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Persistent organic pollutants in benthic and pelagic organisms off Adélie Land, Antarctica

A. Goutte [a,c,*], M. Chevreuil [b], F. Alliot [b], O. Chastel [c], Y. Cherel [c], M. Eléaume [d], G. Massé [a,e]

[a] LOCEAN/IPSL, UMR7159, Université Pierre et Marie Curie, 75005 Paris, France
[b] Laboratoire Hydrologie Environnement, Ecole Pratique Des Hautes Etudes, UMR Sisyphe, Université Pierre et Marie Curie, 75005 Paris, France
[c] Centre d'Etudes Biologiques de Chizé, CNRS UPR 1934, 79360 Villiers-en-Bois, France
[d] Muséum National d'Histoire Naturelle, Département Milieux et Peuplements Aquatiques, UMR 7208 BOREA, CP26, 57 Rue Cuvier, 75231 Paris Cedex 05, France
[e] TAKUVIK, UMI3376 CNRS, Université Laval, G1V0A6 Québec, Canada

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ABSTRACT

The concentrations of polychlorinated biphenyls (PCB), hexachlorobenzene (HCB), pentachlorobenzene (PeCB) and polybrominated diphenylethers (PBDE) were described in benthic and pelagic species collected off Adélie Land, Antarctica. Strong differences were observed among species, with reduced PeCB and HCB levels in benthic species, and elevated PCB levels in the Antarctic yellowbelly rockcod, the Antarctic sea urchin and the snow petrel. Lower-chlorinated congeners were predominant in krill; penta-PCBs in benthic organisms; hexa- and hepta-PCBs in seabirds and cryopelagic fish. This segregation may result from sedimentation process, specific accumulation and excretion, and/or biotransformation processes. The presence of PBDEs in Antarctic coastal organisms may originate from atmospheric transport and partly from a contamination by local sources. Although POP levels in Antarctic marine organisms were substantially lower than in Arctic and temperate organisms, very little is known about their toxic effects on these cold-adapted species, with high degree of endemism.

1. Introduction

The remote Antarctic continent has long been considered to be pristine until contamination by persistent organic pollutants (POPs) was first documented in the 1970s (Risebrough et al., 1976). Polar areas are now considered as final sinks for pesticides and industrial chemicals, due to long-range atmospheric transport and cold-condensation (Simonich and Hites, 1995). Moreover, polar scientific stations as well as growing touristic activities represent an additional source of contamination (e.g. Negri et al., 2006; Hale et al., 2008). Eco-toxicological studies have been extensively conducted in the Arctic, especially on apex predators, and have shown a broad spectrum of detrimental effects, ranging from endocrine disruption, immune dysfunctions, impaired fertility and ultimately high mortality (e.g. Letcher et al., 2010). Cold-adapted species are particularly vulnerable to toxic chemicals, because of their long life-span, low detoxifying activity and seasonal lipid accumulation followed by fasting period, which influence the toxicokinetics of organic pollutants (Clarke, 1983; Bright et al., 1995; Corsolini, 2009; Letcher et al., 2010). In Antarctic biota, only a few studies have reported the presence of polychlorinated biphenyls (PCB), dichloro-diphenyl-trichloroethane (DDT), hexachlorobenzene (HCB) and pentachlorobenzene (PeCB), and most of them focused on a restricted number of taxa (Kennicutt et al., 1995; Goerke et al., 2004; Negri et al., 2006; Corsolini, 2009; Cipro et al., 2010; van den Brink et al., 2011). Global policy measures have led to the reduction of PCBs and DDT releases since the 1970s in the United States and Europe and since 1993 in Russia (Breivik et al., 2004). In turn, this has caused a reduction of POPs levels in Antarctic pelagic fish and seabirds but not in benthic fish (van den Brink et al., 2011). Thus, the dynamics of POP persistence in Antarctic biota over time may differ between the pelagic and benthic zones. To better understand such trends, there is an urgent need to investigate POP levels in a large spectrum of species and trophic levels, differentiating between benthic and pelagic organisms in order to give a broader overview of POP burden in Antarctic marine ecosystems.

Among emerging toxicological compounds, other halogenated contaminants like polybrominated diphenylethers (PBDEs) are widely used as flame retardants in electronics and textiles since the 1970s. They present high environmental stability and persistence (Birnbaum and Staskal, 2004), as well as bioaccumulation and biomagnification properties through marine food webs, as demonstrated in zooplankton, fish, seabirds and seals (de Wit, 2002; Sørmo et al., 2006; Shaw et al., 2009). PBDEs have aroused growing scientific concerns since 2000, because of their exponential increase in many ecosystems including polar regions

* Corresponding author. Tel.: +33 549093514.
E-mail address: goutte@cebc.cnrs.fr (A. Goutte).

