, who have been exposed for a lifetime to mixtures of POPS, may also be vulnerable to late-onset chronic disease (e.g., cardiovascular disease, metabolic disorders including diabetes and thyroid dysfunction, bone disease and cancer).

Data on current human exposure levels to POPS from many regions in the developing world are scarce or unavailable. This paucity of exposure data combined with uncertainty in climate change models for these same regions make predictions of changes in exposure to POPs and risks to health difficult. It is probable that subsistence consumers (especially those harvesting food from the aquatic environment) are at a higher risk due to contamination of their traditional/local food supply. Indigenous peoples in the Arctic are known to be exposed to some of the highest levels of environmentally transported POPs and may become even more exposed from remobilization and revolatilization of some POPs (e.g., HCH and HCB) from melting polar ice and from the Arctic Ocean. Individuals who live in the regions most affected by climate change may spend more time indoors and be exposed to higher levels of typical indoor POPs (e.g., PFOS, PBDEs). Individuals living in or near regions where DDT may be applied for public health reasons, such as to control the increase in prevalence of disease vectors, may become more exposed to this POP.

Several climate-related factors will combine to aggravate the effects of POPs on humans. For example, excessive heat or greater cold, overcrowding and disease spread associated with population migration as land becomes less arable or floods, increased exposure to vector-borne diseases and other microbial pathogens, and changes in the availability and quality of traditional/local foods. Other determinants of health (e.g., socio-economic status, education, adequacy of shelter, general health status) may also combine to adversely affect human responses to POPs and climate change.

7.7. Mitigation co-benefits

Mitigation actions to reduce GHG emissions and short-lived climate forcers (e.g., black carbon or soot) are expected in most cases to result in simultaneous reductions in emissions of unintentionally formed POPs and other contaminants of concern. These reductions may be expected for emissions from major anthropogenic sources of CO_2, including stationary combustion of fuels, incineration of wastes, and transportation. In some cases, however, where there is an increase in the use of biomass as fuel for heating and cooking, unintentional POPs emissions may increase.

Technological and non-technological options for climate change mitigation can be considered when discussing co-benefits for reductions of unintentional POPs. Major technological options include switching fuels, improving combustion efficiency, improving heat recovery and better recycling, and changing combustion technologies. Non-technological measures contributing to co-benefits include measures such as introduction and enforcement of regulations.

7.8. Knowledge gaps

The following key knowledge gaps were identified during the course of the technical review:

- There is a need to identify and improve characterization both of primary and secondary emission sources of several POPs (such as PCBs and PBDEs) and to estimate future scenarios of the need for, and use of, DDT. This is highly relevant for prediction of future levels and trends, as well as for the interpretation of monitoring data.

- There is a lack of adequate monitoring data and assessment tools to evaluate the impact of climate change on changing POPs emissions and concentrations. This is especially true in some developing country regions, including South America, Asia, Africa and the Indian sub-continent. Specific attention also needs to be paid to the effects of climate change on transport mechanisms of POPs, particularly in air, since it is a core media under the GMP.

- There is a need to expand and harmonize temporal trend monitoring in humans on a global basis to assess how levels change and what impact climate change has on these levels, as recognized by the recent GMP reports.

- Computer-run mathematical models of the environmental fate of POPs are important tools for predicting the response of POPs to changes in environmental factors, including climate-related factors. Thus, there is a need to build or improve models for forecasting POPs fate, transport and impact on exposure under projected climate change scenarios. For the credibility of models, evaluation of model results with field data is essential, which requires that adequate monitoring data are available.

- There is a poor understanding of the potential impacts of a changing climate on microorganisms and how the response of microorganisms to climate change may affect the degradation of POPs in soil and water. It is uncertain whether an increase in temperature will increase the metabolic activity of microorganisms and thereby their capacity to degrade POPs or if thermal stress will reduce their capacity to degrade POPs. Identification of the transformation/degradation products of POPs that may be formed in relevant amounts under the conditions of climate change is important for evaluating the effects on ecosystems and human populations because several degradation/transformation products of POPs have been found to possess significant toxic characteristics.

- To better assess POPs exposure pathways and species impacts, there is a need to better understand how food web structures will be affected by climate change.

- There is a need for toxicology studies of some of the newly listed (non-legacy) POPs such as the PBDEs and perfluorinated substances, and some of those substances which have been identified as POPs but not yet listed in the Stockholm Convention annexes, including endosulfan, HBCDs and SCCPs. The studies need also to consider the effects of mixtures of POPs now found in various regions of the world. Both types of studies (exposures to single substances and to mixtures) are needed for estimating the effects of environmentally relevant concentrations of POPs on human populations and other biota.

- There is a need to better understand the combined effects of POPs exposure and climate change stresses on human populations and other biota. While many of the potential stressors have been identified, there are few laboratory and even fewer field studies combining climate change stress with POPs exposure.

- It is not always clear whether climate change mitigation options have fully taken into account negative influences associated with production and distribution of unintentionally produced POPs. For instance, 'carbon capture and storage' strategies to reduce releases of CO_2 to the air will also capture POPs and other contaminants which are then transferred to land and/or aquatic environments, resulting in further environmental contamination of POPs . It is uncertain how much cooperation is currently in place between policy makers who address climate change and those who address POPs management domestically and internationally.

Chapter 8. Policy recommendations

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There are several significant issues to be addressed for the successful implementation of the Stockholm Convention on a national, regional and global scale. Governments still face challenges and responsibilities for the legacy POPs, they need to address newly listed POPs, and they need to update National Implementation Plans in accordance with their respective obligations. Other substances with POP-like characteristics are also under review for inclusion in the Stockholm Convention and may become future obligations under the Stockholm Convention. The challenges of finding replacement chemicals and practices to address the uses of some regulated POPs may be increased because of diverse climatic conditions globally and the requirement under the Convention to prevent the replacement of one POP with another. Climate change may complicate the implementation of the Stockholm Convention even further because of its potential to have a direct impact on present and future management of POPs (e.g., new uses, redistribution, changes in the fate of POPs).

Previous chapters of this report highlight that climate change related effects such as temperature rise, increased frequency and intensity of extreme weather events, and sea level rise are likely to interact with a variety of environmental stressors, including exposure to POPs. While the interaction between climate change and POPs is still a new research area, current information provides evidence that many of the probable effects of climate change are likely to enhance POPs contamination and increase POPs exposure in some regions, thereby counteracting efforts under the Stockholm Convention to eliminate or reduce POPs globally. There is therefore a need for greater prevention and precaution with respect to climate change if the obligations of the Stockholm Convention are to be realized.

Furthermore, and as described in previous chapters of this report, climate change will also have implications for the measurement of the effectiveness evaluation of the Stockholm Convention. The effects of climate change on the release, transport and partitioning of POPs have the potential to complicate significantly the interpretation of measurements of POPs in environmental media and in human tissues. The scientific review in this report concluded that further studies should be encouraged to assess climate influences on levels of POPs in environmental media, as well as potential negative impacts on human and environmental health. In this aspect, the work of the GMP is essential to provide guidance on monitoring and address the scientific gaps and uncertainties that have been identified in this report.

Under conditions of a changing climate, there is also a greater urgency to identify and secure stockpiles and contaminated sites containing regulated POPs and to focus on developing alternatives for POPs listed in Annex B of the Convention. The policy recommendations indicated in section 8.2 are based on the current state of the science and acknowledge the important data gaps which need to be filled as soon as possible.

8.1. Existing initiatives on POPs and climate change

There are several international organizations and programs dedicated to the improvement of knowledge on sources, fate and impacts of POPs in the environment, as well as on the impacts of climate change on human populations and ecosystems. Both scientific and political initiatives exist for POPs and for climate change (see Appendix), but there is an urgent need for improved coordination among these initiatives and programs to ensure that efficiency and better information exchange is promoted. Equally important is the need to promote an approach to identifying and addressing the combined impacts of climate change and exposure to POPs. For instance, the POPs Review Committee (POPRC) of the Stockholm Convention and the Intergovernmental Panel on

Climate Change (IPCC) are the technical bodies that evaluate scientific data and provide support and relevant recommendations for decision-making purposes to the Conferences of the Parties to the Stockholm Convention and the United Nations Framework Convention on Climate Change, respectively. Communication and exchange of information between these groups could provide important data and shared knowledge from both fields, and facilitate the assessment of the combined effects of POPs and climate change.

