TROPHODYNAMIC ACCUMULATION OF BROMINATED FLAME RETARDANTS IN BIOTA OF JAKARTA BAY

TROPHODINAMIK AKUMULASI DARI SENYAWA BROMINATED FLAME RETARDANTS DI BIOTA DARI TELUK JAKARTA

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ABSTRAK

Penelitian ini dimaksudkan untuk mengetahui tingkat kontaminasi, bioakumulasi, dan trofik transfer polutan beracun yang dikenal sebagai brominated flame retardants (BFRs), seperti polybrominated diphenyl ethers (PBDEs) dan hexabromocychlo-dodecanes (HBCDs), pada biota yang mewakili berbagai tingkat trofik di Teluk Jakarta. Sampling organisme dilakukan di teluk bagian timur dengan menggunakan beberapa metode penangkapan. Sampel yang diperoleh dianalisis untuk mengetahui kandungan isotop stabil nitrogen (N) dan karbon (C) dengan menggunakan peralatan GC-C-IRMS, 14 konjener PBDEs menggunakan GC-MS dan tiga isomer HBCDs menggunakan LC-MS/MS. Analisis isotop stabil N dan C menunjukkan bahwa biota yang diamati tersusun oleh beberapa tingkatan trofik yang berbeda. Total konsentrasi dari PBDEs dan HBCDs pada biota bervariasi menurut spesies, berkisar antara 1,6 ng/g berat lemak sampai 57 ng/g berat lemak untuk PBDEs, dan antara tidak terdeteksi (nd) sampai 4,1 ng/g berat lemak untuk HBCDs. Terdapat hubungan positif yang signifikan antara tingkat trofik (TL) dan konsentrasi PBDEs. Namun, hubungan ini tidak terlihat pada polutan HBCDs. Besarnya nilai Trophic Magnification Factor (TMF) dari PBDEs berkisar antara 0,63-3,0; di mana hanya dua (BDE-47 dan BDE–100) dari 14 konjener yang diamati memiliki nilai TMFs lebih dari satu.

Kata Kunci: *Brominated flame retardants, Kontaminasi, Biomagnifikasi, Biota, Teluk Jakarta*

ABSTRACT

The level of contamination, bioaccumulation and potential trophic transfer of toxic pollutants known as brominated flame retardants (BFRs), such as polybrominated diphenyl ethers (PBDEs) and hexabromocychlododecanes (HBCDs), was examined in biota representing different trophic levels in Jakarta Bay. Various organisms were collected using several catching methods during July-August 2007 at eastern part of the bay and were analyzed for nitrogen (N) and carbon (C) stable isotopes, 14 PBDE congeners and three HBCD isomers using GC-C-IRMS, GC-MS and LC-MS/MS, respectively. Analysis of N and C indicated that the biota was composed by different trophic levels within the Jakarta Bay ecosystem. Concentrations of total PBDEs and total HBCDs varied according to species, ranged from 1.6 ng/g lipid wt. to 57 ng/g lipid wt. and below detection limit (nd) to 4.1 ng/g lipid wt, respectively. Furthermore, there was significant positive correlation between trophic level (TL) and concentration of PBDEs was found, but not HBCDs. Trophic Magnification Factors (TMF) values of PBDEs ranged 0.63–3.0 with only two congeners (BDE-47 and BDE–100) having TMFs greater than one.

