Distribution of perfluorinated compounds in water, sediment, biota and floating plants in Baiyangdian Lake, China†

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The distribution of perfluorinated compounds (PFCs) in Baiyangdian Lake, China, was determined in this study. Perfluorooctanoic acid (PFOA) was the dominant PFC in lake water ($1.70\text{--}73.5\text{ ng L}^{-1}$, median 9.72 ng L^{-1}), while perfluorooctane sulfonate (PFOS) was the dominant PFC in sediments ($0.06\text{--}0.64\text{ ng g}^{-1}$ dry wt, median 0.19 ng g^{-1} dry wt) and in aquatic animals ($0.57\text{--}13.7\text{ ng g}^{-1}$ wet wt, median 2.56 ng g^{-1} wet wt). Significant differences in PFC levels were observed among various aquatic animals. We also determined, for the first time, the PFC levels in floating plants, including *Ceratophyllum demersum* L., *Hydrocharis dubia* (Bl.) Backer and *Salvinia natans* (L.), and we found that PFOA and PFNA were the dominant PFCs in these plants. Furthermore, floating plants were observed to have different composition profiles compared to aquatic animals. Geographical differences in PFC levels were also observed, with higher PFC levels in samples from the north part of Baiyangdian Lake than those in the south. The differences in human and industrial activities in different parts of the lake and the discharged wastewater from the Fuhe River may be the major contributors for these geographical differences.

Introduction

Perfluorinated compounds (PFCs) have been used in many consumer products and industrial applications for more than 50 years due to their unique stability and surface activity.^{1,2} These PFCs, especially perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), are being recognized as emerging environmental pollutants because of their wide distribution in the environment^{3–6} and even in the human body.^{7,8} Therefore, the number of studies on PFCs is increasing, especially the ones which deal with the distribution, bioaccumulation and toxic effects of PFCs in the environment.⁹

The application of PFC-related chemicals has been officially restricted and even banned. However, these chemicals are still widely used because of their low cost and versatility, thus the environmental PFCs are mainly from industrial facilities or consumer products. Previous studies have proposed that water is the major medium for the transport of non-volatile anionic PFCs in environment.¹ Indeed, some surface water in several countries was found to be contaminated with PFCs.^{10,11} Moreover, the presence of PFCs in the tissues of fish, birds and marine mammals was also discovered, indicating the bioaccumulation of PFCs in biota from aquatic systems.^{5,12} In addition, sediment may also play an important role in the fate of PFCs: the PFCs in the sediment are not fixed permanently to the sediment; rather, they can be recycled with different biological processes. Although plants are an essential medium for organic pollutants in the environment to enter the food chain, only very limited studies have been conducted in PFC research: Yoo *et al.*¹³ determined PFC levels in plants that were from the biosolid-amended fields near Decatur, AL; Stahl *et al.*¹⁴ demonstrated

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Environmental impact

Water is believed to be a major transportation pathway of PFCs in the environment. Baiyangdian Lake is the largest natural freshwater body in the North China Plain. In this study we characterized the occurrence and distribution of PFCs in this area. We found that the distribution of PFCs had significant geographical differences due to the different pollution sources. Also, floating plants were observed to have different composition profiles to aquatic animals. The potential accumulation of PFCs in sediments and floating plants relative to the water was also evaluated.

that PFOA and PFOS were carried over from soil to plants, and that their levels in plants were dependent on the spikes of their soil levels.

In China, PFCs have been observed in various aquatic systems, including Daliao River,¹⁵ Pearl River and Yangtze River,¹⁶ and the coastal water in Dalian¹¹ and South China.¹⁷ The Baiyangdian Lake is the largest natural freshwater body in the North China Plain, which consists of more than 100 small and shallow lakes linked to each other by thousands of ditches. More than 80% of Baiyangdian Lake is in Anxin County, Hebei province. It is critical to the water supply, aquaculture and tourism of the surrounding areas. With rapid economic development and population increase in this region, the environment of Baiyangdian Lake has been significantly polluted by heavy metal,¹⁸ organochlorine pesticides (OCPs)¹⁹ and polybrominated diphenyl ethers (PBDEs),²⁰ which are closely linked to the anthropogenic and industrial activities. However, little is known about the PFC pollution in this area.