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(e.g. Ikonomou et al., 2002; Hale et al., 2003). Their toxic effects have been mainly described on vertebrates: specifically, PBDEs cause developmental neurotoxicity in rats (reviewed by Costa and Giordano, 2007), disrupt thyroid functions because of their structural similarities with thyroxine (Zhou et al., 2002), and act as estrogen-receptor agonists (Meerts et al., 2001). In that context, production of the penta-and octa-PBDE formulations ceased in the European Union and North America in 2004, but deca-PBDE is still produced and used. Few studies have recently described PBDEs levels in Antarctic fish, seabirds and benthic organisms (Borghesi et al., 2008, 2009; Corsolini et al., 2006; Hale et al., 2008; Yogui and Sericano, 2009; van den Brink et al., 2011), and the current state of knowledge remains scarce in the Antarctic region.

The present study aims to describe the occurrence and levels of HCB, PeCB, PCBs and PBDEs in a broad spectrum of Antarctic organisms, collected off the coast of Adélie Land. The Pointe Géologie archipelago contains a highly diverse marine community, including epibenthic organisms, pelagic fish and seabirds (Micol and Jouventin, 2001; Gutt et al., 2007). However the distribution and abundance of POP in this rich ecosystem have never been explored. In the present study, we searched for the presence of PCBs, HCB, PeCB and PBDEs in euphausiids, ascidian, sea urchin, starfish, teleost fish and eggs of seabirds. Then, we investigated whether POP levels and classes of isomers differ between benthic and pelagic compartments, and among trophic levels.

2. Materials and methods

2.1. Study species and field procedures

The study was carried out near the Dumont D'Urville French station, in the Pointe Géologie Archipelago, Adélie Land, Antarctica (66°40'S, 140°01'E, Fig. 1). Table 1 summarizes information on specimen collection, including their habitats and feeding habits.

Antarctic krill *Euphausia superba* (Dana, 1850) and ice krill *Euphausia crystallorophias* (Holt and Tattersall, 1906) are mainly grazers and were collected using an Isaacs-Kidd Midwater Trawl (IKMT) in January 2011. Bald notothens *Pagothenia borchgrevinki* (Boulenger, 1902) were fished under the sea ice using a fishing rod in November 2010 ($N = 3$). This common cryopelagic fish feeds on sympagic zooplankton (La Mesa et al., 2004). Three abandoned eggs of Adélie penguins *Pygoscelis adeliae* (Wagler, 1832) and six abandoned eggs of snow petrels *Pagodroma nivea* (Forster, 1777) were collected in December 2007 and 2010. Adélie penguins prey upon krill and to a lesser extent fish, while snow petrels mainly feed on fish, thus occupying a higher trophic level than Adélie penguins (Ridoux and Offredo, 1989; Rau et al., 1992). Eggs are useful non-destructive samples to determine POP levels, because of the transfer of contaminants from mother to eggs (Verreault et al., 2006). For ethical reasons, only abandoned eggs were collected, although they may be more contaminated than viable eggs from successful breeders. A colony of the filter-feeder ascidian *Synoicum* sp. was collected using a trawl in January 2011 at 130-meter deep. Two specimens of the Antarctic sea urchin *Sterechinus neumayeri* (Meissner, 1900) and two specimens of the starfish *Saliasterias brachiata* (Koehler, 1920) were collected at ca. 35-meters deep by divers in January 2010 and using a beam trawl in January 2011, respectively. The urchin *Sterechinus neumayeri* is omnivorous, while the starfish *Saliasterias brachiata* is necrophagous (McClintock, 1994). Five specimens of the opportunistic demersal fish Antarctic yellowbelly rockcod *Notothenia coriiceps* (Richardson, 1844) were sampled on the seabed (35-meter deep) using a fishing rod, in the Pointe Géologie Archipelago in April 2010 and in December 2010.

All samples were frozen at −20 °C until they were assayed. POPs were analyzed in whole seabird eggs, fish muscle and the whole body of krill, ascidian, urchin and starfish. Krill samples were pooled due to their low wet weight. Ethical approval for all procedures was granted by the ethics committee of the Ministère de l'Environnement and the French Polar Research Institute (IPEV). The experiments conformed to the code of ethics of animal experimentation in the Antarctic.