8.2. Science-based policy recommendations

The following recommendations reflect the main needs and information gaps identified in this report:

1. Governments are urged to consider the knowledge gaps identified in this report and to encourage and support research to improve, harmonize and consolidate knowledge on the relationship between POPs and climate change, including aspects such as environmental releases, transport, fate, degradation and effects of POPs in a changing climate at the national, regional and global levels.

2. Governments are urged to contribute to the development of decision support systems that include more reliable predictions of future releases and impacts of POPs, other substances with POP-like characteristics and climate change. Better predictive tools would assist in the development of implementation strategies to establish and meet release reduction targets.

3. The UNEP Stockholm Convention's Global Monitoring Plan (GMP) on POPs has been established using organizational structures that include SC Regional Organizational Groups (ROGs) and the SC Global Coordinating Group (GCG). Governments are urged to commit to long-term monitoring networks and to request that the GMP and its advisory groups (ROGs and the GCG) consider the implications of the information presented in this report. Governments should develop strategies to provide a sufficient knowledge base for decision-making, including a better understanding of the relationships between changes in climate and levels of POPs in the environment.

4. The potential for enhanced frequency and intensity of extreme weather events (e.g., flooding and storms) leading to increased releases, modified use patterns, and the risk of remobilization of POPs from waste dumps, soils, sediments, and other reservoirs of POPs, needs to be addressed by all stakeholders, including the industry sector. Governments are urged to improve the management of existing stockpiles and landfills as well as the clean-up of contaminated sites in areas at risk of water incursion, flooding and storm events. New landfills should not be sited in areas at risk of water incursion, flooding and storm events. Additionally, inventories of existing stockpiles of regulated POPs should be updated and inventories for the newly regulated POPs should be developed. Improved information is also required on the amounts and frequency of use of restricted POPs listed in Annex B of the Stockholm Convention.

5. Governments are urged to support developing countries and countries with economies in transition in reducing their emissions of POPs and GHGs. Measures might include, but not be limited to, better collaboration between the Stockholm Convention and the Basel Convention to reduce illegal dumping of hazardous waste or the uncontrolled export of electronic wastes to countries with poor dismantling technologies and poor occupational health protection, approaches for reducing significantly or restricting open burning of waste, and information on best available technology and best environmental practices.

6. Owing to the impacts of climate change and POPs on the most vulnerable and disadvantaged populations such as many indigenous populations which rely on traditional/local diets (especially Arctic populations consuming marine mammals and fish), those in malaria affected regions, and those with poor health and nutrition, governments are urged to identify and implement measures to reduce the combined impacts of climate change and POPs on these most vulnerable populations.

7. Governments are urged to explore and assess opportunities for co-benefits and mitigation measures to reduce emissions of GHGs and POPs through appropriate life-cycle management options and relevant regulations, such as prohibition of open burning of waste, improvement of waste management and more efficient combustion processes. They are also urged to explore and disseminate information on possible mitigation activities and the co-benefits of managing POPs, other contaminants and climate change in an integrated manner. To improve understanding among industry and civil society of the combined effects of POPs exposure and climate change, governments are encouraged to provide capacity building, education, outreach and awareness programs for the general public and the corporate world, in relation to the impacts of POPs and climate change on human health and the environment.

8. An essential step to develop co-benefit strategies at international, national and local scales would be to establish a mandate for multidisciplinary stakeholder working groups, from existing committees on chemicals, wastes and climate change. The role of these groups would be to enhance collaboration and communication between key climate change and POPs stakeholders, which may include various environmental protection authorities, governmental departments and international bodies (including the agencies of the United Nations), the health sector, industry, academia, and other non-governmental stakeholders. Co-operation between all stakeholders and review of existing international and regional agreements on POPs management and climate change mitigation with respect to how they can work better together will be essential success factors for simultaneously reducing the effects of POPs and climate change.

8.3. Conclusions

The recommendations listed in section 8.2 are supported by the current level of knowledge on interactions between POPs and climate change, which recognizes that these are both relevant environmental stressors in their own right and that, in combination, they are both of greater harm to environmental and human health. They also address the uncertainty in the current scientific information.

The issues of POPs and climate change are both global in nature. A coordinated response is needed from decision-makers all over the world to take action to counteract immediate, medium and long-term effects on human health and ecosystems of concurrent exposure to POPs and changing climates.

Given the current knowledge gaps, a precautionary approach is needed to guide the development and adoption of policy actions to ensure that human health and the environment are protected from the negative impacts of POPs and climate change and their combined effects.

Appendix

List of International Initiatives on Chemicals Research and Assessment

International Panel on Chemical Pollution

The International Panel on Chemical Pollution (IPCP) has been established as an organization for scientists involved in environmental pollution issues to bridge the gap between science and policy. In the IPCP, scientists from a wide range of disciplines collaborate with various scientific societies and with each other in an interdisciplinary manner with an objective of gaining credibility in the interpretation of scientific findings for effective communication between science and policy. The main task of this panel is to provide scientific support for decision makers dealing with pollution problems and the assessment and management of chemicals, both at the national and international level and based on current scientific knowledge. Further, IPCP wants to offer expertise gathered within IPCP to deliver state-of-knowledge documents on topics related to chemicals, health and environment for other interested parties/stakeholders. For further reading, see www.ipcp.ch.

Global Monitoring and Assessment Group

A Global Monitoring and Assessment Group (GMAG) is being established within UNEP to formulate schemes and tools for reporting progress under multi-lateral environmental agreements (MEAs) and to advise on integrity and robustness of monitoring and assessment tools. It will be jointly chaired by the Chemicals Branch of the Division of Technology, Industry and Economics (DTIE) and the Division of Early Warning and Assessment (DEWA). The GMAG will consist of global stakeholders such as the UNEP Science Panel, academic institutions, and normative institutions. Decisions by the Conferences of the Parties of multi-lateral environmental agreements or from the International Conference on Chemicals Management (ICCM) and their stakeholders will feed into the GMAG. The GMAG will back-up the schemes to be developed and the assessments at various stages of development and will provide training and distribution of the methods, tools, and schemes. The context for the GMAG can be viewed under the UNEP Programme of Work, Harmful Substances and Hazardous Waste Priority Area, Project 52-P5 and at: http://intranet.unep.org/PDF/52-P5%20Project%20document%20and%20Budget%20SIGNED.pdf

Society of Environmental Toxicology and Chemistry

The Society of Environmental Toxicology and Chemistry (SETAC) recently published a 'Call for Research' (Wenning et al., 2010) which emphasized the importance of the effects of climate change on contaminants, including POPs, to support regulatory decisions. The authors called for the employment of 'broader frameworks to prevent myopic views of environmental issues' as climate change is now a global environmental threat that will impact on all ecosystems in the years to come. SETAC has proposed specialized workshops of international experts to provide recommendations to regulatory agencies on short- and long-term measures for adaption to changing climatic conditions and to identify future research needs to fill data gaps.

Strategic Approach to International Chemicals Management

The Strategic Approach to International Chemicals Management (SAICM) provides a policy framework to promote chemical safety around the world. At the second session of the International Conference on Chemicals Management in Geneva, May 2009, mention was made that *"It was crucial, […], for the link between chemicals and climate change to be accentuated and for a global strategy on knowledge and information to be developed"* (UNEP, 2009). Also that, *"an international chemicals panel, along the lines of the Intergovernmental Panel on Climate Change, could be the answer to filling the gaps in scientific knowledge for politicians and legislators and to enabling them to intensify their efforts to achieve global sustainable chemicals management"* (see www.saicm.org).

Arctic Council

The Arctic Council (www.arctic-council.org) is a high level forum for intergovernmental cooperation and coordination among the eight Arctic States, with the involvement of the Arctic indigenous peoples. The Arctic Monitoring and Assessment Programme (AMAP) is the group under the Arctic Council that is responsible for ongoing assessment of pollution and climate change issues in the Arctic. AMAP also coordinates the circumpolar program to monitor levels, trends and effects of long-range transported contaminants (including POPs) and climate change and its impacts. AMAP assessments have documented the challenges for environmental protection and sustainable development in the Arctic created by long-range transported pollutants and climate change. On the basis of information provided by AMAP, the Arctic Council (2002, 2009) has recognized the need for further understanding of the combined effects of POPs and other environmental stressors, including climate change, on human health and the environment in the Arctic. AMAP has a number of expert groups on climate change and POPs that produce assessments for the Arctic Council and contribute scientific information to organizations including the Stockholm Convention and the Intergovernmental Panel on Climate Change. Several experts from this network of AMAP scientists have been involved in the production of this report.

