PBDEs and PCBs in sediments of the Thi Nai Lagoon (Central Vietnam) and soils from its mainland

Stefania Romano a,⇑, Rossano Piazza b,c, Cristian Mugnai a,1, Silvia Giuliani a, Luca Giorgio Bellucci a, Cu Nguyen Huu d, Marco Vecchiato b,c, Stefano Zambon b, Nhon Dang Hoa d, Mauro Frignana

a CNR-Istituto di Scienze Marine, Via Gobetti 101, 40129 Bologna, Italy
b Dipartimento di Scienze Ambientali, Informatica e Statistica, Università di Venezia, Dorsoduro 2137, 30123 Venice, Italy
c CNR-Istituto per la Dinamica dei Processi Ambientali, Dorsoduro 2137, 30123 Venice, Italy
d Institute of Marine Environment and Resources, 246 Da Nang Street, Haiphong City, Viet Nam

HIGHLIGHTS

- Levels and patterns of PCBs, PCB 11, and PBDEs in surface sediments and soils.
- Main natural and anthropogenic processes in tropical areas are changing rapidly.
- Key processes are identified by salinity, porosity and grain size patterns.
- PCBs, PCB 11 and PBDEs levels are similar to those found far from direct sources.
- Efficacy of degradation processes are confirmed by congener patterns and statistics.

ABSTRACT

Concentration and distribution of PCBs, PCB 11, and PBDEs in both surficial sediment and soil samples, taken from a zone subject to recent accelerated development, were investigated to assess the environmental quality and understand both natural and anthropogenic processes that influence contaminant behaviors. Values of PCB and PBDE are in the lower range of those reported in literature, typical of low impacted coastal zones. This could be due to efficient processes of resuspension and removal. Contaminants in the lagoon showed higher concentrations in sediments from sites close to the city and the outfalls of the industrial area, while soils showed maximum values in the northern samples. In addition, congener patterns and statistical analyses suggest the presence of effective degradation processes, especially for PBDEs, with the exception of the most concentrated samples that may indicate a direct input. PCB 11 is a significant component (up to 18%) in most lagoon sediments. Its presence is strongly associated with fine particles, thus the distribution seems to be driven mainly by the system hydrodynamic and does not trace the sources. Due to evaporation, only flooded agricultural soils show a similar relative abundance of this congener.

1. Introduction

Halogenated organic chemicals have been widely used for a variety of purposes since the beginning of the 20th century, and their industrial production has been widespread for commercial purposes (Alaee et al., 2003). PCBs and PBDEs are two groups of organic chemical substances, both forming a family of 209 congeners.

PCBs, commercially produced mainly as Aroclors, had a myriad of applications (Hu and Hornbuckle, 2010). Their toxicity was confirmed in the 1970s, and therefore their use in open systems has been forbidden ever since. However, they remain a current concern because they are still present in closed systems or stored in landfills, and can be reintroduced in the environment by evaporation and leakage (Bhavsar et al., 2004). Moreover, second-hand items (goods produced before the ban as coolants and lubricants in transformers and capacitors, hydraulic and heat exchange fluids, and so on) are widespread through the black market in Asian...
regions (Wong et al., 2007). The congener PCB 11 (3,3’-dichlorobiphenyl) is absent or present at very low concentration in original commercial Aroclor mixtures (Hu and Hornbuckle, 2010; Rodenburg et al., 2010), and its production from degradation is not likely (Rhee et al., 1993). However, PCB 11 has been shown to be a global contaminant (Rodenburg et al., 2010) and is measured in consumer goods mainly containing azo- and phthalocyanine pigments, including newspapers, packaging, plastic bags, and so on (Rodenburg et al., 2010).