2.2. Chemical analyses

Biological samples were freeze-dried for 48 h and were then ground to obtain a fine powder. The wet weight/dry weight ratio was determined (Table 1). Samples were extracted for the determination of pentachlorobenzene (PeCB), hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) according to Labadie et al. (2010) and Teil et al. (2012). Briefly, label internal standard (^{13}C-BDE −47, −153, −181, −209, and PCB −30, −107) were added to the samples (approximately 3 g dry weight) prior to extraction, and thoroughly dispersed with silica gel and acidic silica. Samples were then extracted with hexane/dichloromethane (1:1) in a sonication bath and centrifuged. This procedure was repeated twice and then the supernatant was concentrated and treated with H_2SO_4. After centrifugation and the removal of the acid layer, extracts were purified on a multilayer column (from top to bottom: acidic silica, 1 g, activated silica gel, 1 g and neutral activated alumina, 1 g). After sample loading, the first fraction was eluted with hexane (20 mL) and the second one was eluted with hexane/dichloromethane (8:2, 15 mL). External standards ^{13}C CB-209 and BB-209 were added to the second fraction previously transferred to an injection vial for PBDEs analyses. The PBDE-congeners analyzed in this study were: BDE-28, −47, −99, −100, −153, −154, −183 and −209. The external standard ^{13}C PCB-194 was added to the first fraction which was combined with the first one for PCB, PeCB and HCB analyses, with a GC–QQQ-MS/MS (EI, 70 eV). PCB-congeners with the following IUPAC numbers were analyzed: 28, 52, 77, 81, 101, 105, 110, 114, 118, 123, 126, 138, 153, 156, 157, 167, 169, 180 and 189. Analyses were carried out using a 7890 A gas chromatograph GC coupled to a 7000 A mass spectrometer (MS; Agilent Technologies, Massy, France). Analytical conditions for GC-MSMS are detailed in the Supplementary file. Identification of analytes was performed by comparing retention times with those determined with standard solutions. Quantification was performed by calculating the response factor for each analyte relative to its corresponding internal standards, and concentrations were obtained using a linear regression analysis of the peak area ratio versus the concentration ratio. MRM parameters for PCBs, HCB and PeCB are detailed in the Supplementary file. Class of isomer patterns was calculated as the percentage of each isomer class with respect to total PCBs.

2.3. Quality assurance and controls

For quality assurance, procedural blanks were analyzed in triplicate for each of the 10 samples and all data were blank corrected. Recovery experiments were performed on samples ($N = 3$ for each tissue type) spiked at 20 ng (Antarctic krill), 50 ng (urchin and muscle of Antarctic yellowbelly rockcod) and 100 ng (eggs of Adélie penguin) for PCBs, at 20 ng for tri-hepta BDE (all samples) and 200 ng for BDE-209 (all samples). Internal standards were added at the very last step of the procedure, directly in the injection vials, so as to asses overall procedure PeCB, HCB, PCB and PBDE recoveries. Spiked matrices were recovered within the acceptance ranges (i.e. 50–130% for 90% of the spiked analytes) suggested by Wade and Cantillo (1994). Method quantification limits (MQLs) for PeCB, HCB, PCBs and PBDEs were determined for Antarctic krill, urchin, muscle of Antarctic yellowbelly rockcod and egg of Adélie

