Tissue Distribution and Biomagnification of Polybrominated Diphenyl Ethers in Snakes From Paddy Fields in the Yangtze River Delta, Southeastern China

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Research Article

Keywords: PBDE, snake, tissue burden, biomagnification, Yangtze River Delta

Posted Date: January 18th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1191979/v1>

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Abstract

In many developing regions, the rapid development in industrialization and urbanization has caused adverse impact on the aqueous ecology and environment. However, there is limited information available on the tissue-specific burden and biomagnification of polybrominated diphenyl ethers (PBDEs) in biota. In the present study, the tissue concentration and distribution of tri- to deca-BDEs were analyzed in terrestrial short-tailed mamushi (*Gloydius Brevicaudus*) and semi-aquatic red-backed rat snake (*Elaphe Rufodorsata*) from the Yangtze River (ChangJiang) Delta, Southeastern China. The total PBDE concentrations of liver, muscle and adipose tissues in two snakes ranged from 29.1-252.2, 10.5-48.9 and 4.36-106.4 ng/g lw, respectively. The congener patterns of PBDEs exhibited the significant difference between two snakes, which may be attributed to different feeding habits and dermal exposure. Tissue-specific burdens in snakes suggested that adipose tissue served as a dominant storage and sink for PBDEs (85.1% for red-backed rat snake and 80.0% for short-tailed mamushi, respectively) compared to liver (8.1% and 12.5%, respectively) and muscle (6.9% and 7.5%, respectively) tissues. Biomagnification potential of PBDEs was investigated via black spotted frogs-red-backed rat snake food chain. The biomagnification factors (BMFs) of tri- to deca-BDEs were in a range of 0.74 to 4.30. Tetra- to octa-BDEs generally exhibited biomagnification potentials through the frog-snake food chain. Moreover, parabolic relationship was observed between BMFs and log Kow of PBDE congeners, and it may be resulted from the combined effects of chemical's hydrophobicity and molecular size. This research, thereby provides data support for biological monitoring being concerned about liver, muscle and adipose tissues of animals.

1. Introduction

Polybrominated diphenyl ethers (PBDEs), are a group of additive flame retardants that have been extensively utilized in many types of electronic products and furniture.(Besis and Samara, 2012) After a rapid increase in use over three decades, the global production of PBDEs reached approximately 310000 tons in 2000 (Stapleton et al., 2011). Because PBDE congeners can easily escape from their host materials into the environment during production, use, and especially from disposal,(Sjodin et al., 2003) they have been routinely detected in a variety of environment matrices (Hites, 2004), food (Domingo, 2012; Schechter et al., 2004) and wildlife (Currier et al., 2020; Wu et al., 2020). However, PBDEs were, unexpectedly, found to be environmentally persistent due to the resistance to various degradation (Besis and Samara, 2012), and their high lipophilicity resulted in a strong bioaccumulation potential (Weijs et al., 2009). Together with their toxic effects, commercial penta- and octa-BDE mixtures have been banned globally under the Stockholm Convention in 2006, and deca-BDE mixtures in 2017 (Sharkey et al., 2020). Despite the strict restrictions on these chemicals, PBDEs are ubiquitously presented in the environment and their residues can transfer and become incorporated into body tissue of living creatures (Zhou et al., 2016b). To data, basic information on these contaminant burdens in biota are relative limited, significantly restricting human and environmental health evaluations

Reptiles are a major group of vertebrate animals that occupies relatively high trophic positions in aquatic-terrestrial ecosystems (Du et al., 2020). Since many reptiles are long-lived species with poor long-distance dispersal abilities, they are accessible to long-term exposure of organic pollutants and subsequent bioaccumulation (Hopkins, 2000). Nevertheless, reptiles were currently one of the least studied vertebrate group in ecotoxicology (Sparling et al., 2010). The existing researches on reptiles primarily concentrated on turtles and/or crocodilians, while those on squamates were still rare (Wu et al., 2020).

Moreover, although there is growing concern on the bioaccumulation and biomagnification potential of PBDEs, most related studies were conducted based on the whole body concentrations, which increased the uncertainties in the estimates of biomagnification potential. (Conder et al., 2008) For example, previous field observations found that PBDEs were generally biomagnified in the North Sea (Weijs et al., 2009), the Atlantic coast (Shaw et al., 2012), and Coastal Florida (Johnson-Restrepo et al., 2005), while the rapid rates of depuration though biotransformation in the Canadian Arctic was simultaneously suggested (Kelly et al., 2008). The inconsistent and widely varying results indicate that further research is urgently needed to investigate the tissue distribution of PBDEs and their biomagnification potential based on tissue-specific in food web.