The current study was designed to investigate the distribution of PFCs in Baiyangdian Lake by evaluating the samples of water, sediment and various aquatic organisms. The potential accumulation of PFCs in sediments and floating plants relative to the water was evaluated.

Experimental

Sampling

Surface water, sediment and biota samples were collected from Baiyangdian Lake on August 23–24, 2008 (Fig. 1). The lake was divided into two major sampling regions: industrial area with sites A–J and village residential area with K–R. All samples were placed on ice and transported to the laboratory immediately after collection.

More than 1 L surface water was collected from each sampling site with a stainless steel bucket, which had been pre-cleaned with methanol and purified water and rinsed with the sample before collection. All water samples were kept at 4 °C in the lab and extracted within one week. Sediments were collected with a stainless steel grab from the surface sediment (0–5 cm), freeze-dried, ground and passed through a 55-mesh sieve, and kept in PE bags at –20 °C until analysis. A total of 16 aquatic animal samples were collected, including turtle

(*Pelodiscus sinensis*, $n = 1$), crab (*Eriocheir sinensis*, $n = 1$), common carp (*Cyprinus carpio*, $n = 1$), yellow catfish (*Pelteobagrus fulvidraco*, $n = 1$), bluntnout bream (*Megalobrama amblycephala*, $n = 1$), crucian carp (*Carassius auratus*, $n = 4$), silver carp (*Hypophthalmichthys molitrix*, $n = 2$), stone moroko (*Pseudorasbora parva*, $n = 1$), loach (*Misgurnus anguillicaudatus*, $n = 1$), lobster (*Palinuridae*, $n = 2$), and shrimp (*Macrobrachium nipponense*, $n = 1$). Only one individual animal as one sample for each species was collected, except shrimp and stone moroko which were pooled with more than 10 animals due to their small sizes. Fish and turtle were dissected to obtain muscle tissues. Soft tissues were obtained from lobster and crab. Shrimp and stone moroko were homogenized due to their small sizes. Finally the biota samples were freeze-dried and wrapped in aluminum foil, placed in polyethylene bags, and kept at –20 °C until analysis. The collected common aquatic floating plants included *Ceratophyllum demersum* L., *Hydrocharis dubia* (Bl.) Backer and *Salvinia natans* (L.). One pooled sample for each species was collected from some sampling sites. The floating plant samples were washed, cut into small pieces and freeze-dried for analysis.

Sample extraction

All samples were spiked with 2 ng of ¹³C₄-PFOS and ¹³C₄-PFOA as the internal standards and aged for 0.5 h before preparation. For water samples, an aliquot of 500 mL of each sample was extracted with an Oasis® WAX cartridge (6 cc, 150 mg; Waters Corp. Milford, USA) after being spiked with internal standards. The target analytes were eluted with 4 mL of CH₃OH and 4 mL of 0.1% NH₄OH/CH₃OH (v/v). The eluate was then concentrated to 1 mL for injection. Sediment was pretreated with 100% methanol sonication. Generally, 1 g of the dry solid sample with 2 ng internal standards was sonicated in 5 mL of methanol at 60 °C for 20 min, and the supernatant was collected after centrifugation. The same procedure was repeated twice. All extracts were combined and the total volume of extract was approximately 20 mL. To concentrate the extracts and remove the impurities, further extraction and purification were performed with the WAX cartridge. The biota samples were extracted with alkaline digestion coupled with our previously established SPE cleanup method.²¹ In the current study, the results showed that the

Fig. 1 Sampling locations.

alkaline digestion method was better than the method of methanol extraction for floating plants.

Data analysis

Bioaccumulation factors (BAF) were calculated based on PFC levels in floating plants and water samples. The formula is: $BAF = [\text{PFC level (ng kg}^{-1}) \text{ in floating plants}] / [\text{PFC level (ng L}^{-1}) \text{ in water}]$.

