

Conclusions and Recommendations

The previous AMAP POPs assessment (de March *et al.*, 1998) made recommendations and identified information gaps on the basis of the state of knowledge that existed in 1997. The research and monitoring of OCs and other halogenated contaminants (i.e., brominated and fluorinated compounds) in the Arctic that has occurred since that time has been influenced by that document. Although the state of knowledge on OCs in the Arctic has clearly advanced, and many knowledge gaps have been filled, others still remain and new questions and concerns have arisen.

One of the most important accomplishments of Arctic research concerning OCs, and the previous AMAP POPs assessment was the role it played in the negotiations of a global agreement to ban the 'dirty dozen' OCs (PCBs, DDT, etc.).

The measurement of 'new' chemicals, in particular brominated and fluorinated compounds, in the Arctic environment and the evidence of biological effects of OCs in polar bears, glaucous gulls, and northern fur seals are highlights of the recent research carried out on POPs in the Arctic.

Despite these advances, the general recommendations made by the authors of the previous AMAP POPs assessment continue to apply. With slight changes, these recommendations are:

- to continue monitoring levels of POPs in the abiotic environment and in biota, with emphasis on temporal and spatial trends and 'new' chemicals;
- to increase the research and understanding of OC transport and fate processes. This is of paramount importance in light of concerns about fundamental changes to Arctic ecosystems (e.g., climate change);
- to continue to refine and develop methods for determining subtle biological effects, relating OC levels to these effects, and integrating these data with information on population level effects and health, with due consideration to confounding factors such as age, sex, condition etc.; and,
- to continue to promote measures to reduce levels of OCs, in particular 'new' and current-use chemicals, in the environment.

7.1. Levels and effects

7.1.1. Air and precipitation

Measurements of POPs in Arctic air have continued on a weekly basis at locations in Canada, Iceland, Norway, Finland, and Russia. A large temporal-trend dataset is now available. Comprehensive interpretation of the data is limited to results from Alert. These results show that half-lives of several PCB congeners, HCH, and chlor-dane-related compounds are much longer than at temperate air monitoring sites (e.g., Great Lakes and the U.K.). Spatial trends are difficult to evaluate because of the large week-to-week variation in concentrations, due

to temperature changes and long-range transport events, as discussed in Section 5.1. The different number and types of chemicals analyzed at each site also makes inter-comparisons difficult. Nevertheless, it is clear that concentrations of most OCs are higher at Ny-Ålesund and in eastern (Dunai) and western (Amderma) Russia than in the Canadian Arctic. 'New' chemicals such as PBDEs and PCNs appear to be important contaminants in Arctic air, however, little is known about their long-term trends. There exist problems with determination of PBDEs and potentially also with other widely used products such as flame retardants, surfactants, and plasticizers (including chlorinated paraffins, perfluorinated alkyl sulfonates and carboxylates and phthalates). The sampling media, emissions from laboratory building materials, or use near the site could inadvertently contaminate the samples.

Long-term precipitation measurements are limited to one site in northern Finland (Pallas) and to studies of glacial snow cores. These studies provide a valuable record of ongoing deposition, which complements air monitoring. Despite the importance of precipitation in delivering POPs to terrestrial and aquatic environments, the geographic coverage of deposition studies does not include sites in the North American Arctic and in Russia. Glaciers in the Russian, Canadian and Alaskan Arctic offer potential sites for examining temporal trends of POPs in snow/ice.

Further work is urgently needed to monitor the levels of PBDEs in air given their increasing presence in Arctic biota (see Sections 4.1.2.5.3 and 5.4.6.1).

Air monitoring at selected locations should continue to study long-term temporal trends of POPs. Efforts should be made to standardize the analytes measured at each site, so that data are more easily inter-compared. The continuation of air and precipitation monitoring is particularly relevant to agreements such as the Stockholm Convention and the UN ECE POPs Protocol, as the resulting data provide a valuable baseline from which to measure future progress. This work should be expanded to new classes of chemicals. Continued studies of dry and wet deposition mechanisms, and scavenging by snow, are needed in order to understand and better model transport pathways as well as to determine fate and sources to the Arctic. Deposition monitoring should be encouraged at sites in North America and Russia. New passive air sampling techniques such as SPMDs should be considered to improve the geographical coverage of air measurements.

7.1.2. Sea- and freshwater

Recent work on HCH isomers has revealed that ocean currents may now be a driving force in OC transport to the Arctic, and ultimately in influencing levels observed in biota. Originally, α -HCH was transported to the Arc-

tic via the atmosphere where it partitioned strongly into cold Arctic water. The reduction in emissions of many 'legacy' OCs has now resulted in their fugacities being greater in the ocean compared with air. For many chemicals, the ocean is therefore now the largest reservoir in the Arctic. Due to a combination of ice cover and circulation of older water from the European Arctic, the highest levels of α -HCH in the world's oceans are found in the Canada Basin and the Canadian Arctic Archipelago. Furthermore, due to its higher water solubility, β -HCH seems to have more efficiently rained out of the atmosphere into the north Pacific surface water, and has subsequently entered the Arctic in ocean currents passing through the Bering Strait, resulting in a time-lag in delivery to the Arctic in comparison with α -HCH. Ultimately therefore, ocean transport may be more important than atmospheric transport in influencing observed levels of some chemicals in Arctic marine biota. Ocean currents, ice cover, and water-air exchange of OCs are all subject to alteration as a result of climate change.

