POP TRANSFER IN ARCTIC MARINE FOOD WEBS

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Introduction

The present study is a review and summary of the Arctic food web bioaccumulation studies conducted in the late 1990s (**Fig. 1**), with a discussion of biological and chemical factors affecting the contaminant accumulation and transfer within food webs[1]. The focus is on “legacy” persistent organic pollutants (POPs), especially organochlorines (OCs), such as PCBs, chlordane (CHLOR), and DDT-related products, with updates and examples of other compounds such as brominated flameretardants (BFR)[2] and perfluorinated compounds (PFAS)[3]. The quantification of legacy POPs in the Arctic marine environment over the past four decades has dramatically increased the breadth and depth of our knowledge of how this class of contaminant accumulates in biota and is subsequently transferred within food webs.

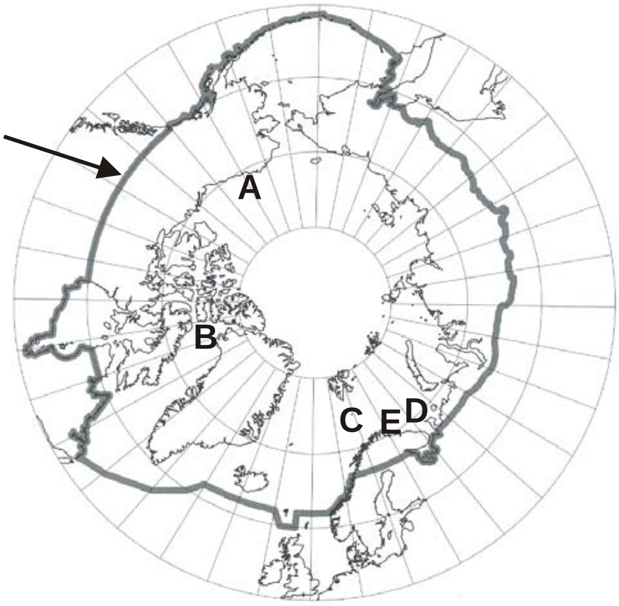


Figure 1. Regions of Arctic marine food web bioaccumulation studies, with AMAP’s definition of Arctic[9].

The Arctic marine ecosystem provides an excellent opportunity to study food web dynamics of OCs because the contribution of point sources to regional contamination is relatively minor, there is a high dependence of lipids in arctic marine food webs and the food webs tend to be long and simple.

Field studies of POP bioaccumulation in arctic marine organisms in the 1970-1980s included fish and species occupying higher trophic levels (seals and polar bears), but marine invertebrates were either not included or were included without separating into taxonomic or functional groups. Other studies lumped invertebrates into selected size classes. Field studies of OC accumulation in arctic marine food webs have only recently begun to investigate the importance of biology and ecology of lower trophic level organisms in the bioaccumulation process. These studies either sort the marine invertebrates to species or genus or consider samples dominated by one species (detailed references in [1]). There have been a number of comprehensive studies on the distribution of OCs in arctic marine food webs in the past decade[4-8]. This has resulted in detailed data sets and new knowledge on chemical and biological variables that influence the bioaccumulation and trophodynamics of OCs in marine food webs. In the later years, this has been accompanied by studies of compounds such as BFRs, chiral compounds, and PFAS. While this summary focuses on Arctic marine ecosystems, the information is relevant to all marine and freshwater systems.

Materials and Methods

The presentation focuses on marine food webs, especially knowledge gained from studies in the White Sea, The Barents Sea, Northern Baffin Bay, and the Beaufort Sea (**Fig. 1**). The dominating species from different trophic positions in the food web were collected by nets and hauls (zooplankton), trawls (fish), or by shooting (birds and mammals). The chemical analyses were performed at accredited laboratories. Please see [1] for references to publications with all details.

Biomagnification is studied by quantifying the increase in contaminant concentration per trophic level (trophic magnification factor TMF, where trophic level (TL) is determined by stable isotopes of nitrogen ($\delta^{15}N$)[4]:

$$Log\ \left[POP_{organism}\ lw\right] = a + bTL + e, \quad where\ TMF = 10^{b} \qquad (1)$$

The biotransformation ability of a species, relative to other species and among the chemicals is studied by metabolic indices (MI)[10]:

$$MI = \frac{\dfrac{[POP]_{predator}}{[PCB-153]_{predator}}}{\dfrac{[POP]_{prey}}{[PCB-153]_{prey}}} \qquad (2)$$

Results and Discussion

Several factors influence the POP bioaccumulation and transfer within food webs. These are both chemical factors such as hydrophobicity and persistence, and biological factors such as and diet and trophic level, lipid content, biotransformation ability and habitat. This is illustrated in the bioaccumulation in zooplankton and ice fauna[11] (**Fig. 2**). Also among these invertebrates at low trophic positions in the food web, with respiratory exchange of contaminants with water, there is an effect of diet. This is seen by higher concentration of persistent and hydrophic OCs (PCB-153) in predacious crustaceans (solid line) compared to herbivorous (stippled line) (**Fig. 2**). The more water-soluble α-HCH, on the other hand, did not differ due to diet, and the variance seen in the box plot is due to other sources of variability such as habitat choice and geography.

