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Pesticide contamination profiles of water, sediment and aquatic organisms in the effluent of Gaobeidian wastewater treatment plant

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ABSTRACT

Organochlorine pesticides (OCPs, including DDT, HCH and HCB) and six indicator polychlorinated biphenyls (PCB 28, 52, 101, 138, 153, and 180) were measured in water, sediment, zooplankton, fish and Chinese softshell turtle (*Pelodiscus sinensis*) from Gaobeidian Lake, which is located in the effluent of Gaobeidian wastewater treatment plant (WWTP) in Beijing, China. DDTs were dominant except for in water. In water, the concentrations of DDTs (6.22 ng l^{-1}) and HCHs (18.0 ng l^{-1}) were less than the limits (l000 ng l^{-1} for DDTs and 5000 ng l^{-1} for HCHs). However, PCBs concentration (20.8 ng l^{-1}) exceeded the limit (14 ng l^{-1}) suggested by the United States Environmental Protection Agency (USEPA). The high ratio of *p,p′*-DDT/DDTs (0.80) in water suggested that DDTs had recently been discharged into the ambient environment despite a longtime ban in China. For fish and *Pelodiscus sinensis*, the accumulation patterns of OCPs and PCBs were different in muscle and liver. And HCB and PCB 153 were significant different in different species ($p < 0.05$). PCBs were dominated by PCB 52 in zooplankton, but by PCB 138 and 153 in *Pelodiscus sinensis*. The highest food web magnification factor (FWMF) was 4.83 for *p,p′*-DDT and the second highest was 4.36 for PCB 101 in Gaobeidian Lake. As compared with the other studies, biomagnification in the present study was not obvious. Trophic levels and age were two important factors that might contribute to the bioaccumulation in the present study.

1. Introduction

Organochlorine pesticides (OCPs) and polychlorinated biphenyls (PCBs) are two groups of the most studied compounds in environmental sciences due to their persistence, semi-volatile nature, accumulation, and toxicity. These compounds can accumulate in exposed organisms and cause adverse effects on both human and wildlife. OCPs were widely used in China from the 1950s to the 1980s and have been detected in many areas including high mountain lakes (Yang et al., 2006). Before being banned in 1983, the total amount of HCHs and DDTs in China were, respectively 4.9 and 0.4 million tons, which accounted for 33% and 20% of the total world production (Zhang et al., 2002). Although OCPs have been banned in most countries in the world (Manirakiza et al., 2002; Yang et al., 2006), these pesticides are still in use with low amounts in developing countries.

Nowadays, the reclamation of wastewater is more and more important for the continuously increasing water requirement (Chen et al., 2005). In Beijig, China, with the increase of population and the coming of 2008 Olympic Games, the existing eight WWPTs cannot meet the requirement any longer, which makes another seven WWPTs to be constructed. Municipal waste water is composed of domestic, industrial and un-off waters from urban areas (Pardos et al., 2004). OCPs enter the environment mainly through non-point sources such as agricultural runoff and vaporization following their field application (Wang et al., 2007). In WWTPs, persistent organic pollutants (including OCPs, PCBs and so on) can derive as a component of urban or agricultural runoff or drainage into the sewerage system, including wet and dry deposition from the atmosphere, and via the contribution of industrial discharges (Katsoyiannis and Samara, 2004). Therefore, WWTPs have been recognized as an important source of toxic contaminants to the aquatic environment (Pham and Proulx, 1997; Katsoyiannis and Samara, 2004; Pardos et al., 2004). Studies on concentrations of OCPs and PCBs in WWTP effluents are becoming more important. Gaobeidian Lake has a surface area of about 0.15 km^2 and its water mainly comes from Gaobeidian WWTP (Fig. 1), which processes approximately 1.0 million tons of wastewater per day and discharges 30% of its effluent into Gaobeidian Lake. The water in Gaobeidian

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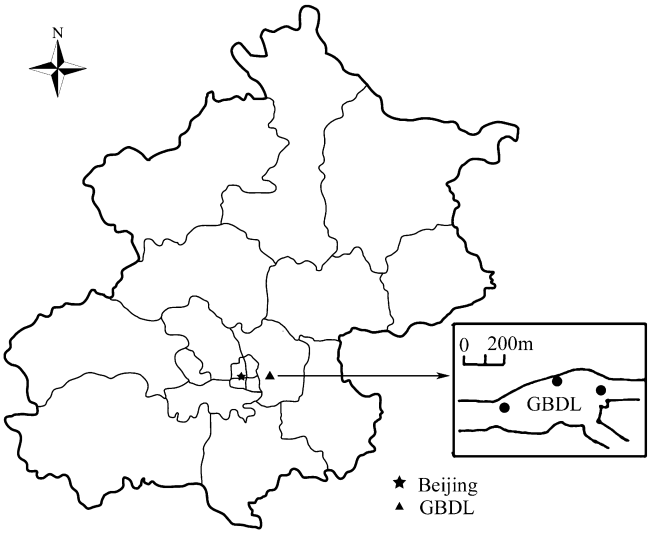

Fig. 1. Map of Gaobeidian and sampling sites. GBDL: Gaobeidian Lake. • means the sampling sites for water and sediment.

Lake first runs into Tonghui River and finally into the largest estuary, Bohai Bay in China.