Keywords: Brominated flame retardants, Contamination, Biomagnifications, Biota, Jakarta Bay

INTRODUCTION

Environmental contaminations by toxic chemicals including emerging pollutants of BFRs such as PBDEs and HBCDs received public attention during recent years.[1] Had being because of their properties such as persistency, biaccumulative nature, biomagnifications potency, and possible adverse effects on wildlife and human. Several studies suggested that these compounds have the propensity to disrupt thyroid hormones, responsible for neurobehavioral changes, affect fetal development, possible cause cancer in laboratory animals, and act as endocrine disrupter.[2,3,4] These compounds are used as additive flame retardants to prevent from fire damage in a wide variety of commercial and household products such as plastics, textiles, and electronic appliances including computers, televiosn, etc. For instance, PBDEs commercial formulations with three degrees of bromination, i.e., penta-BDE, octa-BDE, and deca-BDE are considered as high volume chemical products. Global market demand in 2001 showed that Asia consumed large quantity of the total commercial PBDEs (24,650 tons, 37%) ranking second after Americas (33,100 tons, 49%), whereas Europe was the lowest (8,360 tons, 12%).[1] Due to their large usage and disposal, combine by their physico-chemical properties, they can be found at all environmental compartments.[1,5] As these compounds are lipophilic and persistent, they can be bioaccumulated and biomagnified through food chains. Therefore, bioaccumulation and biomagnification of BFRs in aquatic ecosystems could potentially increase the risk in higher trophic level organisms including human, relative to organisms occupying lower trophic positions.

Jakarta Bay is considered as one of polluted embayments in Indonesia. Previous studies indicated that there have been several indicators showing declining environmental quality and biodiversity in this bay.[6,7,8] For example, it has been reported that species of fish caught by beach-seine have declined from 45 species in 1974 to only 20 species in 2003 and heavy metal contamination are increasing during recent year.[6] Moreover, Damar[7] stated that the Jakarta Bay was also hyper eutrophic (503 g C/m^2/y) which thus often generates the algal blooms and mass mortality of fish often occurred yearly with concentration of dissolved oxygen (DO) as low as 0.14–0.80 mg/l. However, there is little information exist on contamination by other toxic pollutants in Jakarta Bay including persistent organic pollutants (POPs) and new emerging contaminants of BFRs,[8] particularly no data available on the transfer of these pollutants through food chain. Recently, estimation of contaminant biomagnification through a food web (trophic transfer) has become advanced by using stable isotope ratios of bio-elements, such as stable isotope of N and C.[9,10,11,12] The present study aimed to investigate the levels of stable isotopes of N and C, PBDEs and HBCDs in biota of Jakarta Bay. In order to understand their biological occurrence, his study was also to elucidate the accumulation dynamic in various organisms representing from different TL, to calculate their potential biomagnifications and to compare among those other studies worldwide.

Stable N isotopes have been used as a trophic-position indicator and to estimate the biomagnification potential of lipophilic contaminants in diverse ecosystems.[10,11,12,13] Whereas, stable C isotopes are used for estimating carbon source for the food web.[13] The ratio of ^{15}N to ^{14}N and ^{13}C to ^{12}C (in biological tissues relative to air), which are expressed as delta–1^5N ($\delta^{15}N$) and delta–1^3C ($\delta^{13}C$), and presented as per thousand deviations from the standards (‰), can be calculated by the following equation:

$$\delta X\,(‰) = (R_{sample}/R_{standard} - 1) \times 1000 \qquad (1)$$

Where X is ^{13}C or ^{15}N, and R is the corresponding ratio $^{13}C/^{12}C$ or $^{15}N/^{14}N$. In the analytical method for quantification of $\delta^{15}N$ and $\delta^{13}C$, the Pee Dee Belemnite (PDB) limestone carbonate and atmospheric nitrogen (N_2) are generally used as the standards for C and N isotope ratios, respectively.[13]

$\delta^{15}N$ in tissue organism of certain food web typically increases consistently by 3.4%–3.6% with each trophic transfer, because ^{15}N is retained from the food resource relative to ^{14}N.[9] Since concentrations of biomagnifying contaminants also increase with trophic position, there will be a significant relationship between the biomagnify-

ing compounds with increasing $\delta^{15}N$ values in biota; therefore, linear-regression slopes can be used to predict contaminants behavior within food webs. [9,12,13]

Thus, to characterize the possible food web of a given aquatic ecosystem, the TL of each biota can be calculated based on $\delta^{15}N$. The TL of a given organism in an ecosystem ($TL_{consumer}$) can be determined relative to primary consumer which is assumed to have TL of 2 ($TL_{primary\ consumer}$) by using the following equation:[14]

$$TL_{consumer}=2+(\delta^{15}N_{consumer}-\delta^{15}N_{primary\ consumer})/3.8 \quad (2)$$

Where 3.8 is the isotopic enrichment factor and $\delta^{15}N_{primary\ consumer}$ is assumed to be the $\delta^{15}N$ value for *zooplankton* as primary consumer.