With the exception of HCH isomers, measurements of most other POPs in seawater are still too limited, especially in the European Arctic, to support comprehensive assessment of spatial trends. Such information would be valuable, for example for better understanding the higher concentrations of PCBs and DDT in biota in the European Arctic. Ultimately, it is the inventory of contaminants in the water column that is likely to drive the temporal trends of POPs in marine biota. PCB measurements in seawater are very challenging because of low levels and the potential for shipboard as well as laboratory contamination. Ultraclean techniques used by German, Swedish, and Norwegian researchers have yielded far lower PCB concentrations than measurements by Canadian scientists using *in situ* samplers or large-volume solvent extraction.

It is recommended that monitoring of OCs in seawater continue and encompass a greater geographical range, with particular emphasis on the European Arctic for which few measurements are presently available. 'New' chemicals should be incorporated in this monitoring, especially those that are considered persistent but non-volatile (e.g., as demonstrated by recent observations with β -HCH). New technologies, such as SPMDs, should be investigated for obtaining information on long-term, prevailing concentrations in ocean waters and seasonal changes, especially of PCBs. Sites for long-term monitoring of temporal trends should be selected. The difference between various sampling methods for low-level PCBs in Arctic Ocean waters need to be resolved, possibly using side-by-side comparison of sampling methods.

High HCH and DDT levels in Russian river waters first reported in AMAP Phase I have been verified by further data analysis and some additional measurements. Ratios of α -HCH to γ -HCH indicate use of lindane. High proportions of DDT in Σ DDT measurements in Russian waters suggest recent use of DDT. Current levels of POPs in Russian Arctic rivers are, however, largely unknown with few new results available since the mid-1990s. A limited number of samples from the recent

RAIPON/AMAP/GEF study in Russia suggest continuing, relatively high, PCB contamination in surface Arctic freshwaters when compared to measurements from the mid-1990s in Canada.

The general lack of knowledge concerning OC concentrations in Arctic lake waters identified in the previous AMAP assessment report has not been addressed. There is almost no information on 'new' chemicals in Arctic freshwaters. Concentrations of Σ PCBs in the waters of some Arctic lakes in Canada and Russia exceed some guidelines for protection of freshwater aquatic life. Lack of spatial trends of OCs in freshwater makes the assessment of geographic variability in OC levels observed in biota difficult.

Additional studies are needed on geographical trends of OC levels in Arctic lake waters. Determination and monitoring of 'new' chemicals in Arctic freshwaters are needed. The high OC levels found in Russian lake and river waters need further detailed study, including information on sources and spatial and temporal trends.

7.1.3. Sediments

The previous AMAP POPs assessment concluded that "PCB levels in both freshwater and marine sediments generally do not exceed thresholds associated with biological effects". New data on levels of PCBs and OC pesticides in marine sediments of the Canadian Arctic have verified that levels are low in non-harbor areas. PAHs in sediments were not considered in this assessment. Based on recent studies in Norway and the Kola Peninsula, there is a need to assess the role of harbors as a source of OCs to oceans and the local environment. This is particularly true for 'new' and current-use chemicals.

Limited new data on POPs levels in freshwater sediments have been produced since the previous AMAP assessment. Recent OC measurements in Russian freshwater sediments found levels that are similar to other regions of the Arctic, although a single sample from one location had exceptionally high levels of DDT, which appear to be fresh based on high proportions of DDT to its metabolites. Newly available information on OCs in sediments from Russian Arctic rivers showed declining concentrations over the period 1988-1994.

Research on the extent of the influence of harbors on ocean contamination is needed, particularly for 'new' chemicals. Further verification of the extent of DDT contamination in Russian rivers and lakes is desirable.

7.1.4. Soils and vegetation

New data on levels of OCs in Russian soil and vegetation suggest little geographical variation in OC levels in these matrices across the Russian-European Arctic. Levels are at or near detection limits and approach levels found in blanks, which may obscure any trends that may exist. There is a general lack of recent data, making it difficult to assess the global reservoir of OCs and to model global cycling of OCs. Soils and vegetation can represent a significant component of the global environmental reservoir of OCs. A recent global study on the levels and loadings of OCs in soil included only a few Arctic sites.

Extensive monitoring of OCs in Arctic soils and vegetation is not required, although a survey of soil and plant loading of OCs in the Arctic would contribute significantly to global modeling efforts to understand the ultimate fate and time to virtual elimination of these compounds.

7.1.5. Biota

Levels of OCs in Arctic species and environments are generally lower than in temperate areas, except where impacted by a local source. 'New' POPs, such as brominated and fluorinated compounds have been measured in Arctic biota. PBDE levels have increased significantly in the past ten years but are currently still at levels that are orders of magnitude lower than legacy OCs. Species monitored in the circumpolar Arctic during AMAP Phase II are essentially the same as those monitored during AMAP Phase I, with the emphasis on the most heavily contaminant species (polar bear, ringed seals, beluga, glaucous gulls). New data on polar bears, ringed seals, seabirds, and terrestrial mammals and birds from Russia have provided additional insights into circumpolar trends of OCs.

New studies of OC levels at different trophic levels in different marine ecosystems (Alaskan, Canadian, and European) have significantly increased understanding of the factors that influence OC levels and trophic transfer, confirming that biomagnification is a dominant factor in explaining high OC levels in Arctic biota. However, migration is also an important factor in several species and their prey. Physical-chemical properties of the contaminants, and the biological characteristics of the organisms play important roles in observed concentrations throughout the Arctic. Warm-blooded animals (birds and mammals) have been shown to accumulate OCs at a much higher rate than cold-blooded animals (fish and zooplankton). Size of zooplankton and their feeding habits are important variables influencing OC levels, but the understanding of factors influencing OC levels at the base of food webs is limited. Detailed models of bioaccumulation and fate of OCs have been developed for ringed seals and beluga but not for other species, and they have not been linked to food web models.