In the present study, two snake species were collected from paddy fields in the Yangtze River (ChangJiang) Delta (YRD), China. Tri- to deca-BDE congeners were determined in different tissues (including liver, muscle, and adipose) of short-tailed mamushi (*Gloydius brevicaudus*) and red-backed rat snake (*Elaphe rufodorsata*). Our objectives were to (a) investigate the occurrence and congener patterns of PBDEs in snakes; (b) determine the tissue distribution and mass burden of PBDEs in two snake species; and (c) compare the different biomagnification potential of PBDE congeners based on concentrations of frog and snake muscle.

2. Materials And Methods

2.1 Sampling

In October 2011, 7 short-tailed mamushi (*Gloydius brevicaudus*) samples, 9 red-backed rat snake (*Elaphe rufodorsata*) samples, and 45 frog samples (black-spotted frog, *Pelophylax nigromaculatus*) were collected from paddy fields in YRD, China. The sampling sites were located between Shanghai and Jiaxing City. Muscle, liver, and adipose (abdominal fat) samples were scrupulously dissected from 16 snake individuals, and these samples were weighted before treatment. After freeze-dried, the muscle tissues were homogenized in a powder under liquid nitrogen. The muscle mixtures, the fresh liver and adipose of snakes were then stored at -20°C until analysis. The frogs were dissected (for muscle), freeze-dried and stored using same procedure of snakes.

2.2 Chemicals, extraction and analysis

All PBDE congeners (BDE-28, -47, -66, -85, -99, -100, -153, -154, -183, -194, -195, -196, -197, -199, -201, -202, -204, -205, -206, -207, -208 and -209), and internal standard (^{13}C -labeled BDE-77) were gained from

AccuStandard (New Haven, CT). The surrogate standards (^{13}C -labeled BDE-209 and 2,4,5,6-tetrachloro-mxylene (TCMX)) from Sigma-Aldrich (Bellefonte, PA, USA) were used to monitor chemical's losses in treatment process. Chemical solutions, like hexane, dichloromethane (DCM) and acetone of analytical grade, were purchased from Beijing Chemical Factory (Beijing, China). Prior to use, anhydrous sodium sulfate (Beijing Chemical Factory, Beijing, China) were activated at 350 °C for 4 h.

The extraction and clean-up procedures mainly followed the previously reported method with some modifications (Zhou et al., 2016a). In brief, approximately 2 g (dry weight) muscle sample and 2 g (fresh weight) of liver and adipose samples mixed with 5 g anhydrous sodium sulfate was spiked with surrogate standards (^{13}C -labeled BDE-209 and TCMX). Each sample was Soxhlet extracted with 200 ml of hexane/DCM/acetone (1:1:1 v/v) for 24 h. Lipid contents were determined gravimetrically and removed afterwards by treatment with concentrated sulfuric acid. A Pasteur pipette, filled with 0.2 g activated silica gel and 1.0 g acidified silica gel (activated silica/concentrated sulfuric acid, 2:1 w/w) on top was used for further clean-up. After clean-up, each column was conditioned with 7 ml hexane, the extract was added and the analytes eluted with hexane/DCM (10 mL, 1:1, v/v). The extract volume was reduced to near dryness by a gentle stream of nitrogen gas, and then the residue was dissolved to 0.2 mL hexane. Internal standard (^{13}C -labeled BDE-77) was added into the samples before instrumental analysis.

Analysis of PBDEs was performed by gas chromatography (Agilent 7890A) coupled to a mass spectrometry (5975C) using chemical ionization ion source and selective ion monitoring mode (scanning bromine ions m/z 79 and 81). A DB-5MS column (15 m x 0.25 mm i.d. x 0.10 mm film thickness; Agilent J&W) was applied with helium and methane as carrier and reagent gas, respectively. The oven program was 80°C for 2 min, 15°C/min to 300°C, 2°C/min to 310°C and hold for 5 min. The temperature of injector, ion source and transfer line were set at 280°C, 200°C and 290°C, respectively.

2.3 Stable isotope analysis

Stable isotope analysis was applied in this study to investigate the diet preferences of snakes and confirmed whether the black-spotted frog observed in the surrounding was their potential prey specie. Detailedly, a Flash HT element analyzer interfaced coupled with a Thermo Scientific MAT 253 isotope ratio mass spectrometer was performed to analyze the carbon isotope ($\delta^{13}\text{C}$) and nitrogen isotope ($\delta^{15}\text{N}$). The data set on the stable isotope analysis can be found elsewhere, in which the analysis result was stated and detailed out (Zhou et al., 2016a).