International POPs Elimination Network

The International POPs Elimination Network (IPEN), a public interest network of 700 organizations in 100 countries has invested in and conducted chemical monitoring activities related to POPs and other chemicals of concern since 2004. IPEN has focused on generating analytical data in developing countries and countries with economies in transition in order to assist the assessment and environmentally sound management of chemicals in those countries. Initiatives have included monitoring human breast milk for POPs in several continents and the monitoring of POPs in chicken eggs in 17 countries. IPEN's monitoring and assessment of POPs was linked to current waste management practices (including incineration) in those countries which did not adequately address co-benefits related to reductions in GHGs and unintentionally produced POPs, all of which are part of the environmentally sound management of chemicals.

References

Acevedo-Whitehouse, K. and A.L.J. Duffus, 2009. Effects of environmental change on wildlife health. Philosophical Transactions of the Royal Society B, 364:3429-3438.

ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press.

Adler, T., 2003. Aging research – the future face of environmental health. Environmental Health Perspectives, 111(14):A761-765.

Alveblom, A.K., L. Rylander, O. Johnell and L. Hagmar L, 2003. Incidence of hospitalized osteoporotic fractures in cohorts with high dietary intake of persistent organochlorine compounds. International Archives of Occupational and Environmental Health, 76(3):246-248.

AMAP, 2002. Sources and pathways of persistent organic pollutants. In: AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic, pp. 5-20. Arctic Monitoring and Assessment Program (AMAP), Oslo, Norway.

AMAP, 2003. AMAP Assessment 2002: Human Health in the Arctic. Arctic Monitoring and Assessment Program (AMAP), Oslo, Norway. xiv + 137 pp.

AMAP, 2009. AMAP Assessment 2009: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xvii + 254 pp.

Anderson, J.M. and m.R. Peterson, 1969. DDT - Sublethal effects on brook trout nervous system. Science, 164:440-442.

Antoine, D., A. Morel, H.R. Gordon, V.F. Banzon and R.H. Evans, 2005. Bridging ocean color observations of the 1980s and 2000s in search of long-term trends. Journal of Geophysical Research, 110. C06009, doi:10.1029/2004JC002620.

Arctic Council, 2002. Inari Declaration – On the occasion of the Third Ministerial Meeting of The Arctic Council. http://arctic-council.org/filearchive/inari_Declaration.pdf.

Arctic Council. 2009. Tromsø Declaration – On the occasion of the Sixth Ministerial Meeting of The Arctic Council. http://arctic-council.org/filearchive/Tromsoe%20Declaration-1.pdf

ATSDR, 2010. Toxicity Profiles. Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services, Atlanta, GA http://www.atsdr.cdc.gov/toxprofiles/index.asp

Bard, S.M., 1999. Global transport of anthropogenic contaminants and the consequences for the Arctic marine ecosystem. Marine Pollution Bulletin, 38:356-379.

Becker, S., C.J. Hallsall, W. Tych, R. Kallenborn, Y. Su and H. Hung, 2008. Long-term trends in atmospheric concentrations of α- and γ-HCH in the Arctic provide insight into the effects of legislation and climatic fluctuations on contaminant levels. Atmospheric Environment, 42(35): 8225-8233.

Behrenfeld, M.J., R.T. O'Malley, D.A. Siegel, C.R. McClain, J.L. Sarmiento, G.C. Feldman, A.J. Milligan, P.G. Falkowski, R.M. Letelier and E.S. Boss, 2006. Climate-driven trends in contemporary ocean productivity. Nature, 444:752-755.

Bellamy, P.H., P.J. Loveland, R.I. Bradley, R.M. Lark and G.J.D. Kirk, 2005. Carbon losses from all soils across England and Wales 1978-2003. Nature, 437:245-248.

Blais, J.M., D.W. Schindler, D.C.G. Muir, M. Sharp, D. Donald, M. Lafrenière, E. Braekevelt and W.M.J. Strachan, 2001. Melting glaciers: A major source of persistent organochlorines to subalpine Bow Lake in Banff National Park, Canada. Ambio, 30:410-415.

Blais, J.M., L.E. Kimpe, D. McMahon, B.E. Keatley, M.L. Mattory, M.S.V. Douglas and J.P. Smol, 2005. Arctic seabirds transport marine-derived contaminants. Science, 309:445-445.

Blais, J.M., R.W. Macdonald, D. Mackey, E. Webster, C. Harvey and J.P. Smol, 2007. Biologically mediated transport of contaminants to aquatic systems. Environmental Science and Technology, 41:1075-1084.

Blaustein, A.R., J.M. Romansic, J.M. Kiesecker and A.C. Hatch, 2003. Ultraviolet radiation, toxic chemicals and amphibian population declines. Diversity and Distributions, 9:123-140.

Bogdal, C., P. Schmid, M. Zennegg, F.S. Anselmetti, M. Scheringer and K. Hungerbühler, 2009. Blast from the past: Melting glaciers as a relevant source for persistent organic pollutants. Environmental Science and Technology, 43:8173-8177.

Bohlin, P., K.C. Jones, H. Tovalin and B. Strandberg, 2008. Observations on persistent organic pollutants in indoor and outdoor air using passive polyurethane foam samplers. Atmospheric Environment, 42:7234-7241.

Bohmer, S., W. Carroll, E. Fiani, H. Hartenstein, U. Karl, P. Finlay and S. Richter, 2009. Benefits and trade-offs between energy conservation and releases of unintentionally produced persistent pollutants. A report prepared on the behalf of the Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF), Geneva, Switzerland.

Bonefeld-Jorgensen, E.C and P. Ayotte, 2003. Toxic properties of persistent organic pollutants and related health effects of concern for Arctic populations. In: AMAP Assessment 2002: Human Health in the Arctic, pp 57-74. Arctic Monitoring and Assessment Program, Oslo, Norway.

Borgå, K., T.M. Saloranta and A. Ruus, 2010. Simulating climate change-induced alterations in bioaccumulation of organic contaminants in an Arctic marine food web. Environmental Toxicology and Chemistry, 29:1349-1357.

Boyce, D.G., M.R. Lewis and B. Worm, 2010. Global phytoplankton decline over the past century. Nature, 466:591-596.

Brander, K., 2010. Impacts of climate change on fisheries. Journal of Marine Systems, 79:389-402.

Breivik, K., A. Sweetman, J.M. Pacyna and K.C. Jones, 2002. Towards a global historical emission inventory for selected PCB congeners – a mass balance approach. 2. Emissions. Science of the Total Environment, 290:199-224.

Brian, J.V., N. Beresford, J. Walker, G. Pojana, A. Fantinati, A. Marcomini and J.P. Sumpter, 2009. Hypoxia does not influence the response of fish to a mixture of estrogenic chemicals. Environmental Science and Technology, 43:214-218.

Brook, R.K. and E.S. Richardson, 2002. Observations of polar bear predatory behaviour toward caribou. Arctic, 55:193-196.

Buchwalter, D.B., J.J. Jenkins and L.R. Curtis, 2003. Temperature influences on water permeability and chlorpyrifos uptake in aquatic insects with differing respiratory strategies. Environmental Toxicology and Chemistry, 22:2806-2812.

Buckman, A.H., S.B. Brown, J. Small, D.C.G. Muir, J. Parrott, K.R. Solomon and A.T. Fisk, 2007. Role of temperature and enzyme induction in the biotransformation of polychlorinated biphenyls and bioformation of hydroxylated polychlorinated biphenyls by rainbow trout (*Oncorhynchus mykiss*). Environmental Science and Technology, 41:3856-3863.

Burgoa, B. and R.D. Wauchope, 1995. Pesticides in run-off and surface waters. Environmental behaviour of agrochemicals. John Wiley & Sons Ltd.