In this study, a detailed examination was carried out on OCPs and PCBs pollution in Gaobeidian Lake. Water, sediment, zooplankton, fish and *Pelodiscus sinensis* were collected and the contamination profiles of DDT, HCH, HCB and PCBs (28, 52, 101, 138, 153, and 180) were measured. The distribution and bioaccumulation of these compounds were discussed in the ecosystem.

2. Materials and methods

2.1. Sample collection

Gaobeidian Lake (39°54′N, 116°31′E) was located in the effluent of Gaobeidian WWTP, which is the largest WWTP in Beijing, China. The wastewater from Gaobeidian WWTP was directly discharged into the Lake. The temperature of surface water was (29.7 ± 10.6) °C in the lake. Water (n = 6) and surface sediment (n = 6) were collected from three sites (Fig. 1). Zooplankton, fish (including *Cyprinus carpio* (n = 8), *Carassius auratus* (n = 8), *Oreochromis niloticus* (n = 3), and *Clarias lazera* (n = 5)) and Chinese soft-shell turtle (*Pelodiscus sinensis*) (n = 3) were also collected in Gaobeidian Lake. Surface sediment was sieved (63 μm pore size) and then freeze-dried. Zooplanktons (dominating species were *Moina rectirostris*, *Moina micrura* and *Moina macrocopa*) (n = 5) were collected with a 30 μm net and were then concentrated by centrifugation. Muscle and liver of fish and *Pelodiscus sinensis* were sampled, and then all the muscle of one sample was pooled together after they were transferred to laboratory. The age of both *Cyprinus carpio* and *Carassius auratus* ranged from age 3 (n = 4) to age 4 (n = 4), and the age of *Oreochromis niloticus* and *Clarias lazera* were less than age 1 and 5, respectively. All water, sediment, fish, *Pelodiscus sinensis*, and some zooplanktons (n = 3) were collected from December 12 to 25, 2005. The other zooplanktons (n = 2) were collected on October 5, 2006. All samples were kept at −20 °C until analysis.

2.2. Extraction and analysis

The sediment and organisms samples were extracted and cleaned up according to the method (Yang et al., 2006). For water, extraction and clean-up were performed according to the method (Wurl and Obbard, 2005). The samples were analysed for OCPs (HCB, α-HCH, β-HCH, γ-HCH, δ-HCH, *p*,*p*′-DDD, *p*,*p*′-DDE, *p*,*p*′-DDT, and *o*,*p*′-DDT) and six indicator PCBs (PCB 28, 52, 101, 138, 153, and 180). Results were obtained by Agilent 6890 with a ^{63}Ni electron capture detector (micro-ECD) and a column of 30 m length × 0.25 mm i.d × 0.25 μm film thickness was used for separation of OCPs and PCBs. The main peaks in selected samples were confirmed by a Finnigan GC–MS (PolarisQ, USA) using a 50-m DB-5 MS column with He carrier gas. Blanks and recoveries were checked every 8 to 12 samples. High, medium, and low levels of blank and matrix recoveries were analyzed during the experiment. One point standard solution was run every 8 to 10 samples during analysis to detect any deviation in the response of the system. Recoveries of OCPs and PCBs ranged from 73.75% for β-HCH to 98.12% for HCB. Method detection limits (MDLs) ranged from 0.08 ng g^{-1} (ng ml^{-1}) for α-HCH to 0.34 ng g^{-1} (ng ml^{-1}) for *p*,*p*′-DDT. The blanks, recoveries, and deviations were within the acceptable ranges.

3. Results and discussion

3.1. OCPs and PCBs in lake water and sediment

Mean concentrations of compounds in lake water and sediment were, respectively in the following ranking order: PCBs > HCHs > DDTs > HCB and DDTs > HCB > PCBs > HCHs (Table 1). β-HCH and PCB 153 were the most abundant compounds among HCHs and PCBs. In water, HCHs concentration (18.0 ng l^{-1}) was less than 5000 ng l^{-1} suggested by GHZB1-1999 (Chinese guideline in the grade 1–3 surface) and DDTs concentration (6.22 ng l^{-1}) was less than l000 ng l^{-1} suggested by both GHZB1-1999 and the United States Environmental Protection Agency (USEPA). However, PCBs concentration (20.8 ng l^{-1}) exceeded the limit (14 ng l^{-1}) suggested by USEPA.

β-HCH was dominant and the ratio of β-HCH/HCHs ranged from 0.30 to 0.39 in lake water and 0.25 to 0.47 in sediment (Fig. 2a). This might be explained by the fact that α-HCH can be isomerized to β-HCH which has the lowest volatility and also is more persistent with respect to microbial degradation (Howard, 1992; Kouras et al., 1998; Andersen et al., 2001; Rajendran et al., 2005).

The compositions of DDT isomer were different in lake water and sediment. The dominant isomers were *p*,*p*′-DDE in sediment and *p*,*p*′-DDT in water (Fig. 2b). High percentage of *p*,*p*′-DDT can be considered as an indicator of new DDT discharge into ambient environment (Willett et al., 1998). The high ratio of *p*,*p*′-DDT/DDTs (0.80) in lake water suggested that DDTs had recently been discharged into the ambient environment despite a longtime ban in China.