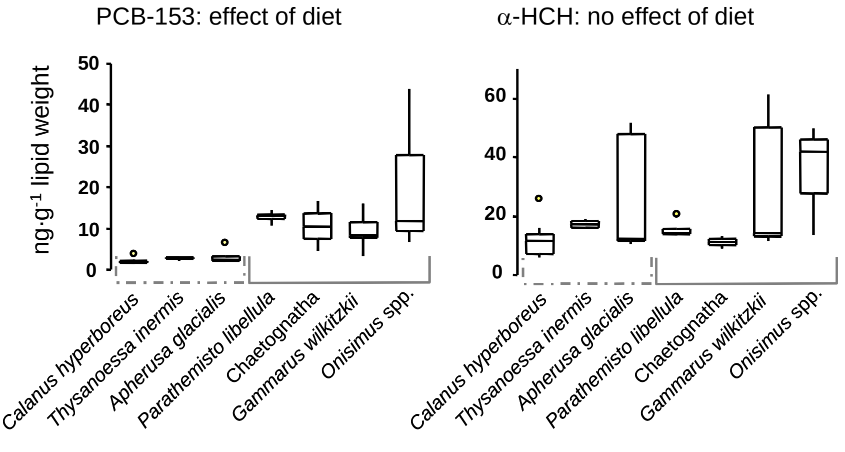


Figure 2. Dietary influence on bioaccumulation also among invertebrates[11].

When a broader range of the food web is considered, the OCs biomagnify in different degrees: i) no biomagnification for compounds like γ-HCH, ii) biomagnification at a steady rate throughout the food web for compounds such as PCB-153, iii) and biomagnification through the food web, but at a faster rate in warm-blooded than in cold-blooded species, like PCB-138 and *cis*-chlordane[12]. This different biomagnification potential leads to changes in the OC pattern from low in the food web to the highest trophic positions, and depend both on changes in exposure, and on differences in biotransformation and elimination abilities (**Fig. 3**). Usually, lower trophic levels are dominated by water soluble compounds similar to the technical mixture or to the one seen in the abiotic environment, whereas the pattern in seabirds and seals is dominated by persistent parent compounds and metabolites.

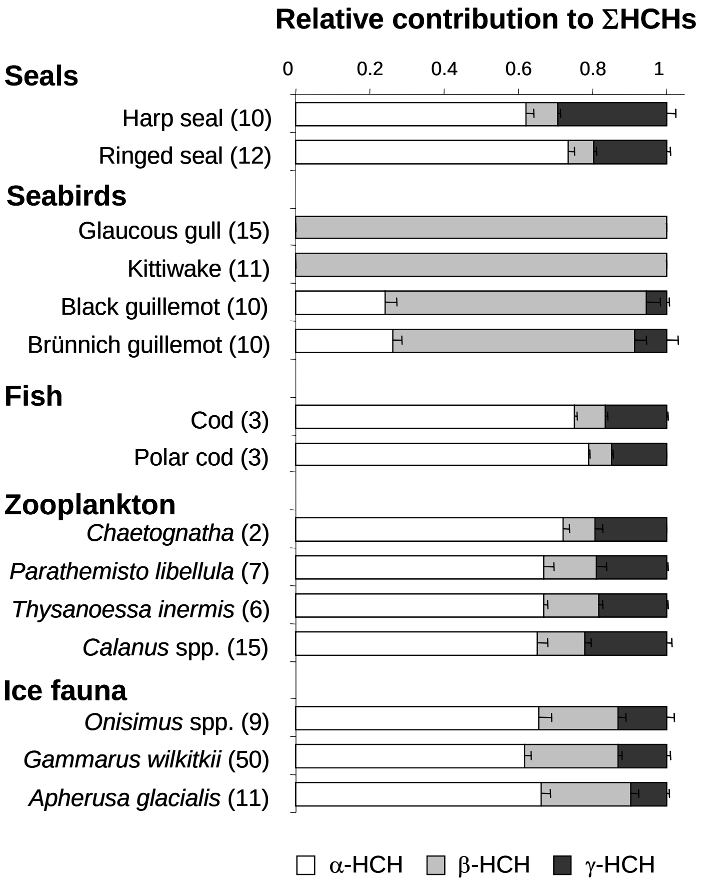
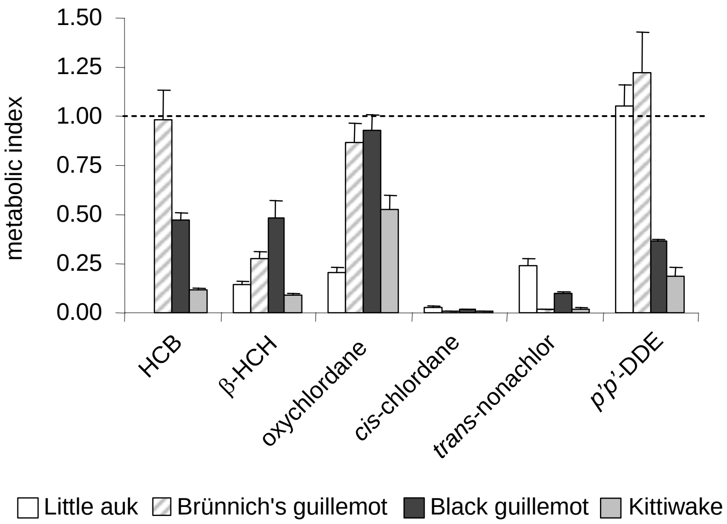