Statistical analyses were performed using the SPSS 13.0 software. Levels below the limit of detection were assigned as LOD/ $\sqrt{2}$. Spearman's correlation (two-tailed test) analysis was used to examine possible correlations among various PFCs in the samples. A Mann–Whitney *U* test was used to assess whether the differences in PFCs levels in the samples were significant between the south and north parts of Baiyangdian Lake.

Results and discussion

PFCs in lake water

PFCs were detected in all water samples (Table 1), revealing the wide distribution of PFC contamination in Baiyangdian Lake. PFOA was the most prominent PFC with a level range of 1.70 to 73.5 ng L⁻¹ (median, 9.72 ng L⁻¹). Site B, which is located at the north of Baiyangdian Lake and within the tourism region, had the highest PFOA level, while site P had the lowest. In addition, site B is also located in the estuary of Fuhe River, which is the main tributary flowing into Baiyangdian Lake while taking wastewater from Baoding city (Fig. 1), indicating the possibility of Fuhe River being a pollution source of PFCs. McLachlan *et al.* proposed that the PFOA emitted from a limited number of industrial facilities can significantly contribute to PFOA loads.²² Indeed, in Baoding city, various industries, including chemical plants, fiber plants and paper mills, are closely located to the Fuhe River, and industrial wastewater was discharged into Fuhe

River. Furthermore, a significantly decreasing trend of PFOA levels was observed in lake water with increasing distances from the estuary of Fuhe River. For example, the PFOA levels in sites B, D, G, C, F and E decreased from 73.5 to 21.1 ng L⁻¹ (Fig. S1†), further indicating the possibility of the Fuhe River being a source of PFC contamination in Baiyangdian Lake.

PFOA has been reported to be the predominant compound in the surface water from different lakes, although most of the previously observed PFOA levels were lower than those in the north part of Baiyangdian Lake (range: 4.26–73.5 ng L⁻¹, median: 30.1 ng L⁻¹) but higher than those in the south (range: 1.71–7.03 ng L⁻¹, median: 2.38 ng L⁻¹) in this study. For example, the PFOA level was reported at 10.6–36.7 ng L⁻¹ (median: 19.5 ng L⁻¹, mean: 21.7 ng L⁻¹) in Taihu Lake,²³ at an average level of 8.7–20.0 ng L⁻¹ in Biwa Lake,²⁴ and at 3.27 to 15.8 ng L⁻¹ (median: 7.2 ng L⁻¹) in lake water from downtown Albany.²⁵ The PFOA levels in lake water collected from Great Lake (0.65 to 5.5 ng L⁻¹)²⁶ and from remote lakes (0.14–0.66 ng L⁻¹),²⁷ however, were much lower than those in the south in this study.

Other PFCs, including PFHpA, PFNA, PFDA, PFOS, and PFBS, were also detected in water samples (Table 1). The levels of PFOS, in a range of 0.11–1.48 ng L⁻¹ (median 0.53 ng L⁻¹), were much lower than those of PFOA. Similar or higher PFOS levels were reported in the lake water in previous studies. For example, Yang *et al.*²³ reported PFOS levels ranging from 3.6–394 ng L⁻¹ (median: 5.8 ng L⁻¹), which was much higher than those in the present study. However, the similar PFOS concentrations for Lake Biwa water (0.8–5.3 ng L⁻¹)²⁴ and for Great Lake water (0.26–5.51 ng L⁻¹)²⁶ were reported in the previous study. The levels of other PFCs, including PFHpA, PFNA, PFDA, and PFBS, were much lower than those of PFOA and PFOS, which is well in line with previous reports. Different pollution sources may have caused the different distribution patterns of PFCs.