As for PCB, PCB composition indicated that the distribution patterns in lake water and sediment were similar and both dominated by higher chlorinated PCB 138 and 153 (Fig. 2c). But some investigations have proved that lower chlorinated PCBs are adapted to solve in water while higher chlorinated PCBs are likely adsorbed to suspended particulate material (Rajendran et al., 2005). The difference between previous studies and our work may be the higher temperature in our study. High temperature may disturb the exchange of water–air and water-sediment in the lake and will accelerate the water–air exchange. PCBs in sediment ranged from 0.91 to 3.70 ng g^{-1} dw (Table 1), which was lower than the values (less than 6.51 ng g^{-1} dw) obtained by Zhang et al. (2004).

3.2. OCPs and PCBs in zooplankton

Zooplankton is an important component affecting food web/chain transfer of organic contaminants. And the concentrations of

Table 1
The concentrations (range and mean) of OCPs and PCBs in water, sediment, zooplankton, fish and *Pelodiscus sinensis*

Compounds	Water[a] (n = 6) Min–max (Mean)	Sediment[b] (n = 6) Min–max (Mean)	Zooplankton[c] (n = 6) Min–max (Mean)	ON[c] (n = 8) Min–max (Mean)		PS[c] (n = 8) Min–max (Mean)		CC[c] (n = 5) Min–max (Mean)		CA[c] (n = 3) Min–max (Mean)		CL[c] (n = 3) Min–max (Mean)	
				Muscle	Liver	Muscle	Liver	Muscle	Liver	Muscle	Liver	Muscle	Liver
HCB	**1.65–4.51 (3.23)**	**2.53–3.12 (2.80)**	**1.58–2.36 (1.95)**	**1.28–3.24 (2.48)**	**3.97–37.2 (16.1)**	**0.61–1.57 (0.98)**	**1.02–5.58 (2.85)**	**1.37–10.6 (6.22)**	**4.82–83.0 (43.9)**	**2.78–11.8 (7.01)**	**12.4–29.3 (19.9)**	**3.65–27.4 (10.5)**	**4.10–25.0 (12.9)**
α-HCH	1.65–5.96 (2.76)	0.21–0.42 (0.33)	nd-0.08 (nd)	0.28–0.36 (0.31)	0.74–3.11 (1.58)	0.37–1.28 (0.71)	0.63–2.44 (1.55)	0.22–0.75 (0.45)	1.24–3.90 (2.53)	0.15–0.67 (0.33)	0.57–1.16 (0.85)	0.33–1.04 (0.60)	0.16–1.33 (0.73)
β-HCH	3.95–10.6 (6.49)	0.26–0.64 (0.46)	nd-0.48 (0.33)	0.80–1.80 (1.43)	3.90–37.2 (16.0)	1.01–1.13 (1.44)	8.43–20.4 (13.3)	0.73–7.10 (2.09)	9.18–26.6 (19.1)	0.70–7.45 (3.18)	2.49–9.37 (4.87)	1.46–5.86 (4.20)	2.31–14.5 (6.65)
γ-HCH	2.45–6.89 (4.42)	0.18–0.25 (0.21)	0.11–0.14 (0.13)	0.49–0.81 (0.67)	1.71–7.94 (3.87)	0.35–1.40 (0.76)	0.36–2.82 (1.58)	0.15–1.58 (0.80)	2.40–6.62 (4.88)	0.33–1.23 (0.59)	0.87–1.91 (1.37)	0.47–1.39 (0.76)	0.27–2.75 (1.14)
δ-HCH	3.34–5.21 (4.31)	0.20–0.32 (0.26)	nd-0.13 (nd)	0.38–0.54 (0.45)	0.76–1.13 (0.88)	0.42–2.45 (1.11)	0.73–1.02 (0.86)	0.22–0.51 (0.42)	0.46–2.89 (1.34)	0.35–0.63 (0.44)	0.64–1.56 (1.08)	0.34–0.83 (0.52)	0.19–0.76 (0.48)
HCHs	**13.2–26.7 (18.0)**	**1.02–1.48 (1.26)**	**0.46–0.78 (0.63)**	**1.88–3.33 (2.85)**	**7.12–49.4 (22.3)**	**2.32–6.13 (4.03)**	**10.2–26.6 (17.3)**	**1.59–9.81 (4.54)**	**4.58–14.0 (8.18)**	**1.85–9.94 (3.76)**	**13.5–36.9 (27.8)**	**2.86–8.48 (6.07)**	**3.25–18.8 (9.00)**