The role of abiotic-biotic interfaces at the base of food webs needs to be better understood in both marine and freshwater environments. This is particularly important if changes in climate and ocean currents alter food webs and distribution or delivery of contaminants. There is a need to study the trophic transfer of 'new' chemicals in marine and freshwater food webs.

Few new data on OCs have been produced for terrestrial biota in Canada, the U.S. or Norway. Terrestrial mammals and birds were, however, included in a recent extensive survey of contaminants in Russian terrestrial herbivores used as food items in traditional diets. In addition, mammals were included in studies of contaminants in Greenland and Faroe Island biota, and in Finland, reindeer were studied. In general, concentrations of persistent OCs in terrestrial mammals were low in the Russian Arctic, the Faroe Islands, Finland, and in Greenland. The exception is high PCDD/F concentrations in

Russian reindeer and mountain hare from the Kola Peninsula, due to the presence there of non-ferrous metal smelters. Concentrations of PCBs in Russian reindeer samples were slightly higher than previous reports for Canadian caribou (mid-1990s). However, no recent data are available from Canada for comparison.

In the previous AMAP assessment, there was some concern for carnivorous and piscivorous mammals (e.g., wolf and mink) which have elevated OC levels, however these levels are orders of magnitude lower than those found in some marine mammals. Few new data are available for these species. For migratory birds of prey, however, levels of OCs are still high and remain a cause for concern, while PBDE levels measured to date are higher than in marine mammals.

While extensive monitoring of OCs in Arctic terrestrial biota is not required, further studies are needed to develop baseline levels for new, emerging POPs such as PBDEs and perfluorinated acids. Monitoring OCs and 'new' chemicals in birds of prey is still warranted, however.

Freshwater biota contain higher levels of POPs than those in terrestrial environments, mainly due to more complex food webs. Lipid-weight PCB levels in freshwater fish are similar or slightly lower than levels in anadromous and marine fish with some major exceptions. Studies on the factors affecting levels in top trophic-level fish in different lake systems are ongoing.

Levels of POPs in the biota of Lake Ellasjøen on the island of Bjørnøya, north of Norway, are the highest measured in a freshwater system of the Arctic. These high levels are believed to be caused by the input of contaminants in guano from seabirds. Nearby lakes that do not receive guano, have much lower POP levels. A similar situation is indicated in fish from a freshwater lake on Jan Mayen.

Ongoing surveys and studies of contaminants in the freshwater food web and the variables influencing levels should continue. Locations where there are elevated OC levels due to local contamination or food web effects, such as Lake Ellasjøen on Bjørnøya, are the most appropriate sites for further work.

A wider range of marine species has been studied compared to the previous AMAP assessment, and considerably more data were available for Alaska and Russia in the current assessment. This wider range of marine species includes plankton, invertebrates, more species of fish, seabirds, pinnipeds, and cetaceans, as well as sea otters, Arctic fox, and polar bears. Levels of OCs in Arctic biota are generally highest in the top trophic-level marine organisms (e.g., great skuas, glaucous gulls, great black-backed gulls, killer whales, pilot whales, Arctic fox, and polar bears). This is particularly true for biomagnifying OCs such as PCBs and DDT. Within species, dietary intake at different trophic levels affects OC levels, as shown for polar bear, walrus, killer whales, Arctic fox, and glaucous gulls; with predation at higher trophic levels leading to higher OC concentrations. New data for OCs have been generated for Arctic fox from sites in Alaska, Canada, and Iceland, filling an important data

gap in the previous assessment. In Arctic fox on Svalbard, concentrations were comparable to, or higher than, in polar bears. The PCB concentrations found in Arctic fox from Alaska, Canada, and inland Iceland were lower, but in foxes from coastal populations in Iceland that feed in the marine food web, concentrations were comparable to those found previously on Svalbard.

Concentrations of MeSO₂-PCB and -*p,p'*-DDE metabolites, OH-PCBs, and a previously unidentified phenolic metabolite of OCS, 4-hydroxyheptachlorostyrene (4-OH-HpCS) have been determined in polar bear and found to be high. Therefore, for Arctic organisms with efficient biotransformation capabilities, metabolite formation may be substantial and analysis of only parent compounds may give a skewed picture of actual contaminant levels. There is also evidence of bioaccumulation of some MeSO₂-PCB metabolites in the Arctic cod – ringed seal – polar bear food web.

Ongoing surveys and studies of contaminants in marine organisms, and the variables influencing levels, should continue.

7.1.6. 'New' chemicals

A number of 'new' chemicals that may be potential POPs have been found in the Arctic. The most surprising finding is the presence of PFOS, which has never been reported previously. This is of particular note because, based on its physical-chemical properties, it was not expected that PFOS would be found in the Arctic. PFOS levels are high in polar bear liver and it is one of the most prominent individual organohalogen chemicals in polar bear, when levels of PCBs, chlordane, and HCH-related chemicals are considered. The presence of PBDEs, chlorinated paraffins, and PCNs was anticipated based on very limited monitoring reported in AMAP Phase I. These newly identified organohalogen compounds are generally at much lower concentrations in Arctic air and biota compared with temperate regions. Nevertheless, temporal-trend studies have proved valuable in demonstrating increasing concentrations in Arctic biota, particularly the PBDEs.