Furthermore, trophic magnification factors (TMFs), which are the markers of cumulative bioaccumulation processes across the food web can be determined from the log-linear regression between the base–10 logarithm ($\log_{10}$) of the lipid equivalent concentration of lipophilic contaminants in biota (C_B) and TL:

$$\text{Log } C_B = (m \times TL) + b \quad .....(3)$$

Where *m* and *b* are the empirical slope and *y*-intercept, respectively. TMFs can be calculated as the antilog of the slope (*m*):

$$TMF=10^m \quad .....(4)$$

METHODOLOGY

Sampling was conducted at eastern part of Jakarta Bay using several catching methods during 31 July–1 August 2007. Particulate organic matter (POM) and a total of 88 specimens belonging to 15 species of marine biota were used in this study (Table 1). Those included zooplankton, green mussels, crab, shrimp, and various fish species such as smudgepot spinefoot, Java spinefoot, patterned tongue sole, northern sand flathead, sailfin catfish, moses perch, large-toothed flounder, diamond trevally, black-edged conger, and giant seaspike. Zooplankton and POM were collected using Kitahara plankton net (Rigosha Co., Ltd., Japan), whereas other biota were collected using trap net and seine net by local fishermen.

Identification of species of fish and their feeding behaviour were based on Allen[15] and

Table 1. Samples, Sampling Date and Feeding Behavior of Organisms Collected from Jakarta Bay

Sample Biota	Species	*n*	Date	Feeding Behavior
POM	-	3	31-07-2007	-
Zooplankton	*Acellota* sp.	1*	31-07-2007	Feeds on phytoplankton
Green mussel	*Perna viridis*	3*	31-07-2007	Suspension feeder
Shrimp	*ni*	3*	1-08-2007	ni
Crab	*ni*	3*	1-08-2007	ni
Smudgepot spinefoot	*Siganus canaliculatus*	5	1-08-2007	Herbivorous, feeds on benthic algae and seagrass
Java spinefoot	*Siganus javus*	5	1-08-2007	Herbivorous, feeds on benthic algae and seagrass
Sailfin catfish	*Paraplotosus* sp.	3	1-08-2007	Feeds on gastropod mollusks and crustaceans
Little jewfish	*Johnius vogleri*	7	1-08-2007	Feeds on crustaceans, show piscivorous tendency
Northern sand flathead	*Platycephalus arevanius*	3	1-08-2007	Feeds on small fish, crabs, prawns, crustaceans
Large-toothed flounder	*Pseudohambus arsius*	2	1-08-2007	Feeds on benthic animals
Moses Perch	*Lutjanus ruselli*	8	1-08-2007	Feed on benthic invertebrates and fish
Patterned tongue sole	*Paraplagusia bilineata*	1*	1-08-2007	Feeds mostly on benthic invertebrates
Diamond trevally	*Alectis indicus*	1*	1-08-2007	Feed on fishes, squids, and crustaceans
Black-edged conger	*Conger cinereus*	1*	1-08-2007	Feeds on fish and crustaceans
Giant seapike	*Sphyraeno jello*	1*	1-08-2007	Feeds mainly on fishes but also takes squid

Note: ni = not identified, n = number of individual, *pooled samples.

Fishbase.[16] In the laboratory, the samples were kept frozen in environmental specimen bank (*es*-BANK) of Ehime University at -20°C until dissection and chemical analyses.