p,p′-DDD	nd–2.42 (0.55)	1.14–1.89 (1.43)	0.45–0.80 (0.59)	0.91–2.08 (1.37)	6.42–27.5 (13.6)	nd–0.23 (nd)	0.72–1.46 (1.20)	0.73–9.42 (4.49)	3.79–63.4 (25.4)	2.77–18.7 (10.3)	nd–41.2 (18.9)	2.47–11.8 (6.89)	5.85–16.0 (9.94)
p,p′-DDE	0.17–3.11 (0.80)	8.14–13.1 (9.99)	1.95–4.25 (2.99)	4.62–9.72 (6.82)	25.1–143 (67.1)	1.18–18.1 (7.12)	25.5–353 (137)	0.98–37.5 (17.5)	8.66–228 (159)	29.9–77.1 (52.2)	62.6–206 (120)	10.2–72.8 (32.6)	23.6–72.7 (46.2)
p,p′-DDT	5.23–13.5 (8.23)	0.47–1.37 (0.91)	nd (nd)	0.96–2.92 (1.64)	2.98–5.57 (4.04)	0.25–5.17 (2.08)	5.60–9.02 (6.86)	nd–3.03 (1.19)	1.60–26.4 (7.85)	0.97–2.41 (1.49)	0.59–1.80 (0.76)	nd–6.53 (1.82)	1.14–3.76 (3.01)
o,p′-DDT	nd–1.38 (0.76)	nd–0.72 (nd)	nd (nd)	nd (nd)	nd–0.37 (nd)	nd–0.40 (nd)	nd–0.72 (0.24)	nd–1.28 (0.51)	nd–4.44 (2.28)	0.31–1.10 (0.69)	0.58–1.16 (0.87)	nd–2.04 (0.86)	nd–3.90 (1.28)
DDTs	**0.17–14.4 (6.22)**	**10.3–15.6 (12.5)**	**2.68–4.93 (3.78)**	**6.68–12.8 (9.97)**	**35.1–176 (84.9)**	**2.38–23.3 (9.41)**	**35.9–360 (146)**	**1.91–44.5 (23.7)**	**14.96–300 (195)**	**33.8–93.1 (64.3)**	**65.0–249 (141)**	**13.5–92.7 (42.2)**	**31.8–92.3 (60.5)**
PCB 28	0.93–1.89 (1.32)	0.20–0.55 (0.35)	0.27–0.45 (0.36)	0.19–0.56 (0.43)	2.89–11.7 (5.92)	nd–0.40 (nd)	0.39–8.52 (3.29)	0.22–3.79 (1.85)	1.34–26.2 (13.6)	0.40–3.62 (2.23)	3.57–9.83 (5.94)	0.82–4.01 (1.69)	1.29–4.81 (2.43)
PCB 52	0.60–3.18 (1.88)	nd–0.67 (0.31)	nd–1.61 (0.60)	nd–0.28 (0.19)	0.40–8.10 (3.03)	nd–0.20 (nd)	0.39–2.37 (1.18)	nd–1.64 (0.57)	0.44–14.1 (6.07)	0.21–2.30 (1.31)	0.71–6.36 (3.36)	nd–5.56 (1.36)	0.40–2.87 (1.28)
PCB 101	0.34–5.26 (3.22)	nd–0.27 (0.19)	nd–0.23 (nd)	0.20–0.29 (0.26)	0.27–6.03 (2.26)	0.17–0.24 (0.21)	nd–0.86 (0.36)	nd–0.21 (nd)	0.23–2.28 (1.16)	nd–0.67 (0.28)	nd–3.94 (0.99)	nd–0.48 (0.22)	nd–0.44 (0.20)
PCB 138	0.33–6.22 (2.62)	nd–0.59 (0.20)	nd (nd)	nd–0.27 (0.15)	0.43–3.38 (1.43)	nd–2.26 (0.81)	1.70–6.08 (3.18)	nd–0.82 (0.25)	nd–8.01 (2.85)	1.01–4.02 (1.97)	0.34–1.68 (0.97)	nd–1.70 (0.41)	0.50–1.46 (1.06)
PCB 153	0.25–35.6 (12.7)	nd–1.80 (0.51)	nd–0.24 (nd)	nd–0.20 (nd)	0.75–2.12 (1.29)	nd–0.30 (nd)	2.71–5.55 (3.91)	nd–0.56 (nd)	0.35–9.58 (3.15)	0.27–1.38 (0.72)	0.84–7.42 (2.07)	0.14–6.90 (1.89)	0.15–0.62 (0.43)
PCB 180	nd–1.17 (0.34)	nd–0.13 (nd)	nd (nd)	nd–0.42 (0.24)	0.15–0.39 (0.23)	nd (nd)	0.70–1.19 (0.87)	nd–0.74 (0.11)	nd–1.25 (0.33)	nd–0.33 (0.12)	nd–0.77 (0.42)	nd–0.48 (0.14)	nd–0.25 (nd)
PCBs	**4.75–43.8 (20.8)**	**0.91–3.70 (1.61)**	**0.65–2.02 (1.19)**	**0.91–1.74 (1.42)**	**4.88–31.8 (14.2)**	**0.63–2.75 (1.58)**	**7.33–23.7 (12.8)**	**1.94–12.0 (6.18)**	**5.26–30.0 (13.3)**	**0.70–5.88 (3.16)**	**2.46–59.1 (26.9)**	**1.29–13.5 (5.70)**	**3.04–8.50 (5.50)**