Until recently, measurements of persistent organic chemicals in the Arctic have been confined to those which can be easily measured using gas chromatography, representing only a fraction of the possible persistent chemicals in commerce. However, the presence of chemicals like PFOS illustrates the need for a very broad analytical approach (PFOS can only be analyzed by Liquid Chromatography-Mass Spectrometry (LC-MS)). Natural halogenated compounds such as Q1 (a heptachlorobipyrrole), MHC-1 (a chloro-bromo-monoterpene), and halogenated dimethyl bipyrroles that have been detected in Arctic biota are another class of chemicals that needs to be considered. Temporal trends and body burdens of these chemicals, which are produced by marine algae, need to be considered when assessing impacts of some closely related anthropogenic chemicals like the PBDEs.

Additional research and monitoring of 'new' chemicals is needed, in particular for brominated compounds that are increasing in concentration. An understanding of circumpolar trends for these 'new' chemicals is needed, in

particular for the Russian Arctic. Work on persistent organic compounds in current industrial, consumer, and agricultural uses should be encouraged, even for chemicals that are not considered to have potential for atmospheric transport to the Arctic based on their physical properties. The influence of point sources for chemicals, such as harbors and waste disposal sites, including waste burning, should be assessed.

In the previous AMAP assessment, only limited data were available on toxaphene concentrations in Arctic biota. A great deal more data are now available, showing that toxaphene is widespread throughout the Arctic. In some seal species, toxaphene concentrations are comparable to PCB concentrations. Some whale species, such as beluga and narwhal, also have particularly high toxaphene levels. Only very limited temporal trend data are available for toxaphene.

Monitoring of toxaphene should be extended and temporal trend monitoring studies of toxaphene established. Biomarkers for toxaphene exposure need to be developed and biological effects monitoring undertaken in those species with high levels.

TBT is found extensively in invertebrates of Arctic harbors, but information on levels in organisms in regions away from harbors remains limited. Butyltin compounds (MBT, DBT, TBT) were present in very low or non-detectable levels in Canadian Arctic and Faroe Island marine mammals, but in Norwegian marine mammals and seabirds are at levels that warrant further study.

Future measurement of TBT should continue to focus on the invertebrate community. Additional work should be carried out to determine levels of mono- and dibutyltin in abiotic and biotic samples in the Arctic because of their ongoing use, which is unrelated to TBT uses.

7.1.7. Biological effects

There has been limited advancement in understanding the effects of low tissue levels or body burdens of OCs or low-level intakes in Arctic biota, which was an identified knowledge gap in AMAP Phase I. Most of the information has been developed for PCDD/Fs, non-*ortho* PCBs, PCB, and DDT using non-Arctic animals. Threshold levels have mainly been established in laboratory animals for effects on reproduction, neurobehavioral development, and immunosuppression. There are major species differences in susceptibility to the toxic effects of POPs. A major gap in knowledge is the sensitivity of Arctic species for effects compared to other species where more knowledge is available. This, in turn, makes it difficult to know if the threshold values determined in other species are valid for comparison with the contaminant levels found in Arctic species.

Another major knowledge gap is the fact that the toxicity mechanisms for many POPs are still not known, and this is an urgent research priority, especially for those substances found at high concentrations in Arctic biota.

There are no, or insufficient thresholds data for many 'new' POPs such as PBDEs and PFOS, as well as for biologically active metabolites of some POPs, such as MeSO₂-PCBs, MeSO₂-*p,p'*-DDE, and OH-PCBs. Thus, it is not currently possible to assess the effects of current levels of these contaminants in Arctic biota.

A future priority area for effects studies and risk assessment is, therefore, determining effects thresholds of POPs for Arctic species, so that more relevant and reliable comparisons can be made. More research is also needed on toxicity mechanisms of many POPs including establishment of effects thresholds for new substances and metabolites.

The most biologically significant effects are those that affect resistance to infection, reproduction and behavior. Anything that negatively affects resistance to infection, reproduction or behavior reduces the margin of safety for the affected species, putting them at higher risk. Assessment of contaminant levels from the previous AMAP assessment suggested that several species were potentially at risk for neurobehavioral, reproductive, and immune system effects. This has now been borne out in biological effects studies carried out on polar bears, northern fur seals, glaucous gulls, and possibly also Steller sea lions. Results from field experiments and laboratory studies give added weight to the possible link between some POPs and specific effects. The implications of these findings are thus, that there are both populations of these species in other areas, and other highly contaminated species, that are being affected by current levels of some OCs. Based on the present evidence, it is believed that effects of biological significance related to OCs exposure are occurring in some Arctic species. These are as follows:

- polar bears may be at higher risk for infections due to immune effects of OCs;
- glaucous gulls with high OC levels may be at risk due to immune, behavioral and reproductive effects, and effects on adult survival;
- northern fur seals may be at higher risk for infections due to immune dysfunction correlated to POP exposure;
- peregrine falcons continue to exhibit eggshell thinning and reproductive effects of OCs;
- Arctic char exhibit immune effects of PCBs; and,
- dogwhelks exhibit the reproductive effects of TBT.

The biological effects studies on polar bears in the Norwegian Arctic show that there is some evidence of reduced cub survival, suppressed immune function, and disturbance of thyroid hormone and retinol homeostasis. Similarly, there are also indications that high OC burdens may affect cub survival in Hudson Bay polar bears. Biological effects studies comparing Canadian and Svalbard polar bears indicate that some serious disturbances in immune responses, as well as in thyroid and retinol systems, may be related to current levels of PCBs. Assessment of these results indicates that population status and health of polar bears with very high PCB levels may be at risk. The significance of these findings on the individual and population levels has therefore to be further investigated.