Stable N and C isotopes were determined using the procedure described by Toyoshima *et al*.[13] Briefly, few mg samples were dried for 24 h at 60°C, ground to a powder and then immersed in chloroform: methanol (2:1) solution for 24 h to remove lipids. The ratios of stable carbon and nitrogen isotopes were analyzed using a gas chromatography-combustion-isotope ratio mass spectrometer (GC–C-IRMS) (PDZ Europa Ltd. ANCA-SL) and presented as per thousand deviations from the standards (‰). Pee Dee Belemnite (PDB) limestone carbonate and atmospheric nitrogen (N_2) were used as the standards for C and N isotope ratios, respectively.

For the BFRs analyses, fourteens PBDE congeners including mono-BDE (BDE-3), di-BDE (BDE-15), tri-BDE (BDE-28), tetra-BDE (BDE-47), penta-BDE (BDE-99, BDE-100), hexa-BDE (BDE–153, BDE-154), hepta-BDE (BDE–183), octa-BDE (BDE-196, BDE-197), nona-BDE (BDE-206, BDE-207) and deca-BDE (BDE-209) and three HBCD isomers (α-, β- and γ-HBCD) were the target compounds of the present study and were conducted according the methods described by Toyoshima *et al*.[13] Briefly, freeze dried samples (equal with 30 g wet weight) were ground with anhydrous sodium sulfate. After spiking with labeled PBDEs ($^{13}C_{12}$-BDE-3, -15, -28, -47, -99, -153, -154, -183, -197, -207 and -209) and HBCD (α-, β- and γ–1^3C_{12}-HBCD) as surrogate standards, the samples were extracted with hexane/acetone (1/1, v/v) using accelerated solvent extractor (ASE 100, Mitsubishi). Part of the extract samples was separated (a sub sample) and used for lipid determination. The extracted sample was then subjected to gel permeation chromatography (GPC; Bio-Beads S-X3, Bio-Rad laboratories, CA, 2 cm i.d. and 50 cm length) for lipid removal. The GPC extract was further purified and fractionated by silica gel chromatography (Wako gel S–1, Wako Pure Chemicals, Japan). First fraction contains PBDEs and 2nd fraction contains HBCDs. A known amount of internal standard ($^{13}C_{12}$-labeled BDE–139 for PBDEs and deuterized HBCD (α-, β- and γ-HBCD-d18) for HBCDs) was added prior to instrumental analysis. Quantification of PBDEs was carried out by gas chromatography (GC Agilent 7980A) with a mass spectrometry detector (MSD Agilent 5975C) in the negative chemical ionization mode. Whereas, for quantification and identification of HBCDs, an Acquity UPLC liquid chromatography equipped with a Quattro Micro API (Waters, Tokyo) triple quadrupole mass-spectrometer was used. Liquid chromatography separation of three stereoisomers (α-,β-, γ-HBCD) was achieved with an Extend-C18 column (2.1 mm i.d. x 100 mm, 1.8 μm, Agilent, Tokyo). The MS-MS analysis in negative mode of electro spray ionization (ESI) was performed in multiple reactions monitoring mode (MRM). Concentration of individually resolved peaks of PBDE and HBCD isomers and congeners were summed to obtain total PBDE (ΣPBDEs) and HBCD concentrations (ΣHBCDs). Lipid contents were determined by measuring the total nonvolatile solvent extractable material in sub samples taken from the original extracts. Procedural blanks were analyzed simultaneously with every batch of seven samples to check for interferences or contamination from solvents and glassware. As the BFRs are liphophilic compounds, concentration of PBDEs and HBCDs was expressed on a lipid weight basis unless otherwise specified. Recovery of ^{13}C-labeled BDEs ranged between 56% and 110% depending on the congeners. Whereas, recovery for ^{13}C-labeled HBCDs ranged between 89% and 108%. Detection limits for BFRs analyzed in this study were calculated as three times the procedural blank, and were in the range of 0.01–0.05 ng/g on a lipid weight basis for mono- to nona-BDE, 1.3 ng/g for deca-BDE and 0.002 ng/g for HBCDs.