nd represents target analytes with concentrations lower than LOD and were treated as zero when calculating the mean values.
ON, *Oreochromis niloticus*; PS, *Pelodiscus sinensis*; CC, *Cyprinus carpio*; CA, *Carassius auratus*; CL, *Clarias lazera*.
[a] Ng l^{-1}.
[b] Ng g^{-1} dw.
[c] Ng g^{-1} ww.

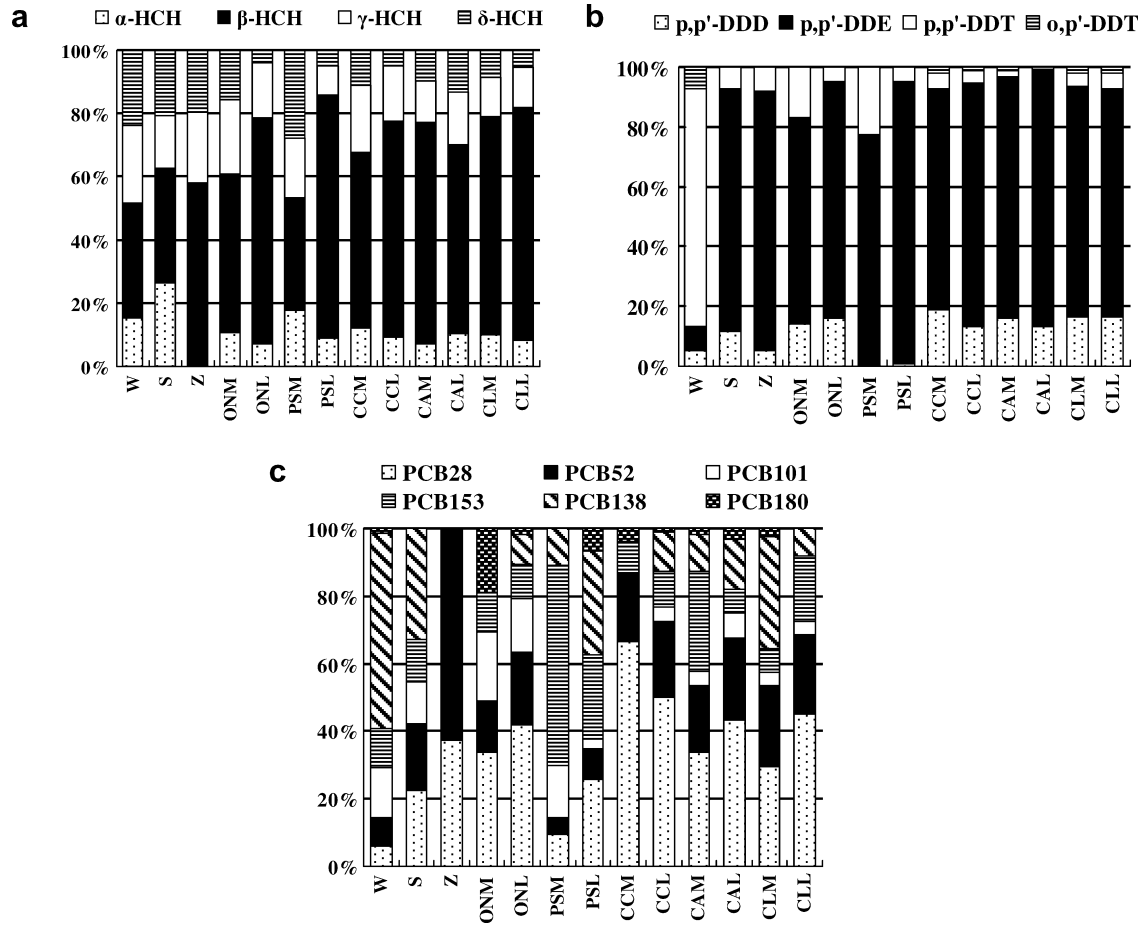

Fig. 2. Mean of the relative contribution of individual isomers to the sum of HCHs (a), DDTs (b) and PCBs (c) in water, sediment, zooplankton, fish and *Pelodiscus sinensis* (W, water; S, sediment; Z, zooplankton; ONM, muscle of *Oreochromis niloticus*; ONL, liver of *Oreochromis niloticus*; PSM, muscle of *Pelodiscus sinensis*; PSL, liver of *Pelodiscus sinensis*; CCM, muscle of *Cyprinus carpio*; CCL, liver of *Cyprinus carpio*; CAM, muscle of *Carassius auratus*; CAL, liver of *Carassius auratus*; CLM, muscle of *Clarias lazera*; CLL, liver of *Clarias lazera*).

contaminants at the base of food web/chain will have a profound effect on the concentrations at higher trophic levels (Fisk et al., 2001b). In zooplankton, the distribution pattern of HCHs, DDTs, HCB and PCBs was similar with that in sediment. β-HCH and *p*, *p*′-DDE were detected at levels of 0.33 ± 0.13 and 2.99 ± 0.94 ng g^{-1} ww and accounted for 56 ± 4% and 74 ± 2% of HCHs and DDTs, respectively. For the PCB congeners, PCB 28 and PCB 52 were dominant congeners, which were 0.36 ± 0.07 and 0.60 ± 0.67 ng g^{-1} ww and accounted for 43 ± 12% and 40 ± 31% of the six indicator PCBs, respectively (Fig. 2c). The results were consistent with those obtained in the previous studies (Fisk et al., 2001b; Braune et al., 2005). For example, Fisk et al. (2001b) found that PCBs in *Calanus hyperboreus* were dominated by lower chlorinated congeners. These findings may be due to the smaller size of zooplankton as well as its position in a lower trophic level and a lack of biotransformation capability compared with fish, mammals and birds (Braune et al., 2005).

3.3. OCPs and PCBs in fish and Pelodiscus sinensis

The distribution patterns of these contaminants were different in muscle and liver.