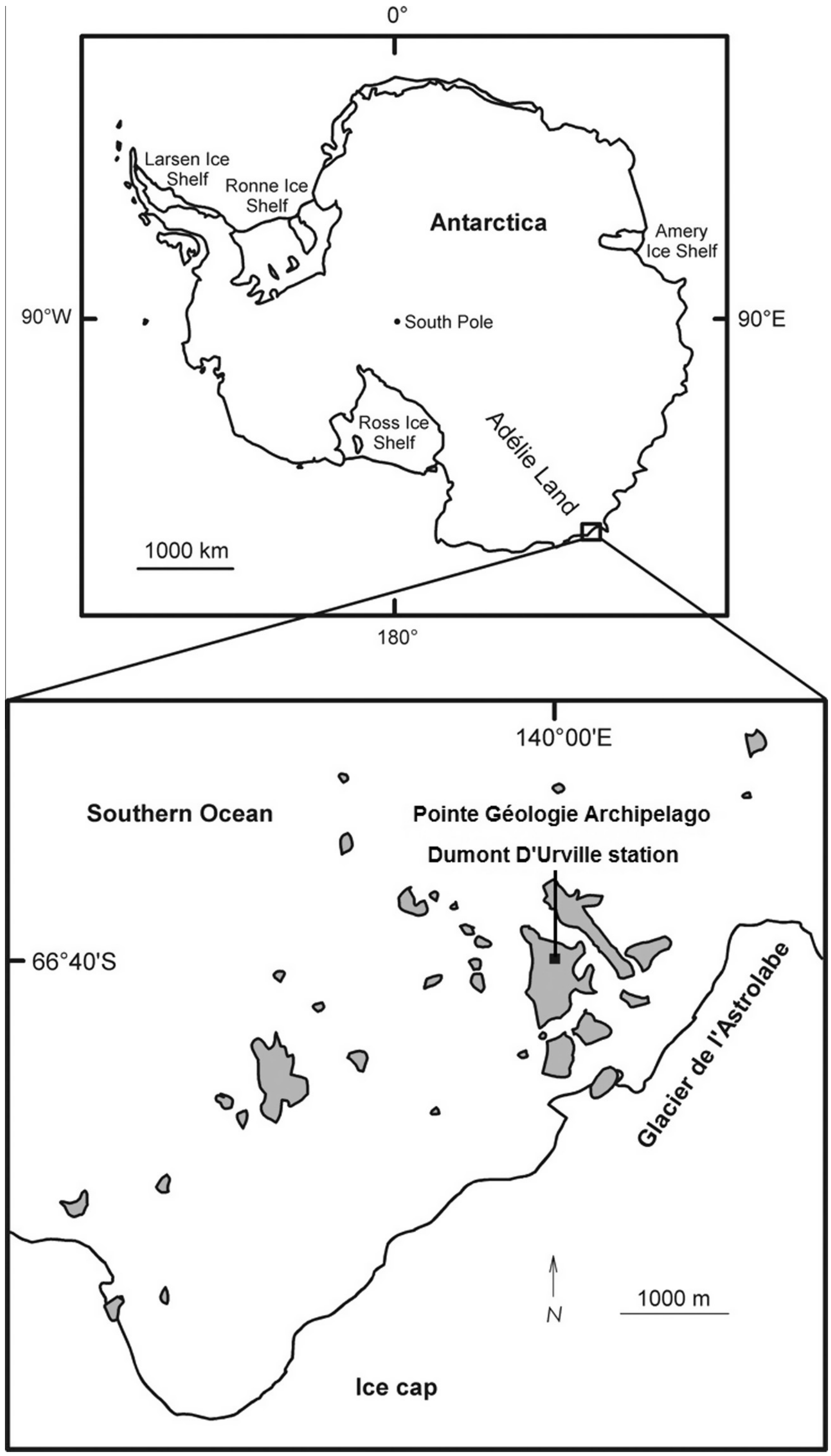

Fig. 1. Map indicating the location of Adélie Land in Antarctica. Biological samples were collected at the Pointe Géologie Archipelago, near the Dumont d'Urville research station.

penguins ($N = 3$ for each tissue type) as 10 times the concentration of spiked samples divided by the signal to noise ratio.

2.4. Statistical analyses

All statistical analyses were performed using R 2.14.2 (R development Core Team 2012). We used Kruskal–Wallis tests and Wilcoxon rank sum tests to compare POP levels (PeCB, HCB, $\sum$ PCBs and $\sum$ PBDEs in ng g^{-1} wet wt) among species, between closed species (the two krill species, the two fish species and the two seabird species) and between benthic and pelagic organisms.

3. Results

3.1. Differential POPs distribution between benthic and pelagic species

POP levels significantly differed between species (PeCB: Kruskal–Wallis $\chi^2 = 20.434$, $df = 8$, $p = 0.009$; HCB: Kruskal–Wallis

Table 1
Studied species with name, group, habitat (benthic or pelagic), feeding habit, tissue, sample size (N), and water content.

Latin name	Common name	Group	Habitat	Feeding habit	Tissue	N	% water content
Euphausia crytallorophias	Ice krill	Krill	Pelagic	Grazer	Whole body	6	73.4
Euphausia superba	Antarctic krill	Krill	Pelagic	Grazer	Whole body	2	73.4
Pagothenia borchgrevinki	Bald notothen	Fish	Pelagic	Zooplanktivorous	Muscle	3	64.2
Pygoscelis adeliae	Adélie penguin	Seabird	Pelagic	Krill eater, piscivorous	Egg	3	63.8
Pagodroma nivea	Snow petrel	Seabird	Pelagic	Piscivorous, krill eater	Egg	6	63.8
Synoicum sp.	Ascidian	Ascidian	Benthic	Filter feeder	Whole body	1	88.4
Saliasterias brachiata	Starfish	Starfish	Benthic	Necrophagous	Whole body	2	69.9
Sterechinus neumayeri	Antarctic sea urchin	Urchin	Benthic	Omnivorous	Whole body	2	78.4
Notothenia corriceps	Antarctic yellowbelly rockcod	Fish	Benthic	Omnivorous	Muscle	5	75.7

$\chi^2 = 21.742$, $df = 8$, $p = 0.005$; $\sum$ PCBs: Kruskal–Wallis $\chi^2 = 24.467$, $df = 8$, $p = 0.002$), except for $\sum$ PBDEs (Kruskal–Wallis $\chi^2 = 13.577$, $df = 8$, $p = 0.093$). This species-difference was partly explained by difference between benthic and pelagic species for PeCB ($W = 155$, $p = 0.006$, Fig. 2A) and for HCB ($W = 155$, $p = 0.016$, Fig. 2B). PeCB and HCB levels were much higher in pelagic than in benthic organisms, especially in bald notothens' muscles (for PeCB) and in seabirds' eggs (for HCB). Concentrations of $\sum$ PCBs did not differ between pelagic and benthic species ($W = 81$, $p = 0.422$, Fig. 2C). PBDEs were detected in 9 of the 30 analyzed biological samples: in starfish, Antarctic yellowbelly rockcod, Antarctic krill, egg of snow petrel, and bald notothen. Concentrations of $\sum$ PBDEs did not differ between benthic and pelagic species ($W = 72$, $p = 0.136$, Fig. 2D).