Although the study of northern fur seals discussed in Section 6.3.4.1 was not designed to elucidate fully the role of OC contaminant exposure-induced immunosuppression in the decline of St. George Island northern fur seals, it did identify a cohort (pups born to young dams) that is at higher risk. OC contaminant exposure at an extremely sensitive and critical period of development must be considered as a potential contributing factor to reduced post-weaning survival based on evidence of a compromised immune system.

The potential effects of environmental contaminant exposure during critical developmental life stages emphasizes the need for further monitoring and research. There is an ongoing need for better biomarkers, and for biomarkers to cover more effects, such as other types of hormone disruption.

Biomarkers for OC effects measure changes at the cellular or individual level and provide warning signals. The results from biomarker studies in the Arctic have shown that there are associations between several biomarkers and OC levels based on measuring biomarker responses and correlating these to levels of OCs. Such results show association but not causation. Many OCs covary so that it is not possible to state equivocally that a certain OC is the cause of the effect seen. These factors make risk assessment very difficult.

There is a general lack of knowledge of the physiology of most Arctic species, particularly those with high OC exposures. This includes knowledge concerning baseline levels of hormones, vitamins, blood variables, immune factors, etc., and other factors that affect these (e.g., time of day, time of year, reproductive state, health status, fasting, etc.) Because of these knowledge gaps, and the influence of confounding factors, other biomarkers studied in Arctic biota (such as thyroid hormones, vitamin A, and cytochrome P450 activity) should be considered indicators of increased exposure. It is however not yet possible to conclude that changes in these imply increased risk.

All the species at risk should be monitored directly for contaminant levels and possible biological effects. Biological monitoring of the most heavily contaminated species should be encouraged, together with studies including the entire food web, in order to clarify and understand the transfer and biomagnification of contaminants. In the Russian Arctic, high-level predators such as polar bear should be studied since OC levels seem to be higher than at Svalbard.

There is a need for refinement and development of sensitive biochemical- or physiological-level assays for use in Arctic biota. For example, development of in vitro methods based on tissues from Arctic species. Practical problems that must be overcome include: the difficulty in collecting biopsy samples from live animals or fresh tissue from hunted animals in remote regions, and related problems in sample preservation and storage. Linkage of the results for planar OCs to bioassays of cytochrome P450 1A1 and 2B activity on sample extracts, a technique widely used in contaminant studies in the Great Lakes, should be considered in order to confirm that the biological activity associated with the measured contaminants is accounted for.

Well-designed studies combining laboratory, semi-field and field studies are needed to determine causation,

particularly for the most highly exposed species in the Arctic. Arctic fox could be a possible model for Svalbard polar bear as they have similar feeding habits on Svalbard. Svalbard foxes have high OC levels. They also go through fasting periods, and immunological tools are available for foxes. Arctic fox can be studied in the field, in semi-field conditions and in the laboratory if blue fox (a color variant of Arctic fox raised on fur farms) are used. A coordinated international project should be developed along these lines so that as many methods, and the knowledge of as many pertinent research groups as possible, can be used. Similar studies are feasible using glaucous gulls.

Studies on the influence of other stressors, such as long periods of fasting in Arctic char, show modulation of these OC-related effects.

More knowledge concerning starvation effects in birds and mammals is needed. Interpretation of correlative hormone studies is hampered by lack of information on other variables, such as long-term fasting/starvation, that may affect hormone levels in wild populations. This makes drawing conclusions from some biomarker studies tenuous.

Other stressors, including the effects of parasites, light, noise, and higher temperatures in the wake of global warming, may make organisms more or less susceptible to the effects of OCs; however, little is known about such influences. For example, there is evidence of immunosuppression in marine mammals due to thermal stress related to a small increase in ocean water temperature. Noise pollution also appears to be immunosuppressive.

More research is needed into the influence of other stressors on organisms, including modulation of OC-related effects.

Outside the Arctic, tumors have been found in wildlife highly exposed to OCs, such as beluga from the St. Lawrence Estuary. An increase in chromosome aberrations and DNA adducts were found in glaucous gull chicks exposed to OCs via food. No other studies of possible mutagenic effects or tumor occurrence have been carried out in any Arctic biota.

Where possible, surveys of tumor incidence in highly exposed marine mammals and seabirds should be carried out, possibly as collaborative efforts with native hunters. Surveys of mutagenic effects in some highly exposed species should be carried out to determine the prevalence of these effects.

Imposex in invertebrates such as dogwhelk has been found to be more widespread in the Arctic than previously thought and is correlated to TBT levels. Imposex has now been reported along the Arctic coast of Alaska, Iceland, Norway, Greenland, and the Faroe Islands. Improvement has been seen in countries where TBT has been banned for use on boat hulls.

Further monitoring of imposex and TBT concentrations along Arctic coasts should continue so as to follow current trends as well as to establish occurrence in areas not previously studied. Monitoring is also needed in order to follow temporal trends when TBT is banned for use as an antifoulant paint on ships. The potential effects of new antifoulant paints that are beginning to replace TBT should be addressed.