In muscle, the ranking order of average organic compounds (OCs: the sum concentrations of OCPs and PCBs) was *Carassius auratus* > *Clarias lazera* > *Cyprinus carpio* > *Oreochromis niloticus* > *Pelodiscus sinensis*, whereas, in liver, the ranking order was *Carassius auratus* > *Pelodiscus sinensis* > *Cyprinus carpio* > *Oreochromis niloticus*> *Clarias lazera*. The levels of HCHs, DDTs, PCBs, and HCB were consistently higher in liver than those in muscle in the present study (Table 1), which was consistent with the previous study (Metcalfe et al., 1999). The difference in patterns of these contaminants in liver and muscle tissue may reflect difference in contaminant metabolism, content and composition of lipids, or the degree of blood perfusion in the various tissues (Metcalfe et al., 1999).

In muscle, the mean HCHs concentrations ranged from 2.85 ng g^{-1} ww in *Oreochromis niloticus* to 6.07 ng g^{-1} ww in *Clarias lazera*. In liver, they ranged from 8.18 ng g^{-1} ww in *Cyprinus carpio* to 27.8 ng g^{-1} ww in *Carassius auratus*. HCHs concentrations were lower than DDTs concentrations, which contrasted with the patterns in water. One possible reason is that high metabolic clearance rates have been reported for HCH isomers in fish (Butte et al., 1991). β-HCH was dominant among HCHs (Fig. 2a). The ratios β-HCH/HCHs ranged from 0.36 to 0.70 in muscle and 0.53 to 0.83 in liver. The two ratios were both greater than those for the typical commercial HCHs (Willett et al., 1998). The ratios of α-HCH/γ-HCH in fish and *Pelodiscus sinensis* were both less than 4 (Fig. 2a), which could be explained by that the industrial HCHs were replaced by the purified active isomer γ-HCH in 1991 in China (Muir et al., 2003).

In muscle, DDTs accounted for 62 ± 4% of OCs in *Oreochromis niloticus*, 67 ± 7% in *Clarias lazera*, 63 ± 12% in *Cyprinus carpio*, 80 ± 3% in *Carassius auratus*, and 57 ± 27% in *Pelodiscus sinensis*. The ratio of DDT/OCs was more than 0.60 in 88% of the liver samples. The highest levels of *p*,*p*′-DDE, which was the most abundant compound

among DDT isomers, were up to 52.2 ± 16.9 ng g^{-1} ww in muscle of *Carassius auratus* and 159 ± 162 ng g^{-1} ww in liver of *Cyprinus carpio*, respectively. In general, DDT contains 75% of *p,p′*-DDT, 15% of *o,p′*-DDT, 5% of *p,p′*-DDE, and less than 5% other species (Kim et al., 2002). However, the ratios of *p,p′*-DDE/ DDTs in the present study ranged from 0.50 to 0.88 in muscle and from 0.49 to 0.98 in liver, respectively (Fig. 2b). The high *p,p′*-DDE levels detected in this study were not particularly surprising because previous studies have proved that *p,p′*-DDE was the major DDT residue in aquatic species (Naso et al., 2005; Sapozhnikova et al., 2005). For example, *p,p′*-DDE was detectable in 92% of fish muscle samples and DDE isomers accounted for approximately 70% of DDTs (Sapozhnikova et al., 2005). Meanwhile, *p,p′*-DDE was detectable in 81% of samples and ranged from nd (below the detection limit) to 11426 ng g^{-1} lipid (Naso et al., 2005). *p,p′*-DDE was the principal DDT isomer because it is the most bioaccumulative and persistent among the isomers in abiotic and biotic components of the aquatic ecosystems (Aguilar, 1984; Andersen et al., 2001). And *p,p′*-DDE is a product of the abiotic breakdown and biotic metabolism of *p,p′*-DDT (Muir et al., 2003).

HCB was found in all organisms and its concentrations ranged from 0.98 to 10.5 ng g^{-1} ww in muscle, which were higher than those in another study (Jiang et al., 2005). The accumulation process for HCB was different in different species ($p < 0.05$).

The highest concentration of PCBs (26.9 ± 18.1 ng g^{-1} ww) was found in liver of *Carassius auratus*. The accumulations of PCB congeners except PCB 153 were similar in different species. PCB 153 were different ($p < 0.05$) in different species in the present study (Fig. 2c), which was consistent with the previous study (Naso et al., 2005). PCB 28 was dominant in fish except in muscle of *Clarias lazera* (Fig. 2c). Previous works showed that those fishes feeding on zooplankton have the ability of biotransformation of PCBs (Brown, 1992; Sijm et al., 1992). However, higher chlorinated congeners PCB 138 and 153 were dominant in *Pelodiscus sinensis* that lives at the bottom of sediment and is carnassial animal. The difference could be explained by abiotic and biotic factors, such as degree of chlorination, logKow of the chemicals, recent habitat, and feeding habits (Naso et al., 2005).

3.4. Relationship of among contaminants in multiple media

There were positive relationships among HCB, HCHs and PCBs (r^2 from 0.47 for HCB and HCHs to 0.52 for HCB and PCBs, $p < 0.05$), which indicated that the accumulations of three compounds were similar in Gaobeidian Lake. There was no significant linear relationship between DDTs and HCHs ($r^2 < 0.10$, $p > 0.05$), which was contrary with the result ($r^2 = 0.83$, $p < 0.05$) observed by Manirakiza et al. (2002) who found that bioaccumulations of DDTs and HCHs were probably similar. The difference between the previous study and our study may result from sampling of different species from different environments.