2.4 Quality assurance/quality control

Procedural blanks were included in every five samples to test background level. Isotopically-labeled surrogate standard was spiked in every sample accounting for processing losses and matrix effects. Limits of quantification for PBDEs (LOQs) were calculated as average blank level ($n=10$) plus ten times the standard deviation of the blank (SD), ranging from 0.04 to 0.82 ng/g. The recoveries of surrogate standards were $82 \pm 15\%$ for ^{13}C -labeled BDE-209 and $94 \pm 8\%$ for TCMX.

2.5 Statistical analysis

For the statistical analysis of PBDE congeners in this study, data detected below LOQ were substituted with the value $LOQ/\sqrt{2}$. Descriptive statistics, Student's *t*-test and Spearman rank correlation were performed using SPSS Statistics Version 23 (IBM Corp.). The significance level was set at 1%. The independent samples *t* test was used to assess the significant difference between two groups of data. The log K_{ow} values of PBDE congeners were gained from previous studies (Tittlemier et al., 2002; Yue and Li, 2013).

3. Results And Discussion

3.1 Occurrence and Congener Group Patterns

Once ingested from diet, hydrophobic organic contaminants (HOCs) were taken up in the gastrointestinal tract, firstly passed through the liver and then redistributed to other organs such as muscle before being finally stored in adipose tissue (Du et al., 2020). The concentrations of PBDE congener groups in liver, muscle, and adipose tissues of two snake species are summarized in Table 1. Hexa-, octa- and nona-BDEs were detected in all tissue samples of two snakes. The total PBDE concentrations of liver, muscle, and adipose tissues ranged from 29.1-252.2, 10.5-48.9 and 4.36-106.4 ng/g lw, respectively. The average Σ PBDEs concentration in muscle samples of short-tailed mamushi (23.1 ng/g lw) was close to those of red-backed rat snake analyzed in the present study (33.2 ng/g lw) and our previous report (28.3 ng/g lw) (Zhou et al., 2016b), but was 1-2 orders of magnitude lower than of water snakes sampled from e-waste sites (Liu et al., 2018; Wu et al., 2013; Wu et al., 2020). Additionally, a significant positive correlation was observed between body weight of snakes and muscle concentrations of PBDEs in all samples ($r^2 = 0.56$, $p < 0.01$; data not shown). This result suggested that the PBDE exposure of snakes might increase with their growth stages. The research focusing on PBDE levels in other tissue of reptiles was relatively limited. Wu et al. (2014) reported that the PBDE exposure of liver sample of Chinese alligators was 920 ng/g lw, significantly higher than the snakes observed in the present study.

Table 1
Tissue concentrations (ng/g lw) of tri- to deca-BDEs of two snake species.