Table 1 PFC levels in lake water collected from Baiyangdian Lake (ng L⁻¹)

	Site	PFPeA ^a	PFHpA ^b	PFOA ^c	PFNA ^d	PFDA ^e	PFUnDA ^f	PFBS ^g	PFHxS ^h	PFOS ⁱ	ΣPFCs
North	A	<LOD	1.31	12.4	0.66	0.21	<LOD	0.51	0.018	0.26	15.4
	B	<LOD	2.73	73.5	1.43	0.66	<LOD	0.39	<LOD	1.25	79.9
	C	<LOD	2.15	30.4	1.02	0.28	<LOD	0.55	<LOD	0.63	35.1
	D	<LOD	2.12	39.3	0.65	0.30	<LOD	0.28	0.084	0.65	43.4
	E	<LOD	1.75	21.1	0.85	0.32	<LOD	0.60	<LOD	0.68	25.3
	F	<LOD	2.05	28.0	0.77	0.20	<LOD	0.59	0.105	0.48	32.2
	G	<LOD	2.24	37.6	1.02	0.43	<LOD	0.39	0.092	0.54	42.3
	H	<LOD	1.68	29.8	1.22	0.46	<LOD	0.67	0.128	1.48	35.4
	I	<LOD	2.28	32.2	1.21	0.30	<LOD	0.52	<LOD	0.67	37.2
	J	<LOD	0.46	4.26	0.83	0.35	<LOD	0.51	0.06	0.37	6.84
Median	—	—	2.09	30.1	0.94	0.31	—	0.52	0.088	0.64	35.3
South	K	<LOD	0.52	7.03	0.91	0.21	<LOD	0.61	0.067	0.51	9.85
	L	<LOD	0.59	2.53	0.57	0.13	<LOD	0.31	<LOD	0.11	4.24
	M	<LOD	0.23	2.87	0.40	0.20	<LOD	0.41	<LOD	0.25	4.35
	N	<LOD	0.52	2.48	0.57	0.15	<LOD	0.34	<LOD	0.16	4.22
	O	<LOD	0.61	2.27	0.74	0.39	<LOD	0.20	0.102	0.57	4.89
	P	<LOD	0.30	1.71	0.78	0.27	<LOD	0.42	<LOD	0.27	3.75
	Q	<LOD	0.38	2.25	0.74	0.50	<LOD	0.45	<LOD	0.54	4.85
	R	<LOD	0.22	1.92	0.63	0.32	<LOD	0.53	<LOD	0.40	4.02
Median	—	—	0.45	2.38	0.69	0.24	—	0.42	—	0.34	4.30

^a Perfluoropentanoic acid ^b Perfluoroheptanoic acid ^c Perfluorooctanoic acid ^d Perfluorononanoic acid ^e Perfluorodecanoic acid
^f Perfluoroundecanoic acid ^g Nonafluorobutane-1-sulfonic acid ^h Perfluorohexane sulfonate ⁱ Perfluorooctane sulfonate

The water samples from the north part of Baiyangdian Lake contained significantly higher levels of detectable PFCs than those from the south parts (Fig. S2†) (Mann–Whitney U test, $p < 0.05$). For example, the levels of PFOA in samples from the north part of lake (sites A–J, 4.26–73.5 ng L⁻¹, median 30.1 ng L⁻¹) were approximately ten fold higher than those in the south part (sites K–R, 1.71–7.03 ng L⁻¹, median 2.38 ng L⁻¹). This huge difference may be directly caused by the lack of contamination sources in the south part of Baiyangdian Lake, where people mainly live on fishing and aquaculture. The north part of lake, however, had several industry facilities nearby, and industrial wastewater from the Fuhe River was constantly discharged into Baiyangdian Lake. Another factor, human activity, may also contribute to the huge difference. The north part is a well-known tourism spot, and the nearby region has a more dense population than that of the south part. PFC concentrations from relatively more industrialized areas were higher than those from the less populated locations. Kim *et al.* also observed a tendency for a gradual decrease from urban to rural area.²⁵ In addition, the levels of other chemical pollutants, such as organochlorine compounds and polycyclic aromatic hydrocarbons, are much higher in Fuhe River than in Baiyangdian Lake.²⁸

The distribution profiles of PFCs were also different between the north and the south of Baiyangdian Lake. PFOA accounted for 81–92% of Σ PFCs in the north area but 46–71% for the south. PFHpA was the second dominant PFC in the water samples collected from the north (3.4–8.5% of Σ PFCs), while the south's second dominant PFC was PFNA (9.2–21% of Σ PFCs). This may be caused by the differences in PFC sources.