The concentrations of α-HCH ($r^2 = 0.88$, $p < 0.05$ (Fig. 3a)) and β-HCH ($r^2 = 0.72$, $p < 0.05$ (Fig. 3b)) were, respectively correlated with γ-HCH. A significant positive correlation ($r^2 = 0.93$, $p < 0.05$) was also observed between β-HCH and HCHs in the present study (Fig. 3c). For PCBs, there was a positive relationship between PCB28 and PCB52 ($r^2 = 0.86$, $p < 0.05$) (Fig. 3 d), which indicated that bioaccumulations of the two compounds were probably similar in the present study. In liver, PCB 28 ($r^2 = 0.92$, $p < 0.05$) and PCB 52 ($r^2 = 0.91$, $p < 0.05$) were correlated with the sum of PCBs; however, no linear correlations were found between PCB 101/PCB 180 and total PCBs.

3.5. Bioaccumulation and biomagnification of OCPs and PCBs in food web

The processes of bioaccumulation and biomagnification of persistent contaminants are complicated because they may be affected by various factors including physiological and environmental factors, such as age, trophic levels, structure of food web,

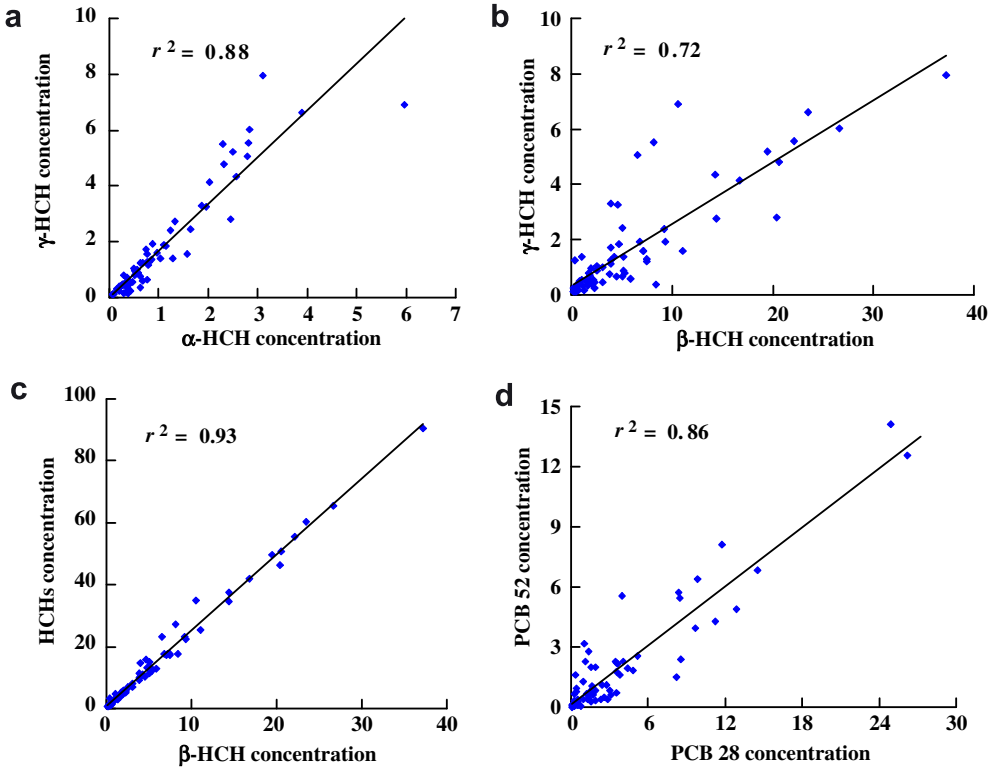

Fig. 3. The correlations among compounds. (a) for α-HCH and γ-HCH, (b) for β-HCH and γ-HCH, (c) for β-HCH and HCHs and (d) for PCB 28 and PCB 52.