The ascidian was the least contaminated organisms in this study. The two krill species presented the lowest concentrations of POPs among pelagic species and the two krill species had no significantly different POPs concentrations (PeCB: $W = 5$, $p = 0.773$; HCB: $W = 6$, $p = 1$; $\sum$ PCBs: $W = 9$, $p = 0.429$) except significantly higher concentration of $\sum$ PBDEs in Antarctic krill ($W = 12$, p-value = 0.016). Bald notothens' muscle had higher PeCB concentration ($W = 15$, p-value = 0.017), higher HCB concentration ($W = 10$, $p = 0.571$), lower $\sum$ PCBs concentration ($W = 0$, p-value = 0.036) and not significantly different $\sum$ PBDEs concentration ($W = 6$, $p = 0.760$). Snow petrels' eggs were more than 3 times more contaminated by PCBs than Adélie penguins' eggs ($W = 18$, $p = 0.024$). This difference between the two seabird species was not detected for PeCB concentrations ($W = 7$, $p = 0.697$), HCB concentrations ($W = 11$, $p = 0.714$), and $\sum$ PBDEs ($W = 10.5$, p-value = 0.637).

3.2. Isomer class patterns

Among PCBs, low-chlorinated isomers (tri- and tetra-CBs) were dominant in ice krill and Antarctic krill, penta- and hexa-CBs were dominant in benthic species, while high-chlorinated isomers (hexa- and hepta-CBs) were dominant in the bald notothen, and in eggs of Adélie penguin and snow petrel (Fig. 3). Among PBDEs, only four congeners were detected: BDE-47 (tetra-BDE), −99, −100 (penta-BDE) and −209 (deca-BDE). The proportion of each congener varied between species (Fig. 4), with a predominance of deca-BDE in bald notothen and the starfish *Saliasterias brachiata*, of tetra-BDE in Antarctic yellowbelly rockcod and snow petrel, and of penta-BDE in Antarctic krill.

4. Discussion

4.1. POP levels in species from Adélie Land: comparison with other areas

In this study we present for first time the distribution and abundances of POPs in some species of the rich ecosystems of the pointe Géologie Archipelago, Adélie Land, Antarctica. It has to be noticed that the high density of seabirds in Adélie Land (Micol and Jouventin, 2001) may have contributed to a local import and concentration of persistent organic pollutants, through excretion, as previously described at Hop island (Roosens et al., 2007). Comparing POP burden with other results from polar and temperate areas remains difficult due to large differences in analytical methods, number of analyzed PCB and PBDE congeners and units among studies. Moreover, the sample size for each species was small, which is characteristic of opportunistic sampling studies in remote environments. When focusing on HCB levels, our results were similar to studies conducted in the Ross Sea on Antarctic krill, eggs of Adélie penguin and eggs of snow petrel (Corsolini et al., 2003, 2011). When focusing on PCB-153, a commonly found congener, the Antarctic yellowbelly rockcod and the starfish were less contaminated than benthic species and starfish species from the Belgian North Sea (Voorspoels et al. 2004). Hence POP levels in species off Adélie Land appear to be relatively low compared to temperate trophic webs.

4.2. Species difference in POPs levels

The present study highlights difference in POPs levels among Antarctic marine organisms off the Pointe Géologie Archipelago, Adélie Land. It has to be noticed that our statistical analyses were limited, because of the small sample size for each species. As a consequence, some results indicating species differences in POPs levels may actually be false positive (type I error).

POP bioaccumulation and biomagnification across polar marine food webs may partly explain species differences in POPs levels (e.g. Fisk et al., 2001; Goerke et al., 2004). Among the pelagic trophic food web, ice krill and Antarctic krill had the lowest POP levels, since they occupy a low trophic level. Moreover, concentrations of PCBs in eggs were higher in snow petrels than in Adélie penguins. It is known that concentrations of PCBs in seabirds'eggs are positively correlated to concentrations in plasma of the laying females (Verreault et al., 2006). This difference among the two seabirds' species could be due to their higher trophic level (Rau et al., 1992; Cherel, 2008), as Adélie penguin feeds mainly on krill, while snow petrel is predominantly piscivorous. Benthic species had no PeCB and reduced HCB levels compared to pelagic organisms. The filter feeder ascidian was the least contaminated in the present study, as it occupies the lowest trophic level. The sea urchins *Sterechinus neumayeri* and the benthic fish *Notothenia coriiceps* had the highest PCBs levels among benthic species, which could be attributed to their omnivorous feeding habit (McClintock, 1994), and/or to their potentially weak efficiency to metabolize contaminants (Brockington and Peck, 2001).