For quality assurance and control, our laboratory participated in the Inter comparison Exercise for Organic Contaminants in Marine Mammals Blubber, organized by the National Institute of Standards and Technology (Gaithersburg, MD) and the Marine Mammal Health and Stranding Response Program of the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (Silver Spring, MD). Standard reference material SRM 1945 was analyzed for selected PBDE congeners. Data from our

analytical method were in good agreement with those for reference materials.[17]

Statistical analysis was performed using Mann-Whitney *U*-test to compare concentrations of PBDEs and HBCDs. Whereas, Spearman rank correlation was used to examine the strength of associations between TL and concentrations of BFRs. All statistical analyses were performed using Stat View program version 5. A probabilistic value of $p<0.05$ was considered significant.

RESULTS AND DISCUSSION

Analysis of stable N and C isotopes as calculated by equation (1) illustrated that the biota of the present study were composed by different trophic levels within Jakarta Bay food web as an increase in $\delta^{15}N$ values from zooplankton to pelagic fish was observed (Figure 1 and Table 2). However, there was no large variation of $\delta^{13}C$ among biota of the present study, indicating that they acquired similar carbon sources within Jakarta Bay ecosystem and may belong to the same foodweb. Based on calculation of equation 2, the TL of each biota was presented in Table 2. In this study, the planktonic isopod crustacean (*Asellota sp.*) which had an average $\delta^{15}N$ of 6.0‰, were assumed as the primary consumer with TL = 2.0. The $\delta^{15}N$ for mussels, shrimps, smudgepot spinefoot, sole and crab (average TLs of 2.6, 2.9, 3.3, 3.7, and 3.7, respectively) indicated that they were the secondary consumers. Some similar feeding habit species such as Java spinefoot showed comparatively higher $\delta^{15}N$ values than smudgepot spinefoot of the same genus, possibly due to their occasional feeding of organisms of upper trophic levels. Other fish such as catfish, flathead, perch, trevally, little jewfish, conger, etc. occupied trophic levels intermediate between 3.9 and 4.5, suggesting that they were some of the top predators in this web and their diets most likely were a mix of fishes and other species. In the present study, giant seaspike which had the highest $\delta^{15}N$ value (16.7‰) was considered as the most top predator in this food web structure with a trophic level of 4.8.

PBDEs and HBCDs were detected in the samples of the present study with varying concentrations, ranging from 1.6–57 ng/g lipid wt. and nd–4.1 ng/g lipid wt., respectively (Table 2). These values were still much lower than those in fresh- and brackish water fishes from Okinawa, Japan such as Hija River and Lake Manko (94-2600 ng/g lipid wt. for PBDEs and nd–1300 ng/g lipid wt. for HBCDs);[18] Yangtze River, China

