SIZE-RELATED BIOACCUMULATION OF ORGANOCHLORINES IN ARCTIC SEA-ICE-AMPHIPODS

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Introduction

In the Arctic, the marginal ice zones in northern Barents Sea and the Greenland Sea have been proposed as areas of high exposure to organisms of organic pollutants like organochlorines[1]. Organochlorines are transported to the Arctic on a long range through the atmosphere, river outlets and ocean currents[2]. Within the Arctic, drifting sea-ice has been suggested as an important transport vector of sediments containing contaminants[1].

Several organisms, such as ice-amphipods of different taxa, live associated with the sea-ice their whole life cycle[3]. Ice-amphipods are recognised as trophic links between ice-algae and ice-associated meiofauna, and larger vertebrate predators such as fish, seabirds and seals[4,5,6]. The ice-amphipods are omnivorous, feeding largely on detritus and algae lumps[7]. However, the species differ in their omnivorous behaviour; some species are mainly herbivorous while others are more carnivorous and necrophagous[7,8,9]. In aquatic organisms, the burden of contaminants may be related to increasing size due to changes in diet and behaviour, surface-to-volume-ratio (influence the direct partitioning with water across the gills), total metabolism and xenobiotic metabolism ability[10]. Previous results indicate that sea-ice origin and the uptake through the diet are most important in determining the burden of organochlorines in ice-amphipods[11]. Since the ice-amphipod *Gammarus wilkitzkii* has a 5-6 years life span, and switches to a less herbivorous diet with increasing age and size[12,13], we predicted that the organochlorine burden would increase with size.

The aim of the present study is to investigate the relationship between organochlorine burden and size in the ice-amphipod *G. wilkitzkii*, and the relationship between diet preference, between-year-variation and organochlorine burden in the ice-amphipods *G. wilkitzkii*, *Apherusa glacialis* and *Onisimus* spp.

Methods and Material

The ice-amphipods were collected in the marginal ice zone north of Svalbard (Fig. 1, Area 1) and in the Fram Strait (Fig. 1, Area 2) in September 1998 and 1999 by SCUBA divers using an electric suction pump[14] or a hand-held net[15]. Individuals of *G. wilkitzkii* were separated in two size categories; small (0-25 mm) and large (>25 mm). All samples were stored frozen (-20°C) until analyses. The organochlorine content was determined by HRGC-ECD as described previously[11]. The samples were analysed for the content of α-, β- and γ-hexachlorocyclohexane (HCHs), hexachlorobenzene (HCB), *cis*-chlordane, oxychlordane, dichlorodiphenyltrichloroethane *p,p'*-DDE, and polychlorinated biphenyls (PCB congeners -28, -31, -52, -99, -105, -138, -153, -180).

Due to similar chemical properties, many of the organochlorine contaminants found in the ice-amphipods correlated, and principal component analysis (PCA[16]) was therefore applied on all compounds to reduce the variables in the statistical analyses. Prior to the PCA, lipid weight concentrations ($ng \cdot g^{-1}$ lw) were logarithmically transformed to reduce variance heterogeneity and to normalise data.

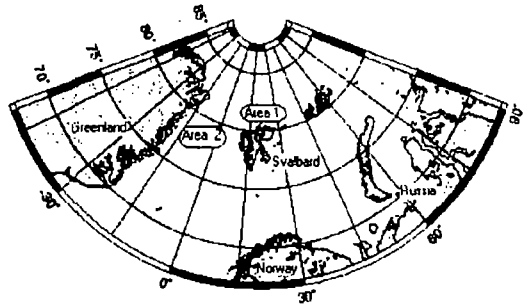

Figure 1. Sampling areas in the Arctic in 1998 and 1999.

Only principal components (PC) with eigenvalues > 1 were included in the statistical analyses[16]. The samples' scores on the extracted PCs were used as dependent variables in analysis of variance to investigate the effect of size on organochlorine burden in *G. wilkitzkii*, and the variation between years for all species. Each analysis was controlled for the variation introduced by significant independent variables such as taxon, sampling area, lipid content and year.