Burkow, I.C. and J.-P. Weber, 2003. Priority contaminants, 'new' toxic substances and analytical issues. In: AMAP Assessment 2002: Human Health in the Arctic, pp. 21-30. Arctic Monitoring and Assessment Programme, Oslo, Norway.

Bustnes, J.O., P. Fauchald, T. Tveraa, A. Helberg and J.U. Skaare, 2008. The potential impact of environmental variation on the concentrations and ecological effects of pollutants in a marine avian top predator. Environment International, 34:193-201.

Campfens, J. and D. Mackay, 1997. Fugacity-based model of PCB bioaccumulation in complex aquatic food webs. Environmental Science and Technology, 31:577-583.

Canaris, G.J., N.R. Manowitz, G. Mayor and E.C. Ridgway, 2000. The Colorado thyroid disease prevalence study. Archives of Internal Medicine, 160(4):526-534.

Capkin, E., I. Altinok and S. Karahan, 2006. Water quality and fish size affect toxicity of endosulfan, an organochlorine pesticide, to rainbow trout. Chemosphere, 64:1793-1800.

Carlson, D.L. and R.A. Hites, 2005. Polychlorinated biphenyls in salmon and salmon feed: Global differences and bioaccumulation. Environmental Science and Technology, 39:7389-7395.

Carrie, J., F. Wang, H. Sanei, R.W. Macdonald, P.M. Outridge and G.A. Stern, 2010. Increasing contaminant burdens in an Arctic fish, burbot (*Lota lota*), in a warming climate. Environmental Science and Technology, 44:316-322.

Chan, H.M., 1998. A database for environmental contaminants in traditional foods in northern and Arctic Canada development and applications. Food Additives and Contaminants, 15:127-134.

Cherry, S.G., A.E. Derocher, I. Stirling and E.S. Richardson, 2009. Fasting physiology of polar bears in relation to environmental change and breeding behavior in the Beaufort Sea. Polar Biology, 32:383-391.

Clark, K.E., F.A.P.C. Gobas and D. Mackay, 1990. Model of organic chemical uptake and clearance by fish from food and water. Environmental Science and Technology, 24:1203-1213.

Colborn, T., 1995. Environmental estrogens - health implications for humans and wildlife. Environmental Health Perspectives, 103:135-136.

Colborn, T., F.S.V. Saal and A.M. Soto, 1993. Developmental effects of endocrine-disrupting chemicals in wildlife and humans. Environmental Health Perspectives, 101:378-384.

Corsolini, S., 2009. Industrial contaminants in Antarctic biota. Journal of Chromatography A, 1216:598-612.

Côté, S., P. Ayotte, S. Dodin, C. Blanchet, G. Mulvad, H.S. Petersen, S. Gingras and E. Dewailly, 2006. Plasma organochlorine concentrations and bone ultrasound measurements: a cross-sectional study in peri- and postmenopausal Inuit women from Greenland. Environmental Health, 5:33.

Couillard, C.M., S.C. Courtenay and R.W. Macdonald, 2008. Chemical-environment interactions affecting the risk impacts on aquatic organisms: A review with a Canadian perspective – interactions affecting vulnerability. Environmental Reviews, 16:19-44.

CPCHE, 2005. Child Health and the Environment: A Primer. Canadian Partnership for Children's Health and Environment. http://www.healthyenvironmentforkids.ca/collections-cpche

Daam, M.A. and P. van der Brinck, 2010. Implications of differences between temperate and tropical ecosystems for the ecological risk assessment of pesticides. Ecotoxicology, 19:24-37.

DeLorenzo, M., S.C. Wallace, L.E. Danese and T.D. Baird, 2009.Temperature and salinity effects on the toxicity of common pesticides to the grass shrimp, *Palaemonetes pugio*. Journal of Environmental Science and Health B, 44:455-460.

Derocher, A.E., H. Wolkers, T. Colborn, M. Schlabach, T.S. Larsen and O. Wiig, 2003. Contaminants in Svalbard polar bear samples archived since 1967 and possible population level effects. Science of the Total Environment, 301:163-174.

Dewailly, E., and P. Weihe, 2003. The effects of Arctic pollution on population health. In: AMAP Assessment 2002: Human Health in the Arctic, pp. 95-105. Arctic Monitoring and Assessment Programme, Oslo, Norway.

Diaz, R.J. and R. Rosenberg, 1995. Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. Oceanography and Marine Biology: An Annual Review, 33:245-303.

Diaz, R.J. and R. Rosenberg, 2001. Overview of anthropogenically-induced hypoxic effects on marine benthic fauna. In: Rabalais, N.N. and R.E. Turner (Eds.). Coastal Hypoxia: Consequences for Living Resources and Ecosystems, pp. 129-146. Coastal and Estuarine Studies No. 58.

Doll, C.N.H., J.P. Muller and J.G. Morley, 2006. Mapping regional economic activity from night-time light satellite imagery. Ecological Economics, 57:75-92.

EC, 2006a. Large Combustion Plants. Integrated pollution prevention and control. Reference document on best available techniques for large combustion plants. July 2006. European Commission, http://eippcb.jrc.es/reference/

EC, 2006b. Waste Incineration. Integrated pollution prevention and control. Reference document on best available techniques for waste incineration. August 2006. European Commission, http://eippcb.jrc.es/reference/

EEA, 2006. Air quality and ancillary benefits of climate change policies. Technical Report No. 4/2006, European Environment Agency.

EEA, 2007. THE EMEP/CORINAIR Atmospheric Emission Inventory Guidebook, European Environment Agency.

EU, 2010. Evaluation of Persistent, Bioaccumulative and Toxic (PBT). European Commission, Joint Research centre, Institute for Health and Consumer Protection. February 2010. http://ecb.jrc.ec.europa.eu/documentation/