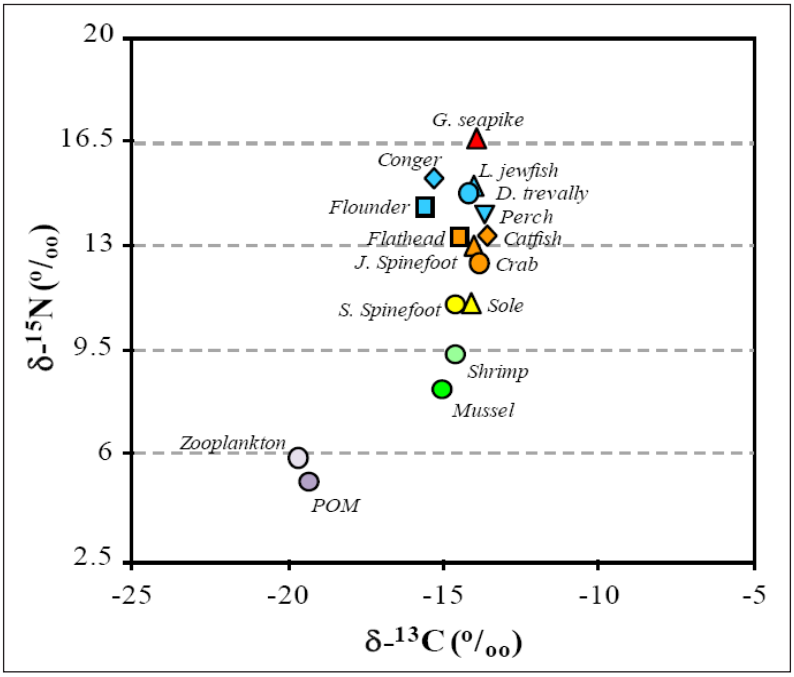

Figure 1. Food web structure of biota at Jakarta Bay based on $\delta^{15}N$ and $\delta^{13}C$ map

(19–1100 ng/g lipid wt. for PBDEs and 13-330 ng/g lipid wt. for HBCDs);[19] Guangzhou, China (46 ng/g lipid wt.)[20] and Hong Kong (4300 ng/g lipid wt.),[21] suggesting low contamination by these compounds in biota from Jakarta Bay. Among BFRs of the present study, concentrations of PBDEs were significantly higher (p<0.05) than HBCDs (Table 2), it could probably due to different amount of usage between these two BFRs. There has been no data available on the status usage of BFRs in Indonesia. However, in Asia, the usage quantity of PBDEs commercial products accounted 24,650 tons, much higher than HBCDs.[5]

Among PBDE congeners analyzed, lower BDE congeners from di- to hepta BDE (BDE-15, -28, -47, -99, -100, -153, -154 and BDE-183) were the generally detected congeners in which tetra BDE (BDE-47) was the predominant (Figure 2), similar to other studies. [18,19,20,21] The predominant of BDE-47 in biota probably due to this congener is more bioaccumulative.[18,19,22] Furthermore, it has been demonstrated that BDEs can be debrominated to form lower congeners within fish tissue,[22] suggesting the possible contribution of BDE-47 to total PBDEs from some debromination from higher BDE congeners. Mono-BDE (BDE-3) was not detected in any samples (Figure 2), probably due to easily elimination of this low molecule weight congener by biota. Whereas, low proportion of higher PBDE congeners, including deca-BDE (BDE-209) could be due to low bioaccumulation potential for these high molecule weight congeners.

The large variation of BFRs concentrations in biota of the present study, particularly for PBDEs, seems to be related to different trophic levels of fish species (Table 2). For instance, as shown in Figure 3, significant increasing in the lipid-normalized concentrations of ΣPBDEs with increasing TL was found (p<0.05). This finding indicated biomagnification of PBDEs in the aquatic food web, with higher trophic organisms had relatively higher concentrations. This was confirmed by TMF value (calculated by equation 4) for ΣPBDEs which had value higher than 1 and p<0.05 (Figure 3 and Table 3). However, this was not in the case for HBCDs (Table 3), indicating that these compounds were not biomagnified. In this study, the TMF values for all 14 PBDE

Table 2. Concentrations of BFRs, Stable Nitrogen and Carbon Isotope and Derived Trophic Level (mean ± standard deviation) of Biota from Jakarta Bay