The correlations among the levels of different PFCs in the Baiyangdian Lake were also examined. Statistically significant correlations were found among PFHpA, PFOA, PFOS and PFNA ($p < 0.01$). Furthermore, the levels of PFDA were significantly correlated with those of PFOS and PFNA ($p < 0.01$). These correlations indicate that these PFCs had similar sources.

Levels of PFCs in sediment

PFCs were also detected in all sediment samples with PFOS as the dominant PFC (Table 2), consistent with previous findings.^{15,29} The dominance of PFOS may be due to its high adsorption potential. The levels of PFOS ranged from 0.06 to 0.64 ng g⁻¹ (median 0.19 ng g⁻¹, dry wt) in the sediment samples, which are similar to the PFOS levels in the sediments from Roter Main River, Germany (0.07–0.31 ng g⁻¹),²⁹ from Daliao River, China (LOD–0.37 ng g⁻¹, dry wt)¹⁵ and from Taihu Lake, China (0.06–0.31 ng g⁻¹, dw).²³ The PFOS levels in sediments collected from Huangpu River and Suzhou River in Shanghai (1.57 to 8.78 ng g⁻¹, dry wt),³⁰ however, were much higher than those in this study.

PFOA was above its LOD in just three sediment samples in this study, and its detected levels were 0.16–0.30 ng g⁻¹ (dry wt), much lower than those of PFOS. However, PFOA concentrations were 2.4–118 times higher than PFOS in sediments collected in Shanghai, China, which has been attributed to more PFOA entering into water bodies.³⁰ Some long-chain perfluorinated carboxylic acids (PFCAs) (C9–C11) were also detected in the sediment samples of Baiyangdian Lake. The levels of PFNA, PFDA, and PFUnDA were <LOD–0.09 ng g⁻¹, 0.05–0.22 ng g⁻¹, and <LOD–0.32 ng g⁻¹, respectively. The correlation between the bioaccumulation of PFCs and their carbon chain lengths has been observed in biota organisms.³¹ In this study, we observed that the levels of long-chain PFCAs were elevated with the carbon chains. Therefore, we hypothesize that the enrichment capacity of PFCs is enhanced with the carbon-chain length in sediment. The PFC distribution in sediment may be affected by inhabitant microbial activities, although experimental evidence is required to test this possibility.

Sediment sorption has been reported to help eliminate PFOA and PFOS in rivers,³² and PFOS has stronger adsorption to sediment than PFOA.²⁹ Consistently, our current study found that the levels of PFOS in sediment samples were 163- to 1182-fold higher than those in water samples from the same sites. At the same time, the detection of PFOA was less frequent than that

Table 2 PFC levels in sediments collected from Baiyangdian Lake (ng g⁻¹ dry wt)