Feely, R.A., C.L. Sabine, K. Lee, W. Berelson, J. Kleypas, V.J. Fabry and F.J. Millero, 2004. Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. Science, 305:362-366.
Florence, T.M., G.M. Morrison and J.L. Stauber, 1992. Determination of trace-element speciation and the role of speciation in aquatic toxicity. Science of the Total Environment, 125:1-13.
Flynn, A., C. McGreevy and E.C. Mulkerrin, 2005. Why do older patients die in a heatwave? Quarterly Journal of Medicine, 98(11):227-229.
Forster, P., V. Ramaswamy, P. Artaxo and 48 others, 2007. Changes in Atmospheric Constituents and in Radiative Forcing. Cambridge University Press.
Gao, H., J. Ma, Z. Cao, A. Dove and L. Zhang, 2010. Trend and climate signals in seasonal air concentration of organochlorine pesticides over the Great Lakes. Journal of Geophysical Research, doi:10.1029/2009JD013627.
Gaunt, P. and S.A. Barker, 2000. Matrix solid phase dispersion extraction of triazines from catfish tissues; examination of the effects of temperature and dissolved oxygen on the toxicity of atrazine. International Journal of Environment and Pollution, 13:284-312.
Geisz, H.N., R.M. Dickhut, M.A. Cochran, W.R. Fraser and H.W. Ducklow, 2008. Melting glaciers: A probable source of DDT to the Antarctic marine ecosystem. Environmental Science and Technology, 42:3958-3962.
Gilman, A.P., 2003. Risk reduction strategies for Arctic peoples. In: AMAP Assessment 2002: Human Health in the Arctic, pp 106-113. Arctic Monitoring and Assessment Programme, Oslo, Norway.
Gilman, A., J. Berner, S. Donaldson, A.A. Dudarev, H.S. Pedersen and J.Ø Odland, 2009a. Factors influencing human exposure to contaminants and population vulnerability. In: AMAP Assessment 2009: Human Health in the Arctic, pp. 9-20. Arctic Monitoring and Assessment Programme, Oslo, Norway.
Gilman, A., P. Ayotte, J. Berner, E. Dewailly, A. Dudarev, E. Bonefeld-Jorgensen, G. Muckle, J. Odland and C. Tikhonov, 2009b. Public health and the effects of contaminants. In: AMAP Assessment 2009: Human Health in the Arctic, pp. 143-190. Arctic Monitoring and Assessment Programme, Oslo, Norway.
Gioia, L., E. Steinnes, G.O. Thomas, S.N. Meijer and K.C. Jones, 2006. Persistent organic pollutants in European background air: derivation of temporal and latitudinal trends. Journal of Environmental Monitoring, 8:700-710.
Gobas, F.A.P.C. and H.A. Morrison, 2000. Bioconcentration and biomagnification in the aquatic environment. In: Boethling, R.S. and D. Mackay (Eds.). Handbook of Property Estimation Methods for Chemicals, pp. 189-232. LEWIS, Florida.
Gobas, F.A.P.C., X. Zhang and R. Wells, 1993. Gastrointestinal magnification: the mechanism of biomagnification and food chain accumulation of organic chemicals. Environmental Science and Technology, 27:2855-2863.
Gouin, T., T. Harner, P. Blanchard and D. Mackay, 2005. Passive and active air samplers as complementary methods for investigating persistent organic pollutants in the Great Lakes Basin. Environmental Science and Technology, 39:9115-9122.
Granberg, M.E. and H. Selck, 2007. Effects of sediment organic matter quality on bioaccumulation, degradation, and distribution of pyrene in two macrofaunal species and their surrounding sediment. Marine Environmental Research, 64:313-335.
Gregg, W.W. and M.E. Conkright, 2002. Decadal changes in global ocean chlorophyll. Geophysical Research Letters, 29: 10.1029/2002GL014689.
Gregg, W.W., N.W. Casey and C.R. McClain, 2005. Recent trends in global ocean chlorophyll. Geophysical Research Letters, 32: doi:10.1029/2004GL021808.
Guthrie, F.E., 1950. Effect of temperature on toxicity of certain organic insecticides. Journal of Economic Entomology, 43:559-560.
Haave, M., E. Ropstad, A.E. Derocher, E. Lie, E. Dahl, O. Wiig, J.U. Skaare and B.M. Jenssen, 2003. Polychlorinated biphenyls and reproductive hormones in female polar bears at Svalbard. Environmental Health Perspectives, 111:431-436.
Hansen, J.C., A. P. Gilman, V. Klopov and J. O. Odland, 1998. Pollution and human health. In: AMAP Assessment Report: Arctic Pollution Issues, pp. 775-844. Arctic Monitoring and Assessment Programme, Oslo, Norway.
Hansen, G.H., R. Kallenborn, H. Kylin, S. Eckhardt, J. Burkhard, A. Stohl, D. Hirdman, H. Sodemann and V. Pavlov, 2009. NORACIA: Impact of climate change on transport and distribution of persistent organic pollutants (POPs) in the Arctic environment. Norwegian Institute of Air Research (NILU) Report.
Harley, C.D.G., A.R. Hughes, K.M. Hultgren, B.G. Miner, C.J.B. Sorte, C.S. Thornber, L.F. Rodriguez, L. Tomanek and S.L. Williams, 2006. The impacts of climate change in coastal marine system. Ecological Letters, 9:228-241.
Harley, K.G., A.R. Marks, J. Chevrier, A. Bradman, A. Sjödin and B. Eskenazi, 2010. PBDE concentrations in women's serum and fecundability. Environmental Health Perspectives, 118:699-704.
Harvell, C.D., C.E. Mitchell, J.R. Ward, S. Altizer, A.P. Dobson, R.S. Ostfeld and M.D. Samuel, 2002. Ecology - Climate warming and disease risks for terrestrial and marine biota. Science, 296:2158-2162.
Haugan, G. and H. Drange, 1996. Effects of CO_2 on the ocean environment. Energy Conversion and Management, 37:1019-1022.
Hebert, C.E., J.L. Shutt and R.J. Norstrom, 1997. Dietary changes cause temporal fluctuations in polychlorinated biphenyl levels in herring gull eggs from Lake Ontario. Environmental Science and Technology, 31:1012-1017.
Henson, S.A., J.L. Sarmiento, J.P. Dunne, L. Bopp, I. Lima, S.C. Doney, J. John and C. Beaulieu, 2010. Detection of anthropogenic climate change in satellite records of ocean chlorophyll and productivity. Biogeosciences, 7:621-640.
Heugens, E.H.W., A.J. Hendriks, T. Dekker, N.M. van Straalen and W. Admiraal, 2002. A review of the effects of multiple stressors on aquatic organisms and analysis of uncertainty factors for use in risk assessment. Critical Reviews in Toxicology, 31:247-284.
Hites, R.A., 2004. Polybrominated diphenyl ethers in the environment and in people: A meta-analysis of concentrations. Environmental Science and Technology, 38:945-956.
Hoegh-Guldberg, O. and J.F. Bruno, 2010. The impact of climate change on the world's marine ecosystems. Science, 328:1523-1528.
Hoerling, M.P., J.W. Hurrell and T.Y. Xu, 2001. Tropical origins for recent North Atlantic climate change. Science, 292:90-92.

Holoubek, I., J. Klanova, J. Jarkovsky and J. Kohoutek, 2007. Trends in background levels of persistent organic pollutants at Kosetice observatory, Czech Republic. Part I. Ambient air and wet deposition 1996-2005. Journal of Environmental Monitoring, 9:557-563.

Hood, E., 2003. Toward a new understanding on aging. Environmental Health Perspectives, 111(14): A756–A759.

Hung, H., R. Kallenborn, K. Breivik and 12 others, 2010. Atmospheric monitoring of organic pollutants in the Arctic under the Arctic Monitoring and Assessment Programme (AMAP): 1993-2006. Science of the Total Environment, 408:2854-2873.

Huovinen, P.S., M.R. Soimasu and A.O.J. Oikar, 2001. Photoinduced toxicity of retene to *Daphnia magna* under enhanced UV-B radiation. Chemosphere, 45:683-691.

IARC, 1987. Monograph on the evaluations of carcinogenicity: An update of IARC Monograph Vols. 1-42, Suppl. 7. World Health Organization, International Agency for Research in Cancer.

IPCC, 2007. Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCS, 2010. Environmental Health Criteria. International Program on Chemical Safety, World Health Organization. http://www.who.int/ipcs/assessment/en/

Jantunen, L.M., P.A. Helm, H. Kylin and T.F. Bidleman, 2008. Hexachlorocyclohexanes (HCHs) In the Canadian Archipelago. 2. Air-water gas exchange of α- and γ-HCH. Environmental Science and Technology. 42:465-470.

Jaward, F.M., N.J. Farrar, T. Harner, A.J. Sweetman and K.C. Jones, 2004. Passive air sampling of PCBs, PBDEs, and organochlorine pesticides across Europe. Environmental Science and Technology, 38:34-41.

Jenssen, B.M., 2006. Endocrine-disrupting chemicals and climate change: A worst-case combination for arctic marine mammals and seabirds? Environmental Health Perspectives, 114:76-80.

Johnson-Restrepo, B. and K. Kannan, 2009. An assessment of sources and pathways of human exposure to polybrominated diphenyl ethers in the United States. Chemosphere, 76:542-548.

Jurado, E., F.M. Jaward, R. Lohmann, K.C. Jones, R. Simo and J. Dachs, 2004. Atmospheric dry deposition of persistent organic pollutants to the Atlantic and inferences for the global oceans. Environmental Science and Technology, 38:5505-5513.

Jurado, E., F. Jaward, R. Lohmann, K.C. Jones, R. Simo and J. Dachs, 2005. Wet deposition of persistent organic pollutants to the global oceans. Environmental Science and Technology, 39:2426-2435.

Kalantzi, O.I., R.E. Alcock, P.A. Johnston, D. Santillo, R.L. Stringer, G.O. Thomas and K.C. Jones, 2001. The global distribution of PCBs and organochlorine pesticides in butter. Environmental Science and Technology, 35:1013-1018.

Kelly, B.C., F.A.P.C. Gobas and M.S. McLachlan, 2004. Intestinal absorption and biomagnification of organic contaminants in fish, wildlife, and humans. Environmental Toxicology and Chemistry, 23:2324-2336.

Kim, J., J. Park, P.G. Kim, C. Lee and K. Choi, 2010. Implication of global environmental changes on chemical toxicity-effect of water temperature, pH, and ultraviolet B irradiation on acute toxicity of several pharmaceuticals in *Daphnia magna.* Ecotoxicology, 19:662-669.

Krümmel, E.M., R.W. Macdonald, L.E. Kimpe, I. Gregory-Eaves, M.J. Demers, J.P. Smol, B. Finney and J.M. Blais, 2003. Delivery of pollutants by spawning salmon: Fish dump toxic industrial compounds in Alaskan lakes on their return from the ocean. Nature, 425:255-256.