Sample Biota	*n*	Fat (%)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	TL	PBDEs (ng/g lw)	HBCDs (ng/g lw)
POM	3	na	−19.3±0.83	5.1±1.0	1.8±0.27	na	na
Zooplankton	1*	na	−19.7	6.0	2.0	na	na
Green mussel	3*	1.9±0.37	−15.0±0.15	8.2±0.77	2.6±0.20	11±1.4	4.1±1.4
Shrimp	3*	0.59	−14.6±0.17	9.4±2.0	2.9±0.56	1.6	nd
Crab	3*	0.79	−13.9±0.13	12.6±0.36	3.7±0.09	20	nd
Smudgepot spinefoot	5	2.8±1.3	−14.6±0.30	11.1±0.46	3.3±0.12	10±1.7	0.22±0.28
Java spinefoot	5	3.0±0.61	−14.0±0.31	13.1±0.48	3.9±0.13	13±1.2	2.8±3.5
Sailfin catfish	3	1.7±1.2	−13.6±0.23	13.4±0.38	4.0±0.10	9.1±2.7	1.7±2.1
Little jewfish	7	1.1±0.36	−13.9±0.55	15.0±0.48	4.4±0.13	16±4.4	0.76±0.74
Northern sand flathead	3	0.53±0.25	−14.4±0.28	13.4±0.58	3.9±0.15	15±9.3	0.07±0.07
Large-toothed flounder	2	0.79±0.36	−15.6±0.53	14.4±1.1	4.2±0.28	23±10	nd
Moses Perch	8	0.88±0.38	−13.9±0.46	14.5±1.1	4.2±0.29	12±0.35	0.87±1.2
Patterned tongue sole	1*	0.82	−14.1	11.2	3.7	22	0.05
Diamond trevally	1*	0.66	−14.2	14.8	4.3	8.2	nd
Black-edged conger	1*	1.37	−15.2	15.3	4.4	12	nd
Giant seapike	1*	0.32	−13.9	16.7	4.8	57	0.14

Note: *n* = number of individual, *pooled samples, PBDEs = total PBDEs from mono- to deca-BDE, HBCDs = total HBCDs, na = not available, nd = below detection limit.

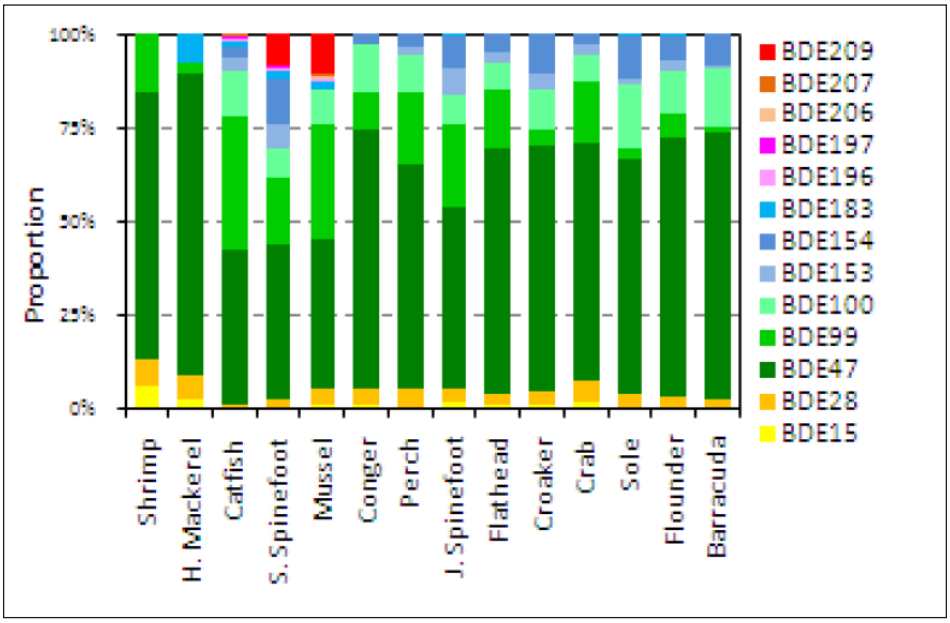

Figure 2. PBDE congener profiles in biota from Jakarta Bay (BDE-3 was not detected)