7.2. Spatial trends

Extensive spatial surveys of OCs in marine mammals (polar bears, ringed seals) and seabirds now give better circumpolar coverage than was available in the previous AMAP assessment. All spatial trends that include the Russian Arctic clearly show that PCB and DDT concentrations are highest in the eastern Barents Sea and Kara Sea area, with concentrations decreasing to the east and west of these, indicating significant local sources of DDTs and PCBs in Russia. This is also indicated by high OC inputs to the Arctic Ocean from the Ob, Taz, Nadym, Pur, and Yenisey Rivers. These rivers have been shown to be significant sources of OCs to the Kara Sea/Arctic Ocean via river water and sediments. Levels of OCs in birds and marine mammals are generally higher in the European Arctic compared to the Alaskan and Canadian Arctic. The exception is HCH, where levels are highest in the Alaskan and western Canadian Arctic due to the recent use of this chemical in Asia. There are also local spatial trends in biota in the Aleutian Islands (Alaska) and Saglek Bay (Canada), particularly in PCB concentrations. These seem to be related to local sources, primarily military sites.

Studies of ringed and harp seals and their food web in the White Sea have shown that levels of PCBs and DDT-related compounds are higher there than in the North American Arctic. Harp seals in the White Sea and eastern Svalbard (the same migrating population) have elevated levels of toxaphene compared to ringed seals in the Canadian Arctic. Toxaphene levels were also relatively high in minke whales from the Barents Sea and eastern Svalbard area compared to the West Greenland stock.

There are numerous gaps in knowledge of spatial trends of OCs in marine biota. Little is known about levels of OCs in biota from the Kara, Laptev, and East Siberian Seas with the exception of a study of PCB/OC pesticides in polar bear blood, and another on ringed seals in the Kara Sea.

Additional surveys of 'legacy' and 'new' POPs are needed in the Russian marine system, particularly in the Kara, Laptev, and East Siberian Seas. Further research is needed to determine and quantify PCB and DDT sources to the Barents/Kara Sea area. In particular, more studies are needed on the influence of military sites (active and inactive) as local sources of OC contamination to the marine environment.

PBDEs (mainly BDE47 and BDE99) have been detected in numerous Arctic animals, including birds of prey, freshwater fish, ringed seals, minke whales, long-finned pilot whales, beluga, polar bears, and seabirds. The

highest levels are in the thousands of ng/g range in pilot whales and birds of prey but otherwise, PBDEs are in the low ng/g range. PDBE levels appear to be higher in glaucous gulls, ringed seals, and beluga at Svalbard than in the same species in the Canadian Arctic. Highest levels are found in some Scandinavian migratory birds of prey such as peregrine falcons and white-tailed sea eagle. Spatial trends of PBDEs are not yet well documented, however. Studies of PBDEs in eggs of birds of prey in Norway and Sweden have found no clear south to north trends.

Circumpolar trends of 'new' chemicals in the Arctic are a very significant data gap and need to be addressed in both the abiotic and biotic environment.

An emerging issue is the possible effect of shifts in trophic structure due to ongoing 'regime shifts' or warming trends, such as the one being observed in the southern Beaufort Sea. This could lead to differences in diet for top predators, which could affect trends in persistent organohalogen contaminants. An illustration of this dietary effect was discussed at the AMAP conference in Tromsø, Norway (January 2002). Most OCs are lower in polar bears in the Chukchi and southern Beaufort Sea coasts than elsewhere. It was pointed out that this may be related to the availability of bowhead whale carcasses in the region, the only area of the Arctic where bowheads are hunted extensively. If, because of climatic shifts, polar bears from this area had more ringed seal in their diet, they would have higher PCB levels since seals are higher in the food web than bowheads and have a different pattern of PCB congeners.

The example of feeding on whales also underlines the need to consider dietary sources and food web pathways of contaminants before inferring regional/geographical trends in levels, and sources in trends. Monitoring programs have begun to make greater use of N and C stable isotope data to gain insight into such dietary effects as well as to study food webs together with top predator sentinel organisms. However, such work requires a multidisciplinary team and substantially more funding for ship time and fieldwork than is usually available for Arctic contaminants work.

Use of stable isotopes of both N and C and newer methods such as fatty acid patterns to elucidate food web effects should be incorporated into future studies.

With the exception of HCH isomers, spatial trends of OCs in marine zooplankton and fish do not match those observed in seabirds and marine mammals. For example, levels of PCBs in lower trophic-level organisms, such as zooplankton and Arctic cod, do not differ between the eastern Canadian Arctic and the European Arctic, although differences are clear for top predators such as seabirds, ringed seals, and polar bears. Toxaphene and PCB levels in seawater in the White Sea were similar or lower than observed in the southern Beaufort Sea. Concentrations of OCs in calanoid copepods and other zooplankton are similar or higher, depending on the OC group, in the Alaskan and Canadian Arctic than in regions around Svalbard. No data are available for marine zooplankton in the Russian sector of the Arctic Ocean. Food web differences may account for more

of the observed differences than has been assumed previously.

The data on which these conclusions are based are however limited, especially in the European Arctic. A comparative survey of OCs in seawater and zooplankton, using similar collection (e.g., time of year) and analytical methods, is therefore suggested. Additional studies on factors influencing OC levels in lower trophic-level biota are also encouraged.

More research is needed to explain the large differences in POP levels at high trophic levels in the Barents Sea ecosystem, as compared to the North American Arctic.

7.3. Temporal trends

Long-term datasets for OCs in air at Alert and Ny-Ålesund have proven to be very valuable records of the current status of OCs in the Arctic and are of particular relevance in light of new global bans on OCs. An assessment of trends in air shows that PCBs at the Alert station are declining very slowly.