The commercial production of PBDEs began in 1970s, as flame retardants in a variety of industrial and consumer applications (Alaee et al., 2003). The commercial products principally contain penta-, octa-, or deca-BDE mixtures (Alaee et al., 2003). Their toxicity and increasing levels in marine mammals, sediments, bird eggs and human tissues make them of environmental concern (De Wit, 2002). Such as PCBs, PBDEs are bioaccumulative, resistant to degradation, and subject to long-range transport (Wang et al., 2005). Currently, the production of penta- and octa-BDEs has been banned in the European Union (EU) and North America. Deca-BDE has also been banned from some of these countries but no restriction on PBDEs exists in Asia (Yan-Ping et al., 2010).

The information about PCB and/or PBDE sources and concentrations in Vietnam is limited to the most industrialized metropolitan areas (e.g., Ramu et al., 2007; Nguyen et al., 2010; Tuan et al., 2010) and some data are available for PCBs in coastal lagoons (Frignani et al., 2007; Giuliani et al., 2011). However, Vietnam has undergone a wide process of economic reform in 1986, which laid the foundations for a market economy, and since then, the country has experienced a high economic growth together with a boom in household food and no-food consumption (Figuié and Moustier, 2009). Then, it is likely that environmental levels of anthropogenic contaminants have increased in response to the recent rapid industrialization/economic development.

The aim of this study was to investigate PCBs, PCB 11, and PBDE concentrations and distributions in surface sediments of the Thi Nai Lagoon and in the mainland soils, improving the knowledge of main natural and anthropogenic processes active in the Lagoon, and some of its environmental characteristics.

2. Study area

Recently, the Thi Nai Lagoon (Fig. 1) has acquired a particular economic importance, because it is one of the key areas designed to drive the socioeconomic development in Central Vietnam, which completion is scheduled for 2020. The Thi Nai bridge, whose construction was completed in 2006, represents the access way to the new economic zone in the Phuong Mai peninsula. This will include tourist sites, together with industrial and residential zones and the enlargement of the commercial port with the building of new facilities. The port of Quy Nhon is one of the most important gates of Vietnam, which is part of the East-West corridor of the Greater Mekong Subregion (NEZA), and can handle ships up to 30000 dwt. To allow the cargo entrance, the area is often dredged (Quy Nhon port website, 2011; VPA, 2011). Presently, the most important economic activities in the lagoon are aquaculture and fisheries.

3. Materials and methods

Sampling locations are shown in Fig. 1a. Sediments (TN) and soils (TS) were collected in June 2010. Soils were collected at selected sites around the border of the Lagoon, each representing an area of particular interest (Fig. 1a): a flooded rice field (TS02); a dry soil from a rice field (TS04); a cultivated field, quite close to a small village (TS05); a flooded rice field by the lagoon border, where several aquaculture ponds are located (TS06); a domestic garden, quite close to the industrial area of the Nhơn Hoi Economic Zone (TS09); a sediment from the Truong Uc River bank in Phuoc Dong Da, the residential area of Qui Nhon (TS11), and an urban grassy soil collected from Nguyen Tat Thanh Park close to the main urban road (TS13).

PCBs and PBDEs were determined on soils and surficial sediment samples by High Resolution Gas Chromatography-Low Resolution Mass Spectrometry (HRGC-LRMS) after extraction and clean-up. 76 chromatographic peaks, representing 92 PCB congeners (12 as double and 2 as triple peaks), were detected among the total 127 congeners searched (IUPAC names of homologues are given in the Supplementary material, Table S1: 1DiCB (11), 16 TriCBs (19, 18, 17, 24 + 27, 16 + 32, 34, 29, 26, 25, 31, 28, 20 + 33 and 22), 20 TeCBs (45, 46, 52, 49, 47 + 48, 44, 42 + 59, 41 + 64 + 71, 40, 67, 63, 74, 70, 66, 56 + 60), 19 PeCBs (104, 93 + 95, 91, 92, 84 + 90 + 101, 99, 97, 87 + 115, 85, 110, 82, 107, 123, 118 and 105), 18 HxCB (136, 151, 135 + 144, 147, 149, 146, 153, 132, 141, 138 + 164, 158, 128 + 167, 156, 157 and 169), 13 HpCBs (179, 176, 178, 187, 183, 174, 177, 171, 172, 180, 193 and 170 +190), 4 OcCBs (199, 196 + 203 and 194), 1 NoCB (208) and PCB 209 (the sole DeCB). 9 PBDEs were detected (17, 28, 47, 66, 100, 99, 85, 153, 183) on a total of 14 searched.