Results and Discussion

The mean levels of all organochlorine compound classes in the ice-amphipods were generally low, ranging from about 2 to about 300 ng·g lw[11]. The PCA applied on *G. wilkitzkii* extracted two PCs,

Table 1. Extracted principal components (PC) based on logarithmically transformed concentrations. Loadings > |*0.60*| are considered to correlate significantly on the PC[16].

	SIZE		YEARS	
	PC 1	PC 2	PC 1	PC 2
Eigenvalues	8.8	3.4	9.3	3.0
% total variance	59.0	22.5	62.0	19.7
Loadings:				
HCB	*0.86*	0.31	*0.91*	-0.11
α-HCH	-0.46	*0.67*	-0.08	*-0.80*
β-HCH	0.03	*0.64*	0.32	*-0.68*
γ-HCH	-0.11	*0.90*	0.27	*-0.89*
Oxychlordane	*0.88*	0.27	*0.92*	-0.18
Cis-chlordane	*0.95*	0.16	*0.97*	-0.05
p,p'-DDE	*0.96*	-0.15	*0.96*	0.14
PCB-28	*0.68*	0.52	*0.79*	-0.29
PCB-31	0.50	*0.75*	*0.72*	-0.50
PCB-52	*0.93*	0.14	*0.79*	-0.09
PCB-99	*0.95*	0.25	*0.97*	-0.06
PCB-105	*0.89*	-0.33	*0.86*	0.42
PCB-138	*0.78*	-0.56	*0.80*	0.53
PCB-153	*0.84*	-0.32	*0.88*	0.29
PCB-180	0.84	-0.25	0.85	0.31

where HCHs and PCB-31 had highest absolute loadings on PC 2, while the rest of the components had highest absolute loadings on PC 1 (Table 1). The PCA applied on all taxa extracted two PCs, where PCBs, chlordanes, *p,p'*-DDE and HCB had highest absolute loadings on PC 1, while HCHs had highest absolute loadings on PC 2 (Table 1).

In *G. wilkitzkii*, the levels of HCB, Chlordanes, *p,p'*-DDE and PCBs (analysed by scores on PC 1) increased from the small to the large size group ($F_{1,46}$=76.0, p=0.0001) (adjusted R^2=0.84), whereas no difference was found between the size groups along PC 2 ($F_{1,45}$= 1.6, p=0.2083) (adjusted R^2=0.87). The compounds along PC 1 are highly lipophilic with high octanol-water partitioning coefficients and high affinity to the amphipod's lipids.

HCHs and PCB-31 along PC 2 are less lipophilic, with a lower octanol-water partitioning coefficient and a greater potential for direct partitioning between the organism's lipids and the seawater. Thus, size-related-bioaccumulation seem to be most important for the more lipophilic and biomagnifying contaminants, such as PCB-153 and PCB-138 (Table 1, Fig. 2). This is consistent with the bioaccumulation pattern found between ice-amphipod taxa with different diets[11], where the concentrations of PCBs, DDTs, HCB and Chlordanes increased with the amphipod's trophic position, whereas no difference was found in the concentrations of HCHs.

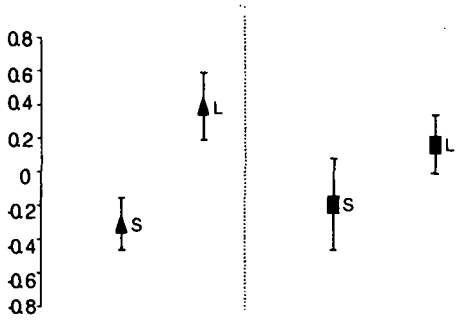

Figure 2. Mean score and standard error on PC 1 (▲) and PC 2 (■) by the samples in size category small (S) and large (L) in *Gammarus wilkitzkii*.