Difference in POP levels between pelagic and benthic species could be due to seasonal ice-dynamics and sedimentation process. Since large blooms of lipid-rich ice algae incorporate the hydrophobic POPs compounds (see Table 2 for Octanol–Water partition coefficient, hereafter log Kow), they are transported from the

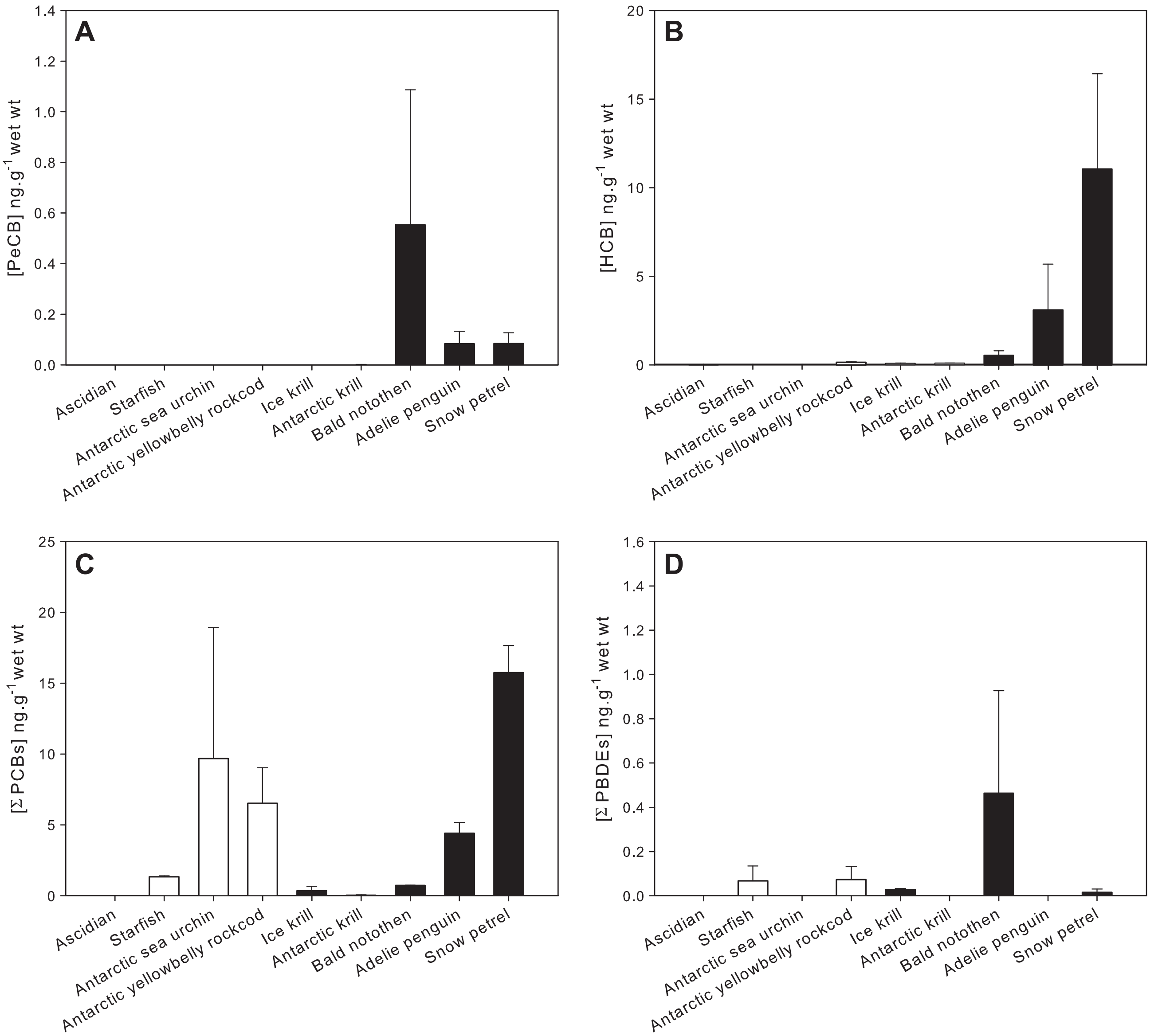

Fig. 2. POP levels in Antarctic marine organisms. Concentrations (mean and SE, ng g^{-1} wet wt) of PeCB (A), HCB (B), Σ PCBs (C), and Σ PBDEs (D) in ice krill (*N* = 6), Antarctic krill (*N* = 2), bald notothen (N = 3), eggs of Adélie penguin (*N* = 3), eggs of snow petrel (*N* = 6), ascidian (*N* = 1), starfish (N = 2), urchin (N = 2) and Antarctic yellowbelly rockcod (*N* = 5). Pelagic species are represented in black and benthic species are presented in white.