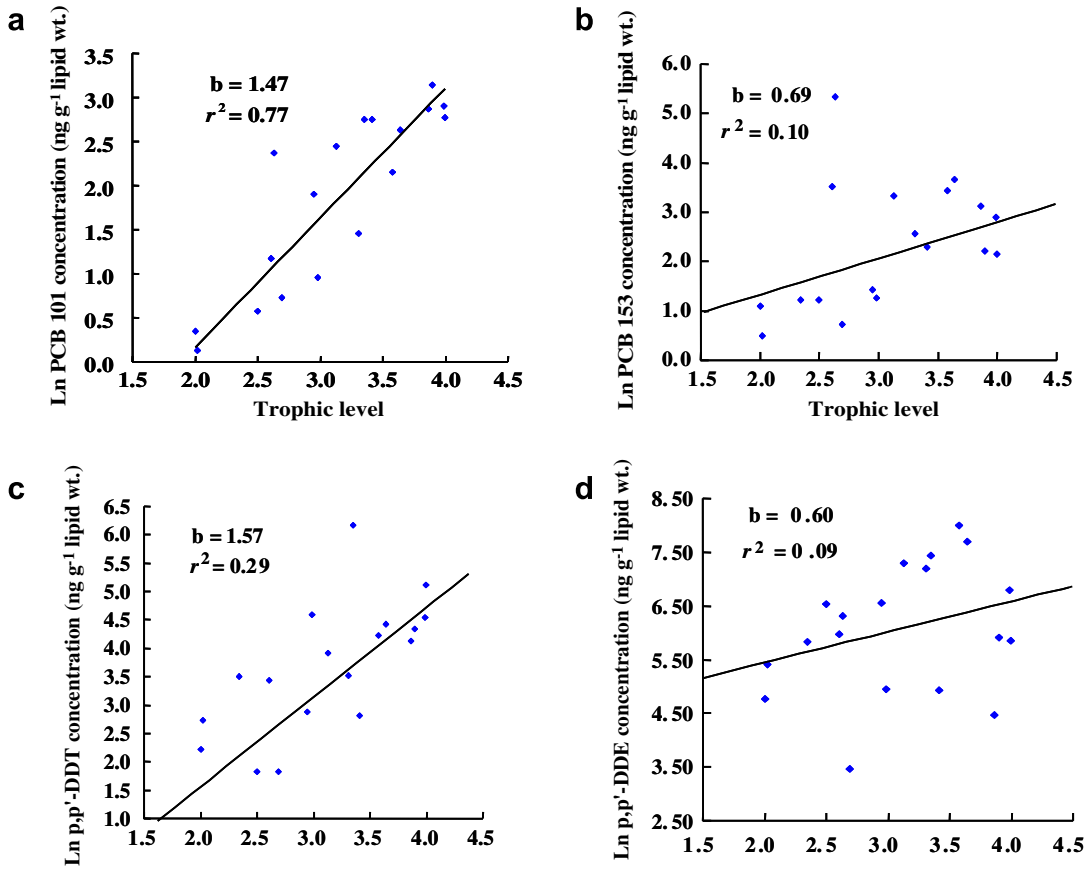

Fig. 4. The relationship of trophic levels and Ln concentrations (Ln ng g^{-1} lipid wt.) in food web. (a) for PCB 101, (b) for PCB 153, (c) for *p,p′*-DDT, (d) for *p,p′*-DDE.

the property of compounds and so on (Fisk et al., 2001a; McIntyre and Beauchamp, 2007). Only one or two factors are insufficient to elucidate the mechanism of bioaccumulation and biomagnifications. Some investigations have found that trophic levels and age were the two most important factors affecting bioaccumulation of organic contaminants (McIntyre and Beauchamp, 2007). The results in the present study also indicated that trophic levels and age affected the process of bioaccumulation and biomagnification. Trophic levels of five organisms were assigned using the relationship described by Fisk et al. (2001a): Trophic level = 2 + (δ^{15}Nconsumer −δ^{15}Nplankton). The trophic levels were 2.52 ± 0.13 for *Clarias lazera*, 2.66 ± 0.45 for *Cyprinus carpio*, 3.44 ± 0.22 for *Carassius auratus*, 3.96 ± 0.05 for *Oreochromis niloticus*, and 3.54 ± 0.28 for *Pelodiscus sinensis* in the present study. The relationships of trophic levels and natural log-transformation (Ln) concentrations (ng g^{-1} lipid wt.) of PCB 101, PCB 153, *p,p′*-DDT, and *p,p′*-DDE in food web were shown in Fig. 4. Food web magnification factors (FWMFs) for the entire food web were calculated by the formula also described by Fisk et al. (2001a): Ln POP concentration = a + (b × trophic level) and FWMF = e^b. The highest FWMF was 4.83 for *p,p′*-DDT and the second highest was 4.36 for PCB 101 in the present study. FWMFs were 2.00 for PCB 153 and 1.77 for *p,p′*-DDE, which were lower than those (4.4 for PCB 153 and 4.5 for *p,p′*-DDE) in freshwater food web only including invertebrate and fish (Kidd et al., 1998). The results indicated that FWMFs would be different in different environments. HCHs with a low lgKow (3.8) have fewer propensities for bioaccumulation than HCB, PCBs and DDTs.

Age was related to concentrations of contaminants in muscle. The average concentrations were positively correlated with the age of *Cyprinus carpio* and *Carassius auratus*. The average concentrations were increased nearly two-fold and four-fold at four years of age compared with three years of age in *Cyprinus carpio* and *Carassius auratus*. The concentrations of contaminants were higher in *Carassius auratus* than those in *Oreochromis niloticus* because *Oreochromis niloticus* were younger than *Carassius auratus* and their faster growth rate resulted in lower concentrations despite their higher trophic levels.

Feeding habit seems to have little influence on contaminant bioaccumulation in this food web. For example, *Pelodiscus sinensis* and *Clarias lazera* are piscivorous, which suggests that these species should have higher trophic levels and higher concentrations. However, the mean trophic levels (3.54 for *Pelodiscus sinensis* and 2.52 for *Clarias lazera*) and concentrations of OCPs and PCBs (Table 1) were lower than those in the other omnivorous species *Carassius auratus* (3.41 for trophic levels). The feeding habit could not offer a satisfactory explanation for the results, which was similar to the previous study (McIntyre and Beauchamp, 2007).

4. Conclusions

Higher levels of OCPs and PCBs were found in aquatic organisms from Gaobeidian Lake. The concentrations of DDTs were 64.3 ng g^{-1} ww in *Carassius auratus* and 42.2 ng g^{-1} ww in *Clarias lazera*, which were higher than the guideline set by USEPA (14.4 ng g^{-1} ww). Therefore, consumption of *Carassius auratus* and *Clarias lazera* from the lake should be cautious. Although this study clearly described the levels of these contaminants in the environment and biota, further investigations are warranted to develop a clear understanding of bioaccumulation and biomagnification.

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