All reported concentrations are relative to dry weight. Detailed information on extractions, analyses, analytical quality, gridding interpolation methods and statistic are reported in the Supplementary material.

4. Results

4.1. Sediment features

Fig. 1a shows the areal distribution of sediment porosity. Values generally increase along a N-S gradient, being lower at the western edge of the lagoon, close to artificial fish farms, and maximum in proximity of the lagoon inlet and the industrial port of Quy Nhơn City. In particular the central area, north of the Thi Nai bridge, shows a patchwork distribution with zones characterized either by lower (−0.55) or higher (−0.65) porosities. The content of fines reflects the porosity distribution (Table 1): sediments of the southern area of the lagoon and the bay are almost exclusively composed by fine particles, whereas the central zone and the eastern edge present intermediate values (about 60% of fines), and the coarsest samples belong to the north-western part with about 14% of fines or less. Soil sample grain sizes show a great variability, the fine content ranging between 0.20 and 72.1% (Table 1).

The areal distribution of salinity (Fig. 1b) divides the lagoon into two main sub-bodies: the lagoon northern of the bridge, with lower salinity (6–19‰) and the southern one, with higher values (15–25‰). Open sea salinity, just in front of the lagoon inlet, is 30‰. In general, salinity increases with the distance from the Cai and Con river mouths, along a NW–SE gradient.

OC contents are relatively low, ranging from 0.33 to 1.95% (Table 1). Soil samples TS02 and TS13 are the richest, with values of 3.78 and 3.86%, respectively. The C/N molar ratios are close to 3.78 and 3.86%, respectively. The C/N molar ratios are close to 9.60 or higher than 10 (10.0–14.9) in lagoon samples. Soils, except for TS05 and TS11, show values above 15 (Fig. 1c). Moreover, δ13C values range within −28.3 to −17.3‰ in surficial sediments and from −25.7 to −22.9‰ in soils (Fig. 1c).

4.2. PCB and PBDE concentration and compositional patterns

Table 1 summarises total concentrations of PCBs (including PCB 11 concentrations), PBDEs, PCB 11 and its relative abundance on total PCBs.
Soil samples TS05, TS06 and TS04 present by far the highest PCB concentrations: 18.6, 15.3 and 13.5 μg kg⁻¹, respectively. Within the lagoon, the highest values are found at TN25C and TN19s (6.40 and 5.19 μg kg⁻¹, respectively), followed by sites TN20s and TN22C (~4 μg kg⁻¹). The remaining sample concentrations are around 2 μg kg⁻¹, while lower values (below 1 μg kg⁻¹) are recorded at TN02s; TN13s; TN14s and TN18s along the northern and western borders of the lagoon.

PBDEs in lagoon samples show the highest values at TN19s and TN22C (9.62 and 8.93 μg kg⁻¹, respectively), while the other samples have concentrations below 1 μg kg⁻¹, with the exception of TN01C and TN28s (1.04 and 1.65 μg kg⁻¹, respectively). Among soils, maximum values are found at TS05 and TS04 (4.02 and 3.27 μg kg⁻¹, respectively), whereas the others show concentrations comparable with the majority of lagoon samples.

PCB and PBDE congener distributions are shown in Fig. 2. PCBs in lagoon samples are generally dominated by low chlorinated congeners, in particular TeCBs, followed mainly by TriCBs. HpCBs and OcCBs are generally low. Samples TN08s and TN12s are characterized by the presence of NoCBs, and traces of DeCBs are found at sites TN19s, TN25C, TN26s and TN28s. Soils contain a wider spectrum of congeners, with the exclusion of MoCBs. There, TeCBs are dominant, followed by TriCBs- and PeCBs. Samples with the highest total concentrations (TS05 and TS06) are an exception, because they show the predominance of intermediate chlorination classes: HxCBs, followed by HpCBs- and PeCBs.