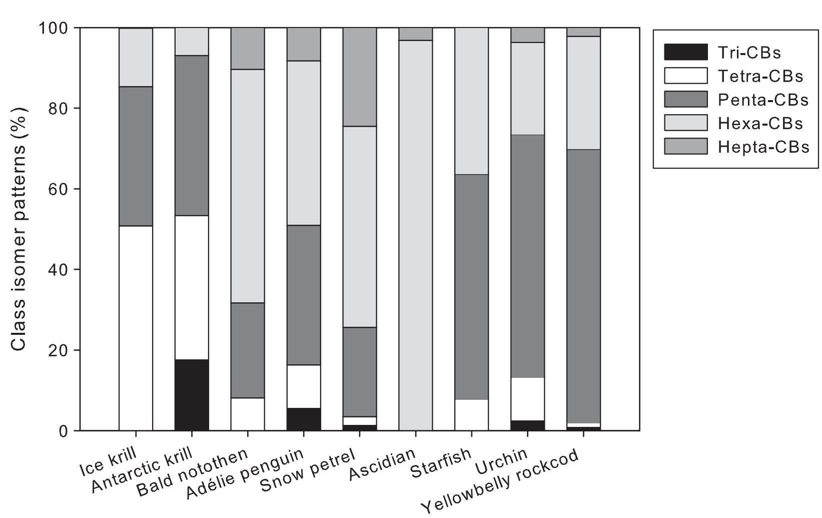

Fig. 3. Class PCB isomer patterns. Relative proportion of tri, tetra, penta, hexa and hepta-PCBs in ice krill (*N* = 6), Antarctic krill (*N* = 2), bald notothen (*N* = 3), eggs of Adélie penguin (*N* = 3), eggs of snow petrel (*N* = 6), ascidian (*N* = 1), starfish (*N* = 2), urchin (*N* = 2) and Antarctic yellowbelly rockcod (*N* = 5).

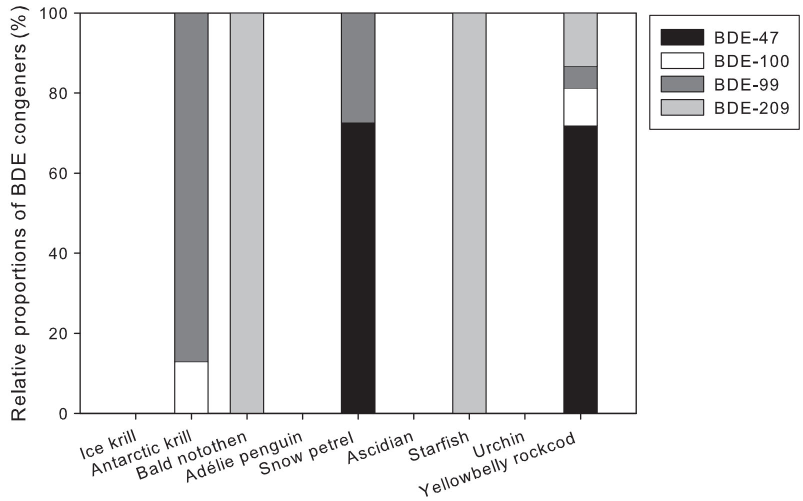

Fig. 4. Relative proportions of BDE congeners. Relative proportions of the detected BDE congeners (BDE-47, −100, −99, 209). PBDEs were found in only two Antarctic krill, one bald notothen, one snow petrel's egg, one starfish, and four Antarctic yellowbelly rockcod.

surface to the seabed through short but intense sedimentation (Wania and Daly, 2002; Dachs et al., 2002). Such effects of sea ice on sedimentation of PCBs have been put forward to explain the increase of PCBs levels in benthic fish during the last decades, in spite of a decrease in PCBs levels reported in pelagic seabirds and fish (Goerke et al., 2004; van den Brink et al., 2011). Furthermore, bio-deposition by filter-feeding organisms, such as blue mussels *Mytilus edulis*, has been shown to significantly increase the downward transport of PCBs from the water column to the bottom in a Baltic coastal ecosystem (Bjöerk et al., 2000). The low HCB levels and the absence of PeCB in benthic species could have resulted from the lower hydrophobicity of these compounds (see Table 2 for log Kow), so that they would be less incorporated into profuse blooms of lipid-rich algae and poorly transported to benthic organisms by sedimentation (Fahl and Kattner, 1993).

4.3. Isomer class patterns

Low-chlorinated PCBs (tri and tetra-CBs) were relatively abundant in the two euphausiids, while high-chlorinated PCBs (hexa and hepta-CBs) were relatively abundant in cryopelagic fish and seabird eggs, as previously noted (Corsolini et al., 2003). These results could have arisen from selective uptake of high-chlorinated PCBs and/or excretion of lower chlorinated congeners by higher-trophic level organisms, the longer lifespan of fish and seabirds compared to krill, and thus longer exposure time, and/or biotransformation process, such as enzymatic efficiency. It is important to note that differences may exist in PCB congener concentrations between eggs and plasma of the laying females (Verreault et al., 2006). Among benthic species, penta-PCBs were predominant, probably due to their high incorporation into ice algae compared to tri-and tetra-CBs (see Table 2 for log Kow).