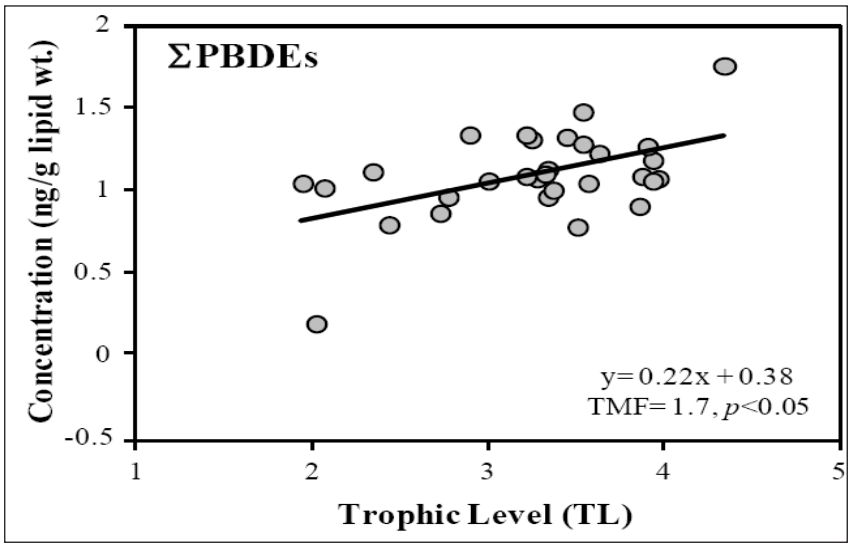

Figure 3. Relationship between PBDEs concentrations and trophic levels of biota from Jakarta Bay.

congeners ranged from 0.69 to 3.0 and for all three HBCD isomers ranged from 0.30-0.57 (Table 3).

Among the PBDE congeners analyzed (Table 3), only BDE-47 (TMF=1.9) and BDE–100 (TMF=1.8) having TMF values significantly greater than one (p<0.05), showed evidence of biomagnification in Jakarta Bay food web. Other BDEs and HBCDs including BDEs-15, -183, -196, -197, -206, -207 and -209, and α-, β- and γ-HBCD were observed to have trophic dilution (TMFs<1) with BDE–15, -206, and -209 showing significant TMF/trophic dilution value (p<0.05). There are not many studies on biomagnification of BFRs in coastal food web, particularly for HBCDs. The TMF of PBDEs in Jakarta Bay was generally lower than those from Lake Winnipeg (TMFs= 1.5–5.2)[10] and Bohai Bay food webs (TMFs= 1.6–7.2),[11] similar with freshwater food web from China (TMFs= 0.26-4.47),[12] but were higher than the values from Canadian Arctic food web (TMFs= 0.8–1.6).[23] The variation of TMFs among the studies may be due to different PBDE

Table 3. TMFs and Significance (*p* values) for BFRs with TL

Congener	TMF	p value
BDE–15	0.59	<0.05
BDE-28	1.4	0.16
BDE-47	1.9	<0.01
BDE-99	1.1	0.66
BDE–100	1.8	<0.05
BDE–153	2.6	0.068
BDE–154	3.0	0.19
BDE–183	0.69	0.092
BDE–196	0.74	0.15
BDE–197	0.91	0.45
BDE-206	0.66	<0.05
BDE-207	0.76	0.22
BDE-209	0.68	<0.01
ΣPBDE-s	1.7	<0.05
α-HBCD	0.30	0.36
β-HBCD	0.57	0.42
γ-HBCD	0.38	0.31
ΣHBCDs	0.40	0.36

levels in the organisms, different environmental conditions (e.g., water temperature) and different food web compositions between these food webs.[12]

CONCLUSIONS

This result indicated a first study to report contamination of BFRs in biota that represented different trophic levels from Jakarta Bay. PBDEs and HBCDs were detected in various biota of the present study, indicating ubiquitous contamination by BFRs in Jakarta Bay ecosystem but with low magnitude contaminations as compared to other polluted areas in China and Japan. Only, PBDEs were biomagnified through Jakarta Bay food web, but this depends on congener specific. Evidence biomagnifications of PBDEs through food web warrant further study on their potential toxicity to wildlife, particularly on the top predators.

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