Figure 3. Changes in HCH isomer pattern in the marine food web.



New POPs are regularly reported from Arctic wildlife[13,14]. For example, polychlorinated naphthalene and perfluorinated alkyl substances (PFAS) is found in glaucous gulls on Svalbard[13,15], and brominated flame retardants and PFAS in polar bear[14,16]. Increasingly, studies on these compounds' behaviour in the food web, or at least among some selected species, is being conducted[2,3]. A study of polar cod, black guillemot and glaucous gull showed that the behaviour of lipid soluble POPs is uncorrelated to the more protein-soluble PFAS, when studying their interrelationship within one species[3]. However, when comparing biomagnification across the food web, the PFAS, PCBs and DDTs increase in the same magnitude across trophic levels[3].

Although legacy POPs decrease in the environment and "new" contaminants increase[9], legacy POPs often and still dominate the contaminant pattern[3], depending on species.

We have gained profound knowledge from all of these studies, but there are still several research topics to be addressed in the near future within the field of bioaccumulation and transfer in food webs. It is especially important to continue process and mechanism related research rather than to "repeat" descriptive studier with new chemicals. Further, valuable knowledge can be gained from using old POPs as models for new ones, e.g. in studies on how climatic changes will influence the contaminant behaviour and dynamic. Although this presentation has focussed on accumulation and transfer within food webs, another important question is what happens at the very base of the food web, in the uptake of contaminants from water to biota.

Figure 4. Metabolic index: biotransformation of chlorinated pesticides in seabirds, in relation to PCB-153 (=1), and corrected for pattern exposure from prey.

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References

1. Borgå K, Fisk AT, Hoekstra PF, Muir DCG. *Environ Toxicol Chem* 2004;23:2367-2385
2. Sørmo EG, MP Salmer, BM Jenssen, H Hop, K Bæk, KM Kovacs, C Lydersen, S Falk-Pettersen, GW Gabrielsen, E Lie, JU Skaare. *Environ Toxicol Chem* (accepted).
3. Haukås M. Master Thesis in Marine Ecology, Dept. og Aquatic BioSciences, University of Tromsø, Norway, September 2005.
4. Fisk, A.T., Hobson, K.A., Norstrom, R.J. *Environ Sci Technol* 2001;35:732-738.
5. Hoekstra PF, O'Hara TM, Fisk AT, Borgå K, Solomon KR, Muir DCG. *Environ. Pollut* 2003;124:509-522.
6. Muir DCG, Savinova T, Savinov V, Alexeeva L, Potelov V, Svetochev V. *Sci Total Environ* 2003;306:111-131.
7. Borgå K, Gabrielsen GW, Skaare JU. *Environ Pollut* 2001;113:187-198.
8. Ruus A, Ugland KI, Espeland O, Skaare JU. *Mar Environ Res* 1999;48:131-146.
9. de Wit C., Fisk A., Hobbs K., Muir D., Gabrielsen G., Kallenborn R., Krahn, M., Norstrom R. and Skaare, J. (2004) AMAP Assessment 2002: Persistent organic pollutants in the Arctic. Arctic Monitoring and Assessment Program. Oslo, Norway.
10. Tanabe S, Watanabe S, Kan H, Tatsukawa R. Marine Mammal Science 1988;4:103-124.
11. Borgå, K.; Gabrielsen, G. W.; Skaare, J. U. *Mar. Ecol. Prog. Ser.* 2002;*235*:157-169.
12. Hop H, Borgå K, Gabrielsen GW, Kleivane LK, Skaare JU. *Environ Sci Technol* 2002;36:2589-2597.
13. Verreault J, Letcher RJ, Muir DCG, et al. Environ Toxicol Chem 2005;24: 2486-2499.
14. Smithwick M, Norstrom RJ, Mabury SA, et al. *Environ Sci Technol* 2006;40:1139-1143
15. Verreault J, Houde M, Gabrielsen GW, et al. *Environ Sci Technol* 2005;39:7439-7445
16. Verreault J, Gabrielsen GV, Chu SG, et al. *Environ Sci Technol* 2005;39:6021-6028