	Site	PFPeA	PFHpA	PFOA	PFNA	PFDA	PFUnDA	PFBS	PFHxS	PFOS	Σ PFCs
North	A	<LOD	<LOD	<LOD	<LOD	0.097	0.15	<LOD	<LOD	0.23	0.47
	B	<LOD	<LOD	0.28	<LOD	0.10	0.20	<LOD	<LOD	0.45	1.03
	C	<LOD	<LOD	0.30	0.12	0.22	0.20	<LOD	<LOD	0.64	1.48
	D	<LOD	<LOD	<LOD	0.052	0.073	0.099	<LOD	<LOD	0.24	0.46
	E	<LOD	<LOD	<LOD	0.089	0.21	0.32	<LOD	<LOD	0.60	1.22
	F	<LOD	<LOD	<LOD	0.050	0.077	0.18	<LOD	<LOD	0.22	0.52
	G	<LOD	<LOD	<LOD	0.044	0.041	0.11	<LOD	<LOD	0.20	0.40
	H	<LOD	<LOD	<LOD	0.058	0.14	0.13	<LOD	<LOD	0.29	0.61
	I	<LOD	<LOD	<LOD	0.034	0.094	0.12	<LOD	<LOD	0.29	0.54
	J	<LOD	<LOD	<LOD	0.063	0.037	<LOD	<LOD	<LOD	0.06	0.16
Median	—	—	—	<0.1	0.055	0.10	0.15	—	—	0.27	0.53
South	K	<LOD	<LOD	<LOD	0.050	0.038	0.051	<LOD	<LOD	0.17	0.31
	L	<LOD	<LOD	<LOD	0.036	0.060	0.043	<LOD	<LOD	0.11	0.25
	M	<LOD	<LOD	<LOD	<LOD	0.051	0.055	<LOD	<LOD	0.13	0.23
	N	<LOD	<LOD	<LOD	0.072	0.12	0.080	<LOD	<LOD	0.19	0.46
	O	<LOD	<LOD	0.16	0.083	0.054	0.072	<LOD	<LOD	0.11	0.48
	P	<LOD	<LOD	<LOD	0.068	0.12	0.073	<LOD	<LOD	0.17	0.43
	Q	<LOD	<LOD	<LOD	0.062	0.088	0.057	<LOD	<LOD	0.13	0.34
	R	<LOD	<LOD	<LOD	0.084	0.092	0.060	<LOD	<LOD	0.14	0.38
Median	—	—	—	<0.1	0.068	0.074	0.059	—	—	0.14	0.36

of PFOS. Furthermore, the levels of PFOS in sediment samples were significantly correlated with those of water samples (Spearman Correlation Test, $p < 0.01$). In addition, the levels of PFOS, PFDA and PFUnDA in sediment samples were also correlated with each other (Spearman Correlation Test, $p < 0.01$), indicating their similar sources.

Similar to water PFCs, the levels of PFCs in sediments from the north part of Baiyangdian Lake were generally higher than those from the south part. In particular, the PFOS and PFUnDA levels were significantly higher in the north part than in the south (Mann–Whitney U test, $p < 0.05$).

PFCs in aquatic organisms

In this study, we determined, for the first time, the PFC levels in floating plants in a natural water body. Three species of floating plants from Baiyangdian Lake were analyzed, including *Ceratophyllum demersum* L., *Hydrocharis dubia* (Bl.) Backer, and *Salvinia natans* (L.) All. PFCs were detected in all floating plant samples (Table 1), with PFNA and PFOA accounting for 40–88% of Σ PFCs (Table 3). PFNA was the dominant PFC in *Hydrocharis dubia* (Bl.) Backer (0.66–20.0 ng g⁻¹, median 6.38 ng g⁻¹) and *Salvinia natans* (L.) All. (1.51–18.4 ng g⁻¹, median 6.81 ng g⁻¹), while PFOA was the dominant PFC in *Ceratophyllum demersum* L. (1.77–5.20 ng g⁻¹, median 3.29 ng g⁻¹). Furthermore, the levels of PFOS (0.26–4.17 ng g⁻¹ dry wt) in floating plants were lower than those of PFNA and PFOA (Table 3), similar to some previous reports.^{14,33} For example, Yoo *et al.*³³ reported PFOA, PFOS and PFNA concentrations in grass samples from field near Decatur, AL at 9.9–202.7 ng g⁻¹, 1.2–16.8 ng g⁻¹ and 1.3–27.4 ng g⁻¹, dry wt,

respectively. In addition, PFOS levels (2.4–3.1 ng g⁻¹ dry wt) in benthic algae of the Great Lakes were reported, higher than those in this study.³⁴