Interestingly, the global contaminant PCB 11 is present in most samples (being below detection limits only at sites TN14s and TS11) at concentrations up to 1.31 μg kg⁻¹ (Table 1). This means that, when present, PCB 11 accounts for 7.3–18.0% and 0.8–15.0% of total PCBs in sediments and soils, respectively.

Surficial sediments and soils are characterized by similar PBDE congener patterns (Fig. 2) with the prevalence of low brominated congeners and the predominance of PBDE 47, 99 and 100. PBDE 153 is present at sites TS04, TS05, TS06, TS13, TN19s, TN22C, TN25C, TN26s and TN28s. Of these, TN22C composition looks peculiar, because it shows a pattern of brominate congeners shifted to higher classes with the prevalence of PBDE 99.
5. Discussion

5.1. Depositional patterns and particle origin in the Thi Nai Lagoon and surrounding soils

Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011). Porosity is defined by the complex interaction of many factors (Athy, 1930), however, the highly significant correlation (Pearson correlation coefficient) observed between fine particles' content and porosity \( r = 0.98, p < 0.01 \) (see Tables S2 and S3 in the Supplementary material) allows to identify some key processes that influence its areal distribution. Indeed, the lagoon's depositional pattern is dominated by the joint flow of the rivers Cai and Con, along a NW-SE gradient, the area close to the lagoon inlet acting as a fine sediment trap (Fig. 1a). North of the bridge, porosity distribution seems to explain how inputs from the Nhon Hoi retardant manufactory plants (Jiang et al., 2011).
To reduce the effect of grain size pattern and OC content on PCB distribution and attempt a source identification, we normalized the PCB concentrations to the contents of both fine particles and OC (see Figs. S1 and S2 in the Supplementary material). PCB total...
concentrations of some sediments significantly increase (i.e., at TN01C, TN02s and TN14s), whereas TN22C and TN25C, TN20s and TN21s are not significantly affected because of the finer bottom composition at these locations. In turn, the value at site TN19s is greatly increased, due to the already high concentration and the mainly sandy composition. The PCB areal distribution pattern is not biased by normalization, hence inputs can be better identified. In particular, sewage outputs from Nhon Hoi Economic Zone seem to affect sites TN05s and TN06s and a northward redistribution process of particles is evidenced by the accumulation at TN22C. Other inputs appear to be the lagoon embayment South-East from the bridge (TN20s and TN21s), together with Quy Nhon City and its port (TN19s, TN28s).

PBDEs, as hydrophobic chemicals, are expected to be associated both with fine particles and organic matter (Bailey et al., 2002), but no such correlations are evidenced by our results (see Table S3 in the Supplementary material). This situation usually occurs when the factor driving the contaminant distribution is the proximity of the inputs. However, the lagoon is characterized by low concentrations, with no clear evidence of significant sources. The PBDE areal distribution almost parallels that of PCBs because maximum concentrations are found in correspondence of Quy Nhon sewages and industrial discharges (TN19s and TN22C: 9.62, 8.93, \( \mu g \cdot kg^{-1} \), respectively). Low correlation between PBDE congeners and OC has been reported by other authors, and attributed to the combined effect of local inputs, transport, mixing, and deposition (Moon et al., 2007; Jiang et al., 2011).