4.4. PBDE exposure in Antarctic marine ecosystems

In spite of growing scientific interest worldwide, PBDEs exposure has been poorly studied in Antarctic biota (Borghesi et al., 2008, 2009; Corsolini et al., 2006; Hale et al., 2008; Yogui and Sericano, 2009; van den Brink et al., 2011). A recent cruise carried out from Southeast Asia toward Antarctica has confirmed the long-range atmospheric transport of PBDEs (Möller et al., 2012). In the present study, PBDEs were detected in less than a third of the biological samples. No clear differences in PBDE levels were observed between benthic and pelagic compartments. However, given our reduced sample size, we could not exclude an effect of sea ice dynamics and sedimentation on PBDE distributions.

Although previous studies have described the bioaccumulation and biomagnification of PBDEs with increasing trophic level (e.g. de Wit, 2002), our analyses did not reveal any accumulation across the food web. This may be attributed to our low sample size and to the low concentrations of PBDEs. The ability of PBDEs to bioaccumulate in organisms has been shown to increase with decreasing degree of bromination (de Boer et al., 2000). Accordingly, BDE-47, a tetra-brominated congener, was predominant in two upper trophic level species, the snow petrel and the Antarctic yellowbelly rockcod. BDE-209 was the main congener present in this study, as previously noted in some Antarctic organisms (Hale et al., 2008;

Table 2
Octanol–Water partition coefficient (Log Kow) for the studied compounds.

	Log Kow	Reference
PeCB	5.17	
HCB	5.5	
PCB28	5.60	Ballschmiter et al. (2005)
PCB52	5.88	Ballschmiter et al. (2005)
PCB101	6.32	Ballschmiter et al. (2005)
PCB110	6.18	Ballschmiter et al. (2005)
PCB77	6.29	Ballschmiter et al. (2005)
PCB81	6.27	Ballschmiter et al. (2005)
PCB123	6.60	Ballschmiter et al. (2005)
PCB118	6.63	Ballschmiter et al. (2005)
PCB114	6.72	Ballschmiter et al. (2005)
PCB153	6.76	Ballschmiter et al. (2005)
PCB105	6.60	Ballschmiter et al. (2005)
PCB138	6.75	Ballschmiter et al. (2005)
PCB126	6.93	Ballschmiter et al. (2005)
PCB167	7.11	Ballschmiter et al. (2005)
PCB156	7.25	Ballschmiter et al. (2005)
PCB157	7.10	Ballschmiter et al. (2005)
PCB180	7.28	Ballschmiter et al. (2005)
PCB169	7.59	Ballschmiter et al. (2005)
PCB189	7.77	Ballschmiter et al. (2005)
PBDE28	5.94	Braekeveldt et al. (2003)
PBDE47	6.81	Braekeveldt et al. (2003)
PBDE100	7.24	Braekeveldt et al. (2003)
PBDE99	7.32	Braekeveldt et al. (2003)
PBDE154	7.82	Braekeveldt et al. (2003)
PBDE153	7.90	Braekeveldt et al. (2003)
PBDE183	8.27	Braekeveldt et al. (2003)
PBDE209	12.61	Hardy (2002)

van den Brink et al., 2011). The presence of PBDEs in Antarctica may originate from atmospheric transport and partly from a contamination by local sources such as touristic or research activities. Indeed, import of personal and professional goods (e.g. plastics, fabrics, electronic equipment) to Antarctic research stations, like McMurdo station might enhance the local release of this deca-brominated congener (Hale et al., 2008). In the present study, local input of BDE-209 is supposed to be relatively low, since less than 100 inhabitants are present in the Dumont D'Urville station during summer and less than 30 during winter. Although BDE-209 is thought to be of reduced toxicity, there is growing evidence that birds and fish are able to debrominate this congener into more toxic lower-brominated congeners (Luross et al., 2002; de Wit, 2002; Kuo et al., 2010; Stapleton et al., 2004; Tomy et al., 2004). As very little is known about the toxic consequences of PBDEs accumulation on Antarctic marine organisms, there is an urgent need to assess the combined effects of POP burden on these cold-adapted species with high degree of endemism.

5. Conclusion

The present study provides a new contribution to the scarce data on POPs levels, including PCBs and PBDEs levels in Antarctic marine species, especially in the highly diverse marine community of the Adélie Land coast. Our data showed differences in POP distribution among species in accordance with their trophic levels and benthic–pelagic coupling.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.marpolbul.2013.10.027.

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