species	red-backed rat snake			short-tailed mamushi		
tissue	liver	muscle	adipose	liver	muscle	adipose
tri-BDE	0.09 ± 0.28	0.39 ± 0.8	0.002 ± 0.005	0.56 ± 0.77	0.43 ± 0.43	0.001 ± 0.003
	(nd-0.83)	(nd-2.2)	(nd-0.01)	(nd-2.22)	(nd-1.13)	(nd-0.01)
tetra-BDE	0.95 ± 2.76	0.35 ± 0.62	0.660 ± 1.78	0.86 ± 0.7	0.11 ± 0.1	0.100 ± 0.1
	(nd-8.32)	(0.02-1.97)	(0.01-5.41)	(nd-1.97)	(0.01-0.22)	(nd-0.26)
penta-BDE	5.43 ± 5.92	0.40 ± 0.41	1.310 ± 1.89	5.90 ± 9.2	0.25 ± 0.26	0.910 ± 0.52
	(nd-15.35)	(0.02-1.2)	(0.23-6.24)	(nd-23.22)	(0.01-0.72)	(0.35-1.78)
hexa-BDE	33.70 ± 31.7	1.12 ± 0.63	7.980 ± 12.8	35.60 ± 22.1	3.42 ± 1.50	5.250 ± 3.82
	(3.1-89.6)	(0.29-2.42)	(1.38-41.4)	(5.91-63.4)	(1.63-6.50)	(1.91-23.2)
hepta-BDE	8.05 ± 7.36	0.89 ± 0.61	2.360 ± 2.87	12.01 ± 7.67	2.19 ± 1.72	5.300 ± 8.97
	(nd-24.8)	(nd-2.31)	(0.71-9.03)	(2.75-24.9)	(nd-5.53)	(1.20-35.6)
octa-BDE	24.80 ± 26.7	1.98 ± 2.42	3.180 ± 5.12	18.10 ± 16.1	2.89 ± 2.00	4.320 ± 6.47
	(3.49-88.7)	(0.39-7.15)	(0.57-16.5)	(2.37-51.6)	(1.15-6.55)	(1.1-28.9)
nona-BDE	28.60 ± 15.3	8.68 ± 7.45	7.770 ± 8.61	40.50 ± 25.8	4.62 ± 4.17	6.480 ± 3.47
	(12.3-58.3)	(1.62-19.6)	(1.29-26.6)	(7.20-71.6)	(1.26-10.7)	(3.31-12.9)
deca-BDE	31.00 ± 26.1	9.34 ± 5.4	0.350 ± 0.41	46.09 ± 28.9	6.25 ± 2.14	0.310 ± 0.22
	(7.95-92.2)	(4.67-19.3)	(nd-1.29)	(7.62-76.75)	(3.91-10.17)	(0.14-0.79)
ΣPBDEs	172.60 ± 58.1	33.20 ± 10.4	28.600 ± 32.7	159.60 ± 84.1	23.10 ± 6.75	19.200 ± 15.8
	(69.7-230.7)	(10.5-48.9)	(4.36-106.4)	(29.1-252.2)	(11.2-40.2)	(9.83-68.0)

The variations of PBDE congener group patterns in different tissues of two snake species, are presented in Figure 1. In liver samples of two snake species, the levels decreased in the order deca-BDE > hexa-BDE > nona-BDE > octa-BDE > hepta-BDE > penta-BDE > tetra-BDE > tri-BDE, contributing to 26.0%, 23.9%, 23.4%, 15.1%, 6.8%, 3.9%, 0.6% and 0.2% of the total PBDE levels, respectively. Deca-BDEs (36.6%) were dominant in snake muscle samples followed by nona-BDEs (31.6%). For adipose samples, nona- and hexa-BDEs were the two most abundant congener groups collectively contributing to 60.3% of total PBDEs. PBDE patterns predominated by deca-BDEs have been observed in various biotic and abiotic matrices (Li et al., 2018; Li et al., 2019; Wu et al., 2020), which may be due to the fact that deca-BDE was the major congener in in-use PBDE commercial products (Abbasi et al., 2015). Furthermore, deca-BDE would be debrominated down to penta- and octa-BDE congeners *in vitro* (Chabot-Giguere et al., 2013). Therefore, the higher concentrations of deca-BDE in liver and muscle compared to those in adipose tissue may be indicative of the metabolic fate of deca-BDE in snakes. The congener group patterns of PBDEs showed the significant difference ($p < 0.01$) between the two snake species (Figure 1). The most fluctuating congeners were octa-BDE, nona-BDE and hepta-BDE for liver, muscle, and in adipose tissues. The interspecies difference for PBDE exposure may be attributed to different feeding habits and dermal exposure (Du et al., 2018), since the short-tailed mamushi generally lives in the terrestrial environment while the red-backed rat snake prefers the semi-aquatic condition (Du et al., 2020).

3.2 Tissue Distribution and Tissue-Specific Burden

Similar tissue distributions of total PBDE levels were observed in two snakes (Figure 1). In most snake samples, the tissue levels followed the order liver > muscle > lipid. This differed from the body distribution of chlorinated paraffins (CPs) in snakes (Du et al., 2020) which coincided with the lipid contents in different tissues (Table 1). Result from the present study suggested that other factors (e.g. bioaccumulation pathway and metabolism) besides the lipid content might influence the tissue-specific accumulation of PBDEs in both red-backed rat snake and short-tailed mamushi. Sun et al. (2017b) investigated the tissue distribution of HOCs in freshwater fish community, and found that the significant accumulation of high lipophilic pollutants in liver tissue compared to other ones. Previous field study of frogs also detected the highest concentrations of HOCs in liver followed by muscle (Du et al., 2019), which might be explained by the fact that liver functioning as storage of glycogen and fat to apparent extent may cause the enhanced POP loads.