Key species such as polar bear, ringed seals, glaucous gulls, and guillemots continue to be monitored for PCBs and OC pesticides. Temporal-trend data are now available over a 25-30-year period for ringed seals and for eggs of several seabird species in the Canadian Arctic, as well as for Arctic char and pike from Swedish lakes. Trends in PCDD/Fs and non- and mono-*ortho* PCBs have been studied in seabird eggs over an 18-year period in the Canadian Arctic. In addition, new temporal-trend studies have been conducted using archived samples (polar bears in Hudson Bay; beluga whales in east Baffin Island; guillemots and Atlantic cod in Iceland; birds of prey in northern mainland Norway; polar bears at Svalbard; and, glaucous gulls at Svalbard). Temporal trends during the 1990s are available for PCBs, DDT, and toxaphene in ringed seals from Nunavik, Hudson Bay, and Greenland, and in harp seals from the White Sea. Temporal trends of OCs in seabirds from Alaska are available, and sample archives now exist which would allow further assessment of trends during the 1990s.

The general observation in all studies and species is that concentrations of total PCBs and total DDT are declining slowly. This reflects the slow decline in inputs from circumpolar countries and the northern hemisphere as these chemicals are phased-out. Major reservoirs, especially of PCBs and DDT, remain in soils in the northern temperate zone. Chlordane-related chemicals as well as dieldrin are also declining in the same species. Less is known about temporal trends of other chemicals that are potential POPs. ΣHCH concentrations have remained stable in ringed seals in the Canadian Arctic, but the proportion of recalcitrant β-HCH, an endocrine active chemical, has increased over the past 25 years. β-HCH has declined in concentration in polar bears in Svalbard (1991-2000) but not in polar bears from western Hudson Bay over the same period. However, β-HCH concentrations have increased while α- and γ-HCH concentrations have declined in seabirds in the Canadian Arctic. This is probably due to the time lag in delivery of β-HCH, which was washed out from the atmosphere via precipitation into the northern Pacific/Bering Sea and has only recently entered the Arctic via

the Bering Strait. Generally, the trends in rates of decline for DDT and α -HCH indicate more rapid declines in the European and Russian Arctic and slower declines in the North American Arctic, particularly during the past decade. PBDE concentrations have increased in beluga and ringed seals in the Canadian Arctic between the early 1980s and the late 1990s. Endosulfan sulfate also appears to have increased in beluga. Chlorinated diphenyl ethers, by-products from the production of pentachlorophenol, have declined in beluga from Cumberland Sound in the eastern Canadian Arctic during the 1990s. Toxaphene levels show increasing temporal trends in seabirds, decreases in burbot and no change in beluga and narwhal in the Canadian Arctic.

There are numerous gaps in knowledge of temporal trends of OCs in marine biota. Temporal-trend information is limited to a relatively narrow range of OC compounds (e.g., PCBs and OC pesticides) with the exception of new studies in the Canadian Arctic on PBDEs and chlorinated paraffins in beluga and ringed seals. No temporal trend information on PBDEs or chlorinated paraffins is available yet for the European Arctic. The temporal-trend studies, especially those involving retrospective analyses of 'new' OCs, are dependent on tissue archives. Maintaining these archives is crucial for continued trend monitoring.

Specimen banking remains a cornerstone of work on temporal trends of OCs in the Arctic and will be critical for future retrospective work on other persistent organics in biota. Only a few Arctic countries (Canada, U.S., and Sweden) have well-established specimen banks and even those are not designed for all major Arctic species. For work on more polar compounds, such as hydroxy-PCBs, halogenated phenolics and perfluorinated acids, which are found mainly in blood plasma, it is clear that a wider range of tissues will need to be archived.

Temporal trend monitoring of a broader range of contaminants in biota, including potential 'new' POPs, should be established. A circumpolar expert group is needed to design guidelines for archiving Arctic samples for future chemical analyses and biological effects studies.

7.4. Sources

High OC levels in Russian rivers reported in the previous AMAP assessment have been verified, although evidence also shows declining trends during the early 1990s. Extremely high levels of DDT were found in the sediment of the Pechora River in Russia in the recent RAIPON/AMAP/GEF study. High levels of OCs in Russian terrestrial and marine biota have also been found. Air, water, and biota monitoring suggest higher proportions of *p,p'*-DDT and lindane compared with other Arctic regions and point to recent or ongoing use. High PCDD/F levels in Russian reindeer, mountain hare, and freshwater fish from the Kola Peninsula are probably the result of proximity to local sources.

Additional studies, including surveys and inventories, are needed to understand the sources of POPs in Russia.

Based on studies in northern Norway and the Kola Peninsula, harbors may be a source of PCBs and other

OCs to oceans. The potential for northern harbors to be continuing sources of contamination to the Arctic Ocean, or to contaminate biota that migrate to other more pristine areas, needs further study.

Results from OC measurements in biota from the Aleutian Islands, and abiotic and biotic samples from Saglek Bay, Labrador, indicate military sites to be a source of PCB input to the local marine environment. Numerous local sources of other OCs may also exist, but very few have been studied. These local sources include burning of wastes in Arctic communities, smelter emissions of PCDD/Fs, industrial and community effluents, dumps, waste sites, etc. Some 'new' chemicals, in particular PBDE, are found in current-use products and pose a local contaminant concern. The role these sources play in loadings to the Arctic are not known.

Surveys of local sources of contamination by OCs, in particular 'new' chemicals, within the Arctic are needed to quantify the emissions and leakage. These include both harbors and military sites. Where emissions are high, actions should be taken to reduce or remediate them.