The increase in PCBs, HCB, chlordanes and *p,p'*-DDE from small to large *G. wilkitzkii* was also consistent with our prediction based on previous diet studies[7,8,13], where juvenile and young adults (small, 0-2 years) of *G. wilkitzkii* were found to have a more herbivorous feeding habit than older adult specimens (large, 3-5 years)[12]. Whereas juvenile specimens have a diet based on ice-algae (diatoms), the growing individuals gradually switch to a more carnivorous diet, constituting e.g. other crustaceans.

The load of organochlorines in all the ice-amphipods (*G. wilkitzkii*, *A. glacialis* and *Onisimus* spp.) was mainly related to sampling areas[11], which were influenced by sea-ice of different origin[17]. In addition, the samples' scores on PC 1 decreased, while the scores on PC 2 increased from 1998 to 1999 (PC 1: $F_{1,65}$=6.3, p=0.0142, adjusted R^2=0.73; PC 2: $F_{1,64}$=358.3, p=0.0001, adjusted R^2=0.87) (Fig. 3). Since PCBs, chlordanes, HCB and *p,p'*-DDE correlated positively with PC 1, their concentrations were thus slightly lower in 1999 than 1998. Also the HCH-concentrations were lower in 1999 than 1998, since HCHs correlated negatively with PC 2.

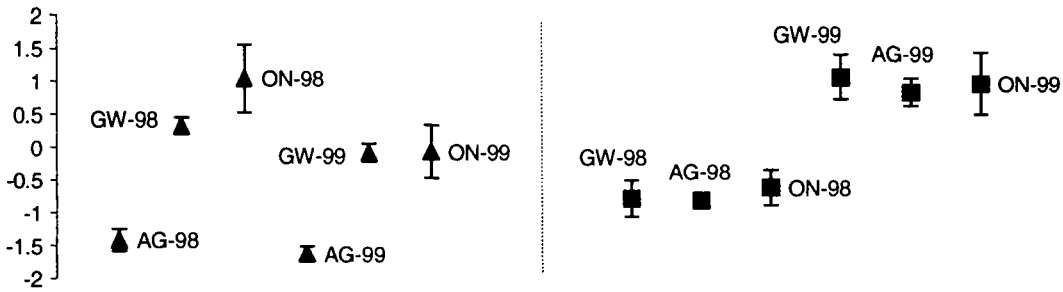

Figure 3. Mean score and standard error on PC 1 (▲) and PC 2 (■) by *Apherusa glacialis* (AG), *Gammarus wilkitzkii* (GW) and *Onisimus* spp. (ON), in the year 1998 (98) and 1999 (99).

Even though there is variation in organochlorine concentrations between years, the taxa's scores on PC 1 and PC 2 are relatively constant, with increasing scores on PC 1 from *A. glacialis* to *G. wilkitzkii* and *Onisimus* spp., whereas there is no difference between the taxa on PC 2 (Fig. 3). Also, the difference between the years is less for PC 1 than PC 2 (Fig. 3). Our data are consistent with assumptions that lipophilic contaminants like PCBs have a high bioaccumulation potential,

whereas less lipophilic compounds like HCHs have a higher partitioning potential from the body lipids to the seawater[18]. The reduced levels of organochlorines from 1998 to 1999 may be due to variation in the transport of contaminants to the Arctic ice pack, both from atmospheric deposition, river run-off and sea-ice production. However, there are few data available, and the observed concentrations may thus be within the "normal" range of organochlorine concentrations found in Arctic ice-amphipods.

Both for studies of size-related bioaccumulation and of temporal variation, higher resolution of the material are needed. However, during our work with ice-associated fauna in the marginal ice zone, a higher resolution was not possible due to the requirement of many organisms per sample for organochlorine analysis and the requirements of a research vessel and divers during fieldwork.

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