The snake liver and muscle samples shared close PBDE congener group patterns with enrichment of deca-BDE, which was very limited in snake lipid samples (Figure 1). The living habit may lead to the different congener group pattern in adipose tissues: reptiles would stop foraging and consume their body fat during brumation in winter; once adipose tissue was used, the highly lipophilic contaminants such as deca-BDE that were previously stored in lipid may redistribute among whole body. Although consumption of fat may reduce the HOC storage in snake adipose tissue, the redistribution process probably increased HOC in other tissues and eventually elevated the risk of exposure toxicity, which should be considered in biomonitoring (Du et al., 2020). Recent studies emphasized that the concentrations of PBDEs in different

tissues may not entirely represent the tissue exposure, mainly due to the varying contaminant concentrations in wildlife tissues through time (Du et al., 2020). For example, HOC concentrations in adipose may be diluted by an increase of body fat (Yordy et al., 2010). In contrast, contaminant burdens are much steady and can reflect the whole exposure to tissues as well as individuals (Du et al., 2019).

In the present study, tissue-specific PBDE burdens of two snake species were calculated as the product of the tissue mass and tissue PBDE concentrations and presented in Figure 2. The body PBDE burdens (sum of three tissue burdens) in red-backed rat snake (400.2 ng) was two folds higher than those in short-tailed mamushi (188.6 ng). The red-backed rat snake individuals in the present study were generally thick in body condition since they had heavy body weight and high proportion in tissues (Table 1), in comparison with the short-tailed mamushi individuals which were considered to be thin. Yordy et al. (2010) also observed the higher contaminant burdens in fatter bottlenose dolphins. Animals with rich fat content may readily store lipophilic compounds in tissues. Simultaneously, there may be differences in metabolic activity between the two snake species, in particularly in snake liver and muscle, and these may be part of the explanation for the differences seen between the two species.

The relative contributions from liver, muscle and adipose tissues to the total PBDE burdens (sum of three tissue burdens) were similar between red-backed rat snake and short-ailed mamushi. The total burdens of two snakes were dominant by adipose (85.1% and 80.0%, respectively) while liver (8.1% and 12.5%, respectively) and muscle (6.9% and 7.5%, respectively) tissues had low proportion of the total burdens. For congener groups, high proportion of tri-BDE burdens were found in muscle tissue of red-backed rat snake (69.1%) and short-tailed mamushi (76.4%). Up to 80% of tetra- to nona-BDE burdens were enriched in adipose tissue of two snakes. For deca-BDE, liver tissue was the main storage tissue contributing to 43.6% of the burdens. These results indicated that the adipose tissue in snakes could serve as a more effective storage and sink for PBDE congeners compared to liver or muscle tissues. In HOC biomonitoring researches, measuring muscle or liver tissue concentrations was a common approach for assessing the chemical exposure in wildlife (Glüge et al., 2018; van Mourik et al., 2016). However, the overlook of adipose data may underestimate the exposure of PBDEs, in particular for animals with rich fat contents.

3.3 Biomagnification Potential

Biomagnification factors (BMFs) of HOC can be calculated by dividing the predator concentration by the prey concentration. Biomagnification is suggested to take place when the BMF value is higher than one. It is of great importance to confirm the predator and prey species in the food web (Glüge et al., 2018). Although snakes are generally seemed as a high trophic species, the diet of these feeders would vary with the environment. Most of red-backed rat snake preferred to live in/near water and choose the aquatic organisms that is the relative abundant and readily available. According to a snake dissection study in YRD, the pond loach, rice field eel and black-spotted frog were supposed as potential major diet for red-backed rat snakes in the local environment (Huang et al., 1990). Further assurance of predator-prey relationship was carried out using stable isotope analysis, and the analyzed $\delta_{13}\text{C}$ and $\delta_{15}\text{N}$ values of red-backed rat snake and its prey candidates have been described in a previous study using the same

samples (Du et al., 2020). $\delta_{13}\text{C}$ values of red-backed rat snake and black-spotted frog were close ($-23.76 \pm 0.89\text{‰}$ and $-24.83 \pm 0.41\text{‰}$, respectively) whereas red-backed rat snake was enriched in $\delta_{15}\text{N}$ ($9.33 \pm 0.62\text{‰}$ SD) compared with their diet ($7.36 \pm 1.21\text{‰}$ SD). For pond loach and rice field eel, the $\delta_{13}\text{C}$ values were significantly lower than those observed in red-backed rat snakes ($p < 0.05$), which indicated that the pond loach and rice field eel were not the major carbon sources of red-backed rat snakes. These results confirmed the direct predator-prey relationship between the red-backed rat snakes and black-spotted frogs in the paddy field food web.