Other PFCs, including PFPeA and PFCAs with long-chains (C10, C11), were also detected (Table 3). No statistically significant differences were observed for the levels of these PFCs among different floating plants tested in this study through the Mann–Whitney U test. However, some differences still existed and showed some trends of changes. For example, the PFC levels in *Salvinia natans* (L.) All. were a little higher than those in the other two species in the Baiyangdian Lake. The levels of PFNA were higher in floating plants from the south part of Baiyangdian Lake than those from the north (Table 3), in contrast to the water and sediment PFCs. This difference may come from a historical accumulation of PFNA in the south with preferential plant enrichment. However, PFOS levels in *Salvinia natans* (L.) All. collected in north Baiyangdian Lake (2.51–4.67 ng g⁻¹ dry wt) were higher than those collected in the south (1.14–1.76 ng g⁻¹ dry wt). Furthermore, the PFC profiles in floating plants were also quite different between the south and north parts of Baiyangdian Lake. For example, in *Hydrocharis dubia* (Bl.) Backer samples collected in sites A–G (the north area), PFOA and PFNA accounted for 36.1–43.3% and 13.3–34.3% of Σ PFCs, respectively, while they accounted for 20.2–28.7% and 49.6–56.5%, respectively, in samples collected in sites J–P. Similar trends were also observed for *Ceratophyllum demersum* L. and *Salvinia natans* (L.) All. The bioaccumulation factors (BAF) in floating plants were calculated based on the PFC levels in Baiyangdian Lake water and floating plants. In detail, the log BAF values for PFOS, PFOA, PFNA, and PFDA were 3.0–4.1, 1.9–3.7, 2.9–4.4, and 3.2–4.2, respectively. The log BAF values

Table 3 PFC levels in floating plants collected from Baiyangdian Lake (ng g⁻¹ dry wt)

		Site	PFPeA	PFHpA	PFOA	PFNA	PFDA	PFUnDA	PFBS	PFHxS	PFOS	Σ PFCs
<i>Hydrocharis dubia</i> (Bl.) Backer	North	C	0.32	<LOD	6.50	5.15	1.35	0.62	<LOD	<LOD	1.07	15.0
		E	0.32	<LOD	1.65	0.66	0.53	0.12	<LOD	<LOD	0.97	4.25
		G	0.38	<LOD	4.27	1.58	1.87	0.94	<LOD	<LOD	2.80	11.8
		J	0.22	<LOD	10.2	20.1	3.57	0.63	<LOD	<LOD	0.84	35.5
	South	L	0.31	<LOD	2.79	5.15	1.29	0.19	<LOD	<LOD	0.68	10.4
		N	0.23	<LOD	4.03	7.60	2.01	0.69	<LOD	<LOD	0.78	15.3
		O	0.31	<LOD	3.25	9.00	2.23	0.39	<LOD	<LOD	0.86	16.0
		P	0.24	<LOD	5.75	9.15	1.30	0.19	<LOD	<LOD	0.26	16.9
		Median	0.31	—	4.15	6.38	1.61	0.50	—	—	0.85	15.2
<i>Ceratophyllum demersum</i> L.	North	A	<LOD	<LOD	1.85	1.20	1.27	1.32	<LOD	<LOD	1.96	7.60
		C	0.32	<LOD	3.22	0.96	1.21	0.43	<LOD	<LOD	1.81	7.93
		E	<LOD	<LOD	1.77	0.86	0.82	0.38	<LOD	<LOD	1.42	5.25
		G	0.37	<LOD	4.79	1.77	2.95	1.44	<LOD	<LOD	4.22	15.5
	South	J	0.41	<LOD	5.00	2.84	1.05	0.42	<LOD	<LOD	0.93	10.7
		L	0.38	<LOD	3.43	6.90	1.71	0.49	<LOD	<LOD	1.02	13.9
		N	0.30	<LOD	2.57	5.00	2.03	0.84	<LOD	<LOD	1.62	12.3
		O	0.30	<LOD	5.20	8.35	2.49	0.45	<LOD	<LOD	2.14	18.9
		P	<LOD	<LOD	3.29	4.58	1.67	0.69	<LOD	<LOD	0.78	11.0
		Median	0.30	—	3.29	2.84	1.66	0.48	—	—	1.62	10.8
<i>Salvinia natans</i> (L.) All.	North	A	<LOD	<LOD	3.22	2.06	3.28	1.34	<LOD	<LOD	3.45	13.3
		C	0.20	<LOD	7.30	9.50	2.69	0.56	<LOD	<LOD	2.59	22.8
		E	0.46	<LOD	3.13	1.51	1.94	0.64	<LOD	<LOD	2.52	10.2
		G	0.23	<LOD	5.60	2.07	2.44	0.97	<LOD	<LOD	4.67	16.0
	South	L	0.19	<LOD	6.00	12.4	2.56	0.82	<LOD	<LOD	1.31	23.3
		N	0.29	<LOD	2.02	4.13	1.77	0.59	<LOD	<LOD	1.14	9.92
		O	0.32	<LOD	10.4	18.4	3.84	1.41	<LOD	<LOD	1.76	36.1
		P	0.31	<LOD	6.65	10.6	2.37	1.05	<LOD	<LOD	1.33	22.3
		Median	0.26	—	5.80	6.81	2.50	0.90	—	—	2.14	19.2