All eight Arctic countries have now signed both the UN ECE Protocol on POPs and the global Stockholm Convention on Persistent Organic Pollutants. The Arctic countries are encouraged to rapidly ratify and implement these conventions.

7.5. General monitoring and assessment

Variability between analytical methods continues to be a problem (e.g., number of PCB congeners analyzed continues to vary between laboratories), although the situation has improved since the previous AMAP assessment. The analysis of toxaphene and 'new' chemicals needs to be addressed, especially chemicals such as perfluorinated compounds that have very different analytical methodologies.

Virtually all laboratories submitting analytical results for this assessment have taken part satisfactorily in international interlaboratory comparisons. The AMAP POPs program has been a major stimulus for this. However, contamination during sampling and laboratory analysis remains an issue, especially for PCBs and brominated flame retardants. Detection limits used by various studies vary widely. Levels of some POPs approach blank levels especially in the case of terrestrial herbivores.

Future AMAP monitoring programs for POPs should continue to use a quality assurance program with mandatory participation of laboratories in interlaboratory comparisons for key matrices. Quality assurance programs for sampling strategy and sample collection should also be developed.

Despite AMAP recommendations, PCB results continue to be given as sums of anywhere from seven to 90 congeners, making comparisons difficult. Most laboratories determined at least seven CB congeners (CBs 31/28, 52, 101, 118, 138, 153, and 180). However, the sum of the above seven represented between 11 and 65% of Σ PCBs in sediments, 50% in mosses, 50 to 66% in biota, and

only 10 to 30% of Σ PCBs in air. The lack of quantification of more than 7-10 congeners in air samples has made it difficult to use the results in source and pathway studies.

The number of CB congeners should be standardized, and future analyses should require, as a minimum, a somewhat larger number of congeners to be determined, including toxicologically important mono-ortho PCBs such as CB105 and 118. Determination of 30 to 40 selected congeners (the exact number would have to be assessed by careful consideration of congener patterns in each matrix) should give results close to those for the sum of all possible congeners, with the other congeners contributing relatively little to Σ PCBs.

Current methods for quantifying toxaphene may overestimate levels in some samples such as marine mammals and underestimate it in others such as air. The use of different quantification methods has limited the assessment of current atmospheric loadings of toxaphene to the Arctic Ocean and is a matter that needs to be resolved. Some laboratories are now reporting only concentrations of specific toxaphene congeners, which makes comparisons to older data difficult.

Future monitoring should include determination of total toxaphene (by negative ion MS) for comparison with past work as well as selected chlorobornane congeners. This work should include at least ten major congeners found in air and biota, not just Parlars 26, 50, and 62. Lack of commercial standards hampers this, and there is an urgent need for more standards to be made available.

While broad ranges of 'new' chemicals are being investigated in Arctic biota, there is also a need for models to predict the kinds of compounds that are in commercial use, and that may have 'Arctic accumulation potential'. Much progress in modeling has been made in this regard, but a strategy for developing a list of possible chemical contaminants needs to be considered in order to anticipate new chemical threats rather than focusing most resources on the list of 'legacy' OCs, as is being done at present.

Future studies of OCs in Arctic marine biota could benefit from more of a 'campaign' approach to coordinate monitoring and measurements (sites, sampling timing, and analytical methodology) similar to the approach taken for some human tissue sampling under the AMAP program. There is presently some degree of coordination for air measurements of OCs, although lists of analytes vary between laboratories, but there is almost no coordination for measurements in biota. Most groups are using the OSPAR Joint Assessment and Monitoring Program (JAMP) protocols for monitoring biota recom-

mended by AMAP. Extension of mussel watch type programs from more southerly regions is possible in some locations and has been implemented on an experimental basis in northern Labrador/Nunavik, northern Norway, and Greenland.

For air and water sampling, future programs should consider use of passive sampling devices, for example, plastic/triolein or XAD resin SPMDs for air and water, which are showing promising results in trials in Norway and Canada.

OC levels in biota can vary dramatically between individuals of the same species and population due to differences in age, size, growth rate, and sex. These differences are even more of an issue when OC concentrations are compared between populations from different regions or sites, and different times. Robust statistical analysis that incorporates these biological characteristics is of paramount importance when assessing spatial and temporal trends. Failure to carry out such statistical analysis can result in faulty conclusions and recommendations.

Also critical for future evaluation of temporal and spatial trends of OCs, is the availability of data for the assessment, including results for individual samples and associated biological data. The AMAP data centers can theoretically perform this function. Unfortunately, large amounts of data that have now been published in peer-reviewed journals and used in the previous AMAP assessment are still not yet in the AMAP data centers, especially data from Canada, the U.S., and Russia. This situation is bound to get worse as scientists involved in the previous and current AMAP assessments retire or change jobs. A renewed effort by AMAP to archive data in data centers with full access after a reasonable period is needed.

It is strongly suggested that statistical analysis of all OC data incorporate all relevant and available biological data. New monitoring programs should include a suite of biological measurements. Results from monitoring programs should be published in peer-reviewed journals, and efforts should be made to have government reports peer-reviewed. Data should be compiled in (AMAP) data centers to ensure their future accessibility.

Many current analytical reference materials have relatively high levels of contaminants, which are not always appropriate for use in analysis of low-level samples from the Arctic, and can result in cross-contamination during sample analysis. There are currently no standard analytical reference materials for 'new' contaminants.

There is a need for development of 'made for the Arctic' analytical reference materials based on common matrices used for analysis (blubber, blood, other tissues, sediments). These should include legacy OCs, their metabolites, toxaphene, and other new chemicals of concern.