Kwok, K.W.H., K.M.Y. Leung, V.K.H. Chu, P.K.S. Lam, D. Morritt, L. Maltby, T.CM. Brock, P.J. Van den Brink, MStJ Warne, M. Crane, 2007. Comparison of tropical and temperate freshwater species' sensitivities to chemicals: implications for deriving safe extrapolation factors. Integrated Environmental Assessment and Management, 3:49-67.

Lamon, L., H. von Waldow, M. MacLeod, M. Scheringer, A. Marcomini and K. Hungerbuhler, 2009. Modeling the global levels and distribution of polychlorinated biphenyls in air under a climate change scenario. Environmental Science and Technology, 43: 5818-5824.

Landrigan, P.J., B. Sonawane, R.N. Butler, L. Trasande, R. Callan and D. Droller, 2005. Early environmental origins of neurodegenerative disease in later life. Environmental Health Perspectives, 113(9):1230-1233.

Letcher, R.J., J.O. Bustnes, R. Dietz, B.M. Jenssen, E.H. Jørgensen, C. Sonne, J. Verreault, M.M. Vijayan and G.W. Gabrielsen, 2010. Exposure and effects assessment of persistent organohalogen contaminants in arctic wildlife and fish. Science of the Total Environment, 408:2995-3043.

Li, Y.F., 1999. Global gridded technical hexachlorocyclohexane usage inventories using a global cropland as a surrogate. Journal of Geophysical Research, 104:23785-23797.

Li, Y-F., T. Harner, L. Liu, Z. Zhang, N.-Q. Ren, H. Jia, J. Ma and E. Sverko, 2010. Polychlorinated biphenyls in global air and surface soil: distributions, air-soil exchange and fractionation effect. Environmental Science and Technology, 44:2784-2790.

Longnecker, M.P. and J.L. Daniels, 2001. Environmental contaminants as etiologic factors for diabetes. Environmental Health Perspectives, 109(S6):871-876.

Longnecker, M.P., M.A. Klebanoff, J.W. Brock and H. Zhou, 2001. Polychlorinated biphenyl serum levels in pregnant subjects with diabetes. Diabetes Care, 24:1099-1101.

Lorber, M., 2008. Exposure of Americans to polybrominated diphenyl ethers. Journal of Exposure Science and Environmental Epidemiology, 18:2-19.

Lougheed, T., 2010. The changing landscape of Arctic traditional food. Environmental Health Perspectives, 118(9):387-393.

Lovejoy, T.E. and L. Hannah, 2005. Climate Change and Biodiversity. Yale University Press.

Lydy, M.J., J.B. Belden and M.A. Ternes, 1999. Effects of temperature on the toxicity of m-parathion, chlorpyrifos, and pentachlorobenzene to *Chironomus tentans*. Archives of Environmental Contamination and Toxicology, 37:542-547.

Ma, J., H. Hung and P. Blanchard, 2004a. How do climate fluctuations affect persistent organic pollutant distribution in North America? Evidence from a decade of air monitoring. Environmental Science and Technology, 38:2538-2543.

Ma, J.M., Z.H. Cao and H. Hung, 2004b. North Atlantic Oscillation signatures in the atmospheric concentrations of persistent organic pollutants: An analysis using Integrated Atmospheric Deposition Network-Great Lakes monitoring data. Journal of Geophysical Research, 109: D12305. doi:10.1029/2003JD004435

Macdonald, R.W., L.A. Barrie, T.F. Bidleman and 26 others, 2000. Contaminants in the Canadian Arctic: 5 years of progress in understanding sources, occurrence and pathways. Science of the Total Environment, 254:93-234.

Macdonald, R.W., D. Mackay, Y.F. Li and B. Hickie, 2003. How will global climate change affect risks from long-range transport of persistent organic pollutants? Human and Ecological Risk Assessment 9, 643-660.

Macdonald, R.W., T. Harner and J. Fyfe, 2005. Recent climate change in the Arctic and its impact on contaminant pathways and interpretation of temporal trend data. Science of the Total Environment, 342:5-86.

Mackay, D. and A. Fraser, 2000. Bioaccumulation of persistent organic chemicals: mechanisms and models. Environmental Pollution, 110:375-391.

MacLeod, M., W.J. Riley and T.E. Mckone, 2005. Assessing the influence of climate variability on atmospheric concentrations of polychlorinated biphenyls using a Global-Scale Mass Balance Model (BETR-Global). Environmental Science and Technology, 39:6749-6756.

Majkova, Z., E. Oesterling, M. Toborek and B. Hennig, 2008. Impact of nutrition on PCB toxicity. Environmental Toxicology and Pharmacology, 25:192-196.

Marubini, F. and M.J. Atkinson, 1999. Effects of lowered pH and elevated nitrate on coral calcification. Marine Ecology Progress Series, 188:117-121.

Maruya, K.A., K.L. Smalling and W. Vetter, 2005. Temperature and congener structure affect the enantioselectivity of toxaphene elimination by fish. Environmental Science and Technology, 39:3999-4004.

Masoro, E.J. and J.B. Schwartz, 2001. Exploration of aging and toxic response issues: Final Report. Prepared for Risk Assessment Forum, US Environmental Protection Agency, by Versar, Inc. www.epa.gov/raf/publications/pdfs/aging_internet.PDF

Matson, C.W., A.R. Timme-Laragy and R.T. Di Giulio, 2008. Fluoranthene, but not benzo[*a*]pyrene, interacts with hypoxia resulting in pericardial effusion and lordosis in developing zebrafish. Chemosphere, 74:149-154.

McKinney, M.A., E. Peacock and R. Letcher, 2009. Sea ice-associated diet change increases the levels of chlorinated and brominated contaminants in polar bears. Environmental Science and Technology, 43:4334-4339.

McKinney, M.A., I. Stirling, N.J. Lunn, E. Peacock and R.J. Letcher, 2010. The role of diet on long-term concentration and pattern trends of brominated and chlorinated contaminants in western Hudson Bay polar bears, 1991–2007. Science of the Total Environment, 408:6210-6222.

Meijer, S.N., W.A. Ockenden, E. Steinnes, B.P. Corrigan and K.C. Jones, 2003. Spatial and temporal trends of POPs in Norwegian and UK background air: Implications for global cycling. Environmental Science and Technology, 37:454-461.

Miller, D.L. and D.M. Ogilvie, 1975. Temperature selection in brook trout (*Salvelinus fontinalis*) following exposure to DDT, PCB or phenol. Bulletin of Environmental Contamination and Toxicology, 14:545-551.

Moore, S.E., 2008. Marine mammals as ecosystem sentinels. Journal of Mammalogy, 89:534-540.

Moore, S.E. and H.P. Huntington, 2008. Arctic marine mammals and climate change: Impacts and resilience. Ecological Applications, 18:S157-S165.

Muir, D., B. Braune, B. DeMarch, R. Norstrom, R. Wagemann, L. Lockhart, B. Hargrave, D. Bright, R. Addison, J. Payne and K. Reimer, 1999. Spatial and temporal trends and effects of contaminants in the Canadian Arctic marine ecosystem: a review. Science of the Total Environment, 230:83-144.

Multigner, L., J.R. Ndong, A. Giusti, M. Romana, H. Delacroix-Maillard, S. Cordier, B. Jégou, J.P. Thome and P. Blanchet, 2010. Chlordecone exposure and risk of prostate cancer. Journal of Clinical Oncology, 28:3457-3462.

Narahashi, T., 2000. Neuroreceptors and ion channels as the basis for drug action: Past, present, and future. Journal of Pharmacology and Experimental Therapeutics, 294:1-26.

Nemet, G.F., T. Holloway and P. Meier, 2010. Implications of incorporating air quality co-benefits into climate change policymaking. Environmental Research Letters, 5:014007-014016.

Nizzetto, L., M. MacLeod, K. Borgå and 16 others, 2010. Past, present, and future controls on levels of persistent organic pollutants in the global environment. Environmental Science and Technology, 44:6526-6531.

Noyes, P.D., M.K. McElwee, H.D. Miller, B.W. Clark, L.A. Van Tiem, K.C. Walcott, K.N. Erwin and E.D. Levin, 2009. The toxicology of climate change: Environmental contaminants in a warming world. Environment International, 35:971-986.