In the present study, biomagnification factors (BMFs) of PBDE congeners were calculated by dividing the lipid-normalized muscle concentration of red-backed rat snakes by the lipid-normalized muscle concentration of black-spotted frog. As shown in Figure 3, more than half of individual BDE congeners (13 out of 22) displayed BMF values above one. The BMF values of tri-BDE, tetra-BDE, penta-BDE, hexa-BDE, hepta-BDE, octa-BDE, nona-BDE and deca-BDE averaged at 0.75, 2.30, 1.62, 2.61, 3.10, 4.30, 0.85 and 0.74, respectively. In general, tetra- to octa-BDEs exhibited biomagnification potentials through the frog-snake food chain. The BMFs of PBDEs in the present study were comparable with those reported between predators and prey from an e-waste recycling site in South China (0.13-5.30) (Wu et al., 2020), but lower than those observed in the North Sea (0.6-15) (Weijs et al., 2009), the Atlantic coast (14-54) (Shaw et al., 2012), and the feeding experiment (7.2-20.6) (Luo et al., 2013). These results may suggested the trophic magnification potentials were affected by the behavior of predator and distinctive ecology, in which the food resource would vary markedly.

Parabolic relationship was observed between BMFs and $\log K_{ow}$ values of PBDE congeners (Figure 3). The BMFs increased with increasing number of bromine atoms up to 8 and then rapidly declined as bromine atom number raised. It was noteworthy that the BMFs plots dropped dramatically after hepta-BDE indicating the limited biomagnification potential of nona- and deca-BDEs ($\text{Br} \geq 9$) probably due to their very high molecular weight. Similar results have also been observed in bioaccumulation of PBDE (Wu et al., 2020), bioaccumulation of CPs (Sun et al., 2017a), trophic magnification of CPs (Zhou et al., 2018) and bioaccumulation study for other halogenated HOC (Zhu et al., 2015). PBDE congeners with higher bromine number tend to have higher $\log K_{ow}$ values (Tittlemier et al., 2002; Yue and Li, 2013) resulting in higher biomagnification potential. However, the breakpoint from positive to negative correlation was approximately $\log K_{ow}$ 8.6. The parabolic trend showed that the biomagnification potential of PBDE congeners appeared to be related to both hydrophobicity and molecular size of chemicals. The congener groups with low-moderate $\log K_{ow}$ values (tri- to octa-BDEs) have smaller molecular size, and therefore, lipophilicity is the dominant factor. For congener groups with high $\log K_{ow}$ values (nona- and deca-BDEs), larger molecular size may increase the difficulty of transmembrane and limit their bioavailability and biomagnification potential.

4. Conclusions

The present study presented one-hand data of tissue-specific levels and burdens of PBDE congeners in two snakes. The total PBDE concentrations of liver, muscle, and adipose tissues ranged from 29.1-252.2, 10.5-48.9 and 4.36-106.4 ng/g lw, respectively. Tetra- to nona-BDEs were preferentially accumulated in snake adipose tissues while liver was an important storage and sink of deca-BDE. BMFs results through frog-snake food chain confirmed the varying biomagnification potentials for different PBDE congeners. Parabolic relationship was found between BMFs and $\log K_{ow}$ values of PBDE congeners, which may be resulted from the combined effects of hydrophobicity and molecular size of chemicals. Further research could focus on the toxicity, trophic transfer and biotransformation of PBDEs in different reptile tissues.

Declarations

Data availability: Most of the data generated or analysed during this study are included in this published article. In addition, the datasets used and/or analysed during the current study are not available.

Acknowledgments: We appreciate the samples provided by Shimadzu (China) Company and Tongji University.

Funding: This research received no external funding.

Contributions: Xiuming Jing: Conceptualization, Methodology, Writing original draft, Writing - Review and Editing, Software, Data Curation. Xueqiu Wang: Review and Editing, Formal analysis, and Supervision. Hongjuan Lv: Investigation, Data Curation. Futian Liu: Writing - Review and Editing, Software, Data Curation.

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Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Conflicts of Interest: The authors declared that they have no conflicts of interest to this work.

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Figures

Figure 1

Congener group pattern of PBDEs in muscle, liver, and adipose of two snake species

Figure 2

Tissue-specific burdens of tri- to deca-BDEs (ng) in two snake species

Figure 3

Biomagnification factors (BMFs) of PBDE congeners derived from the the red-backed rat snake/ black-spotted frog relationship. The green rectangle represents BMF values less than 1, BMFs above which may suggest biomagnification