Table 4 PFC levels in biotic organisms collected from Baiyangdian Lake (ng g⁻¹ wet wt)

	PFOS	PFOA	PFNA	PFDA	PFUnDA	PFDODA	PFTTrDA	PFTA	ΣPFCs
Common carp	13.7	0.13	0.49	2.39	0.53	0.06	0.07	<LOD	17.4
Yellow catfish	1.00	0.06	0.06	0.82	0.53	0.12	0.08	<LOD	2.67
Silver carp	2.04	0.06	0.18	1.59	0.93	0.15	0.22	0.06	5.19
Crucian carp	5.11	0.08	0.22	1.46	0.60	0.10	0.11	0.05	7.69
Bluntnout bream	1.26	0.04	0.23	1.25	0.83	0.11	0.19	0.03	3.95
Stone moroko	8.01	0.35	0.53	2.34	1.47	0.30	0.10	0.01	13.1
Loach	3.08	0.08	0.47	1.83	0.90	0.19	0.25	0.02	6.81
Lobster	0.51	0.53	0.16	0.19	0.32	0.17	0.16	0.02	2.08
Shrimp	4.65	0.12	0.46	1.60	0.74	0.12	0.37	<LOD	8.07
Turtle	2.56	0.06	0.10	0.55	0.50	0.08	0.28	0.03	4.15
Crab	1.17	0.02	0.29	2.42	0.90	0.21	0.29	0.06	5.37

for PFCs were similar to ones in fish muscle reported in the previous study,^{35,36} indicating that PFCs may have similar potential accumulation in floating plants to ones in fish.

Organic pollutant levels may be affected by diet choice and metabolic capability.³⁷ This may explain the significant differences in PFC levels among various aquatic animals in this study. PFOS was the dominant PFC accounting for 21.8–78.9% of ΣPFCs in the aquatic animals of Baiyangdian Lake, ranging from 0.51 to 13.7 ng g⁻¹ wet wt (median 2.56 ng g⁻¹) (Table 4). Martin *et al.* detected the highest PFCs level in benthic species, suggesting that the sediment was a major source of PFCs to the food chain in Lake Ontario.³⁸ However, in this study, the highest level of PFOS was detected in common carp and not in benthic species (loach and crab). Ye *et al.* reported that the PFOS levels in the fillets of common carp in the Mississippi River were in the range of 11–90 ng g⁻¹ wet wt,³⁹ which were higher than those in this study. PFDA was the second dominant PFC in most aquatic animal samples from Baiyangdian Lake (0.19–2.42 ng g⁻¹ wet wt), similar to the observations of Li *et al.* from fish muscles.⁴⁰ In addition, PFDA was found to be the dominant PFC in crabs (2.42 ng g⁻¹ wet wt), which was more than two times higher than other PFCs (Table 4).

In summary, we found that PFCs were widely distributed in the water, sediments and biotic organisms in Baiyangdian Lake. The wastewater discharged from the Fuhe River in the north of Baiyangdian Lake may be a major source of PFCs.

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