Occhipinti-Ambrogi, A., 2007. Global change and marine communities: Alien species and climate change. Marine Pollution Bulletin, 55:342-352.

Odland, J.O., A. Carlsen, S. Donaldson, A. Dudarev, C. Furgal and P. Weihe, 2009. Risk communication. In: AMAP Assessment 2009: Human Health in the Arctic, pp. 191-204. Arctic Monitoring and Assessment Programme, Oslo, Norway.

OECD, 2008. CO_2 emissions from fuel combustion. International Energy Agency (IEA), Organization for Economic Cooperation and Development, OECD Publishing.

Oskam, I.C., E. Ropstad, E. Dahl, E. Lie, A.E. Derocher, O. Wiig, S. Larsen, R. Wiger and J.U. Skaare, 2003. Organochlorines affect the major androgenic hormone, testosterone, in male polar bears (*Ursus maritimus*) at Svalbard. Journal of Toxicology and Environmental Health, 66:2119-2139.

Parker, B.R., R.D. Vinebrooke and D.W. Schindler, 2008. Recent climate extremes alter alpine lake ecosystems. Proceedings of the National Academy of Sciences USA, 105:12927-12931.

Paterson, G., K.G. Drouillard and G.D. Haffner, 2007. PCB elimination by yellow perch (*Perca flavescens*) during an annual temperature cycle. Environmental Science and Technology, 41:824-829.

Patra, R.W., J.C. Chapman, R.P. Lim and P.C. Gehrke, 2007. The effects of three organic chemicals on the upper thermal tolerances of four freshwater fishes. Environmental Toxicology and Chemistry, 26:1454-1459.

Pavlov, V., 2007. Modelling of long-range transport of contaminants from potential sources in the Arctic Ocean by water and sea ice. In: Orbaek, J.B., T. Tombre, R. Kallenborn, E. Hegseth, S. Falk-Petersen and A.H. Hoel (Eds.). Arctic-Alpine Ecosystems and People in a Changing Environment, pp. 329-350. Springer Verlag.

Pavlov, V.K. and O.A. Pavlova, 2008. Sea ice drifts in the Arctic Ocean. Seasonal variability and long-term changes. In: Tewles, K.B. (Ed.), Pacific and Arctic Oceans: New Oceanographic Research, pp. 157-186. NOVA Science Publishers, Inc. Series: Arctic Region and Antarctica Issues and Research.

Peltonen, H., M. Kiljunen, H. Kiviranta, P.J. Vuorinen, M. Verta and J. Karjalainen, 2007. Predicting effects of exploitation rate on weight-at-age, population dynamics, and bioaccumulation of PCDD/Fs and PCBs in herring (*Clupea harengus* L.) in the Northern Baltic Sea. Environmental Science and Technology, 41:1849-1855.

Pörtner, H.O. and R. Knust, 2007. Climate change affects marine fishes through the oxygen limitation of thermal tolerance. Science, 315:95-97.

Powell, J.H. and D.R. Fielder, 1982. Temperature and toxicity of DDT to sea mullet (*Mugil-cephalus* L). Marine Pollution Bulletin, 13:228-230.

Pozo, K., T. Harner, F. Wania, D.C.G. Muir, K.C. Jones and L.A. Barrie, 2006. Toward a global network for persistent organic pollutants in air: Results from the GAPS study. Environmental Science and Technology, 40:4867-4873.

Presley, S.M., T.R. Rainwater, G.P. Austin, S.G. Platt, J.C. Zak, G.P. Cobb, E.J. Marsland, K. Tian, B. Zhang, T.A. Anderson, S.B. Cox, M.T. Abel, B.D. Leftwich, J.R. Huddleston, R.M. Jeter and R.J. Kendall, 2005. Assessment of pathogens and toxicants in New Orleans, LA following hurricane Katrina. Environmental Science and Technology, 40:468-474.

Prins, G.S., 2008. Endocrine disruptors and prostate cancer risk. Endocrine-Related Cancer, 15(3):649-656.

Pulkrabova, J., M. Suchanova, M. Tomaniova, V. Kocourek and J. Hajslova, 2008. Organic pollutants in areas impacted by flooding in 2002: A 4-year survey. Bulletin of Environmental Contamination and Toxicology, 81:299-304.

Reynaud, S. and P. Deschaux, 2006. The effects of polycyclic aromatic hydrocarbons on the immune system of fish: A review. Aquatic Toxicology, 77:229-238.

Richardson, A.J. and D.S. Schoeman, 2004. Climate impact on plankton ecosystems in the Northeast Atlantic. Science, 305:1609-1612.

Rigét, F., A. Bignert, B. Braune, J. Stow and S. Wilson, 2010. Temporal trends of legacy POPs in Arctic biota, an update. Science of The Total Environment, 408:2874-2884.

Ritter, R., M. Scheringer, M. MacLeod, U. Schenker and K. Hungerbuhler, 2009. A Multi-individual pharmacokinetic model framework for interpreting time trends of persistent chemicals in human populations: Application to a postban situation. Environmental Health Perspectives, 117:1280-1286.

Ritter, R., M. Scheringer, M. MacLeod and K. Hungerbuhler, 2011. Assessment of non-occupational exposure to DDTs in the tropics and the north - Relevance of uptake via inhalation from indoor residual spraying. Environmental Health Perspectives. doi: 10.1289/ehp.1002542, http://dx.doi.org/10.1289/ehp.1002542

Rosenzweig, C. and M.L. Parry, 1994. Potential impact of climate-change on world food-supply. Nature, 367:133-138.

Ross, P., R. DeSwart, R. Addison, H. VanLoveren, J. Vos and A. Osterhaus, 1996. Contaminant-induced immunotoxicity in harbour seals: Wildlife at risk? Toxicology, 112:157-169.

Roze, E., L. Meijer, A. Bakker, K. Van Braeckel, P. Sauer and A. Bos, 2009. Prenatal exposure to organohalogens, including brominated flame retardants, influences motor, cognitive and behavioral performance at school age. Environmental Health Perspectives, 117:1953-1958.

Rylander, L., A. Rignell-Hydbom and L. Hagmar, 2005. A cross-sectional study of the association between persistent organochlorine pollutants and diabetes. Environmental Health, 4: 28.

Ryther, J.H. and C.S. Yentsch, 1957. The estimation of phytoplankton production in the ocean from chlorophyll and light data. Limnology and Oceanography, 2:281-286.

Satpute, N.S., S.D. Deshmukh, N.G.V. Rao, S.N. Tikar, M.P. Moharil and S.A. Nimbalkar, 2007. Temperature-dependent variation in toxicity of insecticides against *Earias vitella* (Lepidoptera: Noctuidae). Journal of Economic Entomology, 100:357-360.

Schecter, A., N. Shah, J.A. Colacino, S.I. Brummitt, V. Ramakrishnan, T.R. Harris and O. Papke, 2009. PBDEs in US and German clothes dryer lint: A potential source of indoor contamination and exposure. Chemosphere, 75:623-628.

Schenker, U., M. Scheringer and K. Hungerbuhler, 2007. Including degradation products of persistent organic pollutants in a global multi-media box model. Environmental Science and Pollution Research, 14:145-152.

Scheringer, M., 1997. Characterization of the environmental distribution behavior of organic chemicals by means of persistence and spatial range. Environmental Science and Technology, 31:2991-2897.

Schiedek, D., B. Sundelin, J.W. Readman and R.W. Macdonald, 2007. Interactions between climate change and contaminants. Marine Pollution Bulletin, 54:1845-1856.

Schindler, D.W. and J.P. Smol, 2006. Cumulative effects of climate warming and other human activities on freshwaters of Arctic and Subarctic North America. Ambio, 35:160-168.

Schrum, C., 2001. Regionalization of climate change for the North Sea and Baltic Sea. Climate Research, 18:31-37.

Schuster, J.K., R. Gioia, K. Breivik, E. Steinnes, M. Scheringer and K.C. Jones, 2010. Trends in European background air reflect reductions in primary emissions of PCBs and PBDEs. Environmental Science and Technology, 44:6760-6766.

Seibel, B.A. and P.J. Walsh, 2003. Biological impacts of deep-sea carbon dioxide injection inferred from indices of physiological performance. Journal of Experimental Biology, 206:641-650.

Silbergeld, E.K., 1973. Dieldrin - effects of chronic sublethal exposure on adaptation to thermal-stress in freshwater fish. Environmental Science and Technology, 7:846-849.

Simonich, S.L. and R.A. Hites, 1995. Global distribution of persistent organochlorine compounds. Science, 269:1851-1854.

Singh, P.P., A.S. Udeaan and S. Battu, 1992. DDT and HCH residues in indoor air arising from their use in malaria control programs. Science of the Total Environment, 116:83-92.

Solomon, G.M. and p.M. Weiss, 2002. Chemical contaminants in breast milk: Time trends and regional variability. Environmental Health Perspectives, 110:A339-A347.

Sowers, M., J. Luborsky, C. Perdue, K.L. Araujo, M.B. Goldman and S.D. Harlow, 2003. Thyroid stimulating hormone (TSH) concentrations and menopausal status in women at the mid-life: SWAN. Clinical Endocrinology (Oxford), 58:340-347.

Thomann, R.V., J.P. Connolly and T.F. Parkerton, 1992. An equilibrium model of organic chemical accumulation in aquatic food webs with sediment interaction. Environmental Toxicology and Chemistry, 11:615-629.

Tremolada, P., V. Burnett, D. Calamari and K.C. Jones, 1996. A study of the spatial distribution of PCBS in the UK atmosphere using pine needles. Chemosphere, 32:2189-2203.

Undeman, E., T.N. Brown, F. Wania and M.S. McLachlan, 2010. Susceptibility of human populations to environmental exposure to organic contaminants. Environmental Science and Technology, 44:6249-6255.

UNEP, 2005. General technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (POPS). Basel Convention Series. SBC Nr. 2005/1.

UNEP, 2009. Report of the International Conference on Chemicals Management on the work of its second session. Geneva, 11-15 May, 2009. www.saicm.org

Vaktskjold, A., B. Deutch, K. Skinner and S.G. Donaldson, 2009. Food, diet, nutrition and contaminants. In: AMAP Assessment 2009: Human Health in the Arctic, pp. 21-48. Arctic Monitoring and Assessment Programme, Oslo, Norway.

Van Oostdam, J. and S. Donaldson, 2009. Human tissue levels of environmental contaminants. In: AMAP Assessment 2009: Human Health in the Arctic, pp 61-110. Arctic Monitoring and Assessment Programme, Oslo, Norway.

Vasiliu, O., L. Cameron, J. Gardiner, P. Deguire and W. Karmaus, 2006. Polybrominated biphenyls, polychlorinated biphenyls, body weight, and incidence of adult-onset diabetes mellitus. Epidemiology, 17:352-359.

von Waldow, H., M. MacLeod, M. Scheringer and K. Hungerbuhler, 2010. Quantifying remoteness from emission sources of persistent organic pollutants on a global scale. Environmental Science and Technology, 44:2791-2796.

Vos, J.G., E. Dybing, H.A. Greim, O. Ladefoged, C. Lambre, J.V. Tarazona, I. Brandt and A.D. Vethaak, 2000. Health effects of endocrine-disrupting chemicals on wildlife, with special reference to the European situation. Critical Reviews in Toxicology, 30:71-133.

Walther, G.-R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg and F. Bairlein, 2002. Ecological responses to recent climate change. Nature, 416:389-395.

Wania, F. and M.S. McLachlan, 2001. Estimating the influence of forests on the overall fate of semivolatile organic compounds using a multimedia fate model. Environmental Science and Technology, 35:582-590.

Weber, K. and H. Goerke, 2003. Persistent organic pollutants (POPS) in antarctic fish: levels, patterns, changes. Chemosphere, 53:667-678.

Weber, R., C. Gaus, M. Tysklind and 20 others, 2008a. Dioxin- and POP-contaminated sites – contemporary and future relevance and challenges. Environmental Science and Pollution Research, 15:363-393.

Weber, R., M. Tysklind and C. Gaus, 2008b. Dioxin – contemporary and future challenges of historical legacies. Environmental Science and Pollution Research, 15:96-100.

Weisskopf, M.G., P. Knekt, E.J. O'Reilly, J. Lyytinen, A. Reunanen, F. Laden, L. Altshul and A. Ascherio, 2010. Persistent organochlorine pesticides in serum and risk of Parkinson disease. Neurology, 74:1055-1061.

Wenger, D., A.C. Gerecke, N.V. Heeb, M. Zennegg, M. Kohler, H. Naegeli and R. Zenobi, 2008. Secondary effects of catalytic diesel particulate filters: reduced aryl hydrocarbon receptor-mediated activity of the exhaust. Environmental Science and Technology, 42:2992-2998.

Wenning, R.J., S.E. Finger, L. Guilhermino, R.C. Helm, M.J. Hooper, W.G. Landis, C.A. Menzie, W.R. Munns, J. Römbke and R.G. Stahl, 2010. Global climate change and environmental contaminants: a SETAC call for research. Integrated Environmental Assessment and Management, 6:197-198.

WHO, 2005. Children's Health and the Environment: A Global Perspective. World Health Organization, Geneva.

Wigle, D., 2003. Child Health and Environment. Oxford University Press.

Wilford, B.H., M. Shoeib, T. Harner, J.P. Zhu and K.C. Jones, 2005. Polybrominated diphenyl ethers in indoor dust in Ottawa, Canada: Implications for sources and exposure. Environmental Science and Technology, 39:7027-7035.

Wilken, M., F. Walkow, E. Jager and B. Zeschmar-Lahl, 1994. Flooding area and sediment contamination of the river Mulde (Germany) with PCDD/F and other organic pollutants. Chemosphere, 29:2237-2252.

Wingfield, J.C., 2008. Comparative endocrinology, environment and global change. General and Comparative Endocrinology, 157:207-216.

Wrona, F.J., T.D. Prowse, J.D. Reist, J.E. Hobbie, L.M.J. Levesque, R.W. Macdonald and W.F. Vincent, 2006. Effects of ultraviolet radiation and contaminant-related stressors on Arctic freshwater ecosystems. Ambio, 35:388-401.

Wu, R.S.S., 1999. Eutrophication, water borne pathogens and xenobiotic compounds: environmental risks and challenges. Marine Pollution Bulletin, 39:11-22.

Yamashita, N., S. Taniyasu, G. Petrick, S. Wei, T. Gamo, P.K.S. Lam and K. Kannan, 2008. Perfluorinated acids as novel chemical tracers of global circulation of ocean waters. Chemosphere, 70:1247-1255.

Zala, S.M. and D.J. Penn, 2004. Abnormal behaviours induced by chemical pollution: a review of the evidence and new challenges. Animal Behaviour, 68:649-664.

Zebe, E. and D. Schiedek, 1996. The lugworm *Arenicola marina*: a model of physiological adaptation to life in intertidal sediments. Helgol Meeresunters, 50:37-68.

Acronyms

γ-HCH	Gamma-hexachlorocyclohexane (also known as lindane)
2,3,7,8-TCDD	2,3,7,8-tetrachloro dibenzo-*p*-dioxin
AMAP	Arctic Monitoring and Assessment Programme
BAT	Best available techniques (or technologies)
BEP	Best environmental practices
CO_2	Carbon dioxide
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
GCG	Global Coordination Group
GEF	Global Environment Facility
GHG	Greenhouse gas
GMP	Global Monitoring Plan
HBCDS	Hexabromocyclododecanes
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
NAO	North Atlantic Oscillation
PAHS	Polycyclic aromatic hydrocarbons
PBDES	Polybrominated diphenyl ethers
PCBS	Polychlorinated biphenyls
PCDDS	Polychlorinated dibenzo-*p*-dioxins
PCDFS	Polychlorinated dibenzofurans
PeCB	Pentachlorobenzene
PentaBDE	Pentabromodiphenyl ether
PFC	Perfluorinated compound
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonates
PFOS-F	Perfluorooctane sulfonyl fluoride
POM	Particulate organic matter
POPS	Persistent organic pollutants
SCCPS	Short-chained chlorinated paraffins
TDI	Tolerable daily intake
UNEP	United Nations Environment Programme
UV	Ultraviolet

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