5.4. Sediment homologue/congener patterns and potential sources

In most samples, the concentration of each class of PCB homologues (Fig. 2) is generally below 2.16 \( \mu g \cdot kg^{-1} \) (e.g., TeCBs, TN25C) for sediments and 5.62 \( \mu g \cdot kg^{-1} \) (e.g., TriCBs, TS04) for soils, and a significant \((p < 0.05)\) or highly significant \((p < 0.01)\) correlation with fines is observed (Table S2 in the Supplementary material). The general predominance of light congeners may account for selective long range atmospheric transport (Iwata et al., 1994) and/or degradation processes such as photolysis of highly chlorinated PCBs (Bailey et al., 2002). Contrarily, the higher contributions of heavier congeners at TS05 and TS06, coupled to the fact that they present the highest total PCB concentrations (as for TS04), suggest the occurrence of a close direct input. These sites are located in the proximity of small rural settlements, far from Quy Nhon city (Fig. 1), and common practices there are both the use of untreated wastewater or water from contaminated rivers for farmland irrigation (Tuan et al., 2010), and the disposal of wastes close to households. All these factors can enhance the presence of halogenated contaminants in soils. Moreover, the construction of wastewater treatment facilities in these areas has not followed the pace of urbanization (IWMI – International Water Management Institute, 2001) and, when present, the plants are hardly functioning or have a very low coverage.

The relevant presence of PCB 11 in most samples (at least 7% of total PCBs, Table 1) accounts for specific sources. The release of PCB 11 must be associated with human activities utilizing pigments or dyes (Hu and Hornbuckle, 2010) and thus linked to the increasing use of new consumer goods. These products are likely to enter wastewaters and combined sewer overflows, therefore PCB 11 can be a tracer of emissions from industrial syntheses of paint pigments (Hu and Hornbuckle, 2010). Indeed, its relative abundance is higher than 15% at TN05s (in front of the NEZA sewage outputs), and in the proximity of Quy Nhon port (TN26 and TN28), but its highest percentages are to be found near the lagoon inlet, where fine sediments accumulate. Clearer conclusions are weakened by the fact that DiCBs (composed exclusively by PCB 11 in this study) show highly significant correlation with fines \((r = 0.61, p < 0.01)\), Table S2 in the Supplementary material), which influence DiCBs’ distribution and pattern. In addition, volatilization processes occurring in dry agricultural soils, urban parks and river banks cannot be excluded.

Many PBDE congeners are significantly correlated among themselves, while no relationships are found between these chemicals and OC contents, fine fractions, and porosity (see Table S3 in the Supplementary material). Several studies have reported that high molecular weight congeners can be metabolized to less brominated compounds including tri- to hexa-BDEs, e.g. PBDE 47, 99 and 100 (Moon et al., 2002, 2007; Soderstrom et al., 2004). Therefore, debromination may be their principal source in the area.

Fig. 3. Cluster analysis (Euclidean distance and Ward’s method) for the comparison of sample relative abundances with commercial mixtures for PCBs (a) and PBDEs (b). Color boxes highlight the clusters.
Cluster analyses (using the Euclidean distance and Ward method) on relative abundances of congeners/congener groups were performed to compare our samples' fingerprint to main PCB and PBDE commercial mixtures (Fig. 3). As expected, PCB sample compositions show similarities with lighter commercial products (e.g. Aroclor 1248), except for TS05 and TS06. In turn, PBDE commercial mixtures are not grouped with our samples, except for: (1) TN22C and TS05, which show an affinity to major penta-BDE commercial mixtures (70-5DE and DE-74), and (2) TN04s and TN25C that are close to the heavy octa- formulation, due to the absence of PBDE 47 in their pattern. It may be argued that the differences observed in the composition of both PCBs and PBDEs in sediments and soils with commercial products might be due to mixing, selective transport and degradation. The evidences discussed above suggest a significant role of the different stability and resistance to degradation for PCBs and PBDEs. However, at TS04, TS05, TS06, TN19s and TN22C, both PCBs and PBDEs resemble the composition of original mixtures, probably due to recent point inputs. This hypothesis is also confirmed by PCA plots (Figs. S3 and S4, in the Supplementary material) performed on homologues/congeners composition of sediment and soil samples.

Acknowledgements

Funds for this work were provided by the Italian Ministry of Foreign Affairs – Directorate General for Cultural Cooperation and Promotion (MAE-DGCCP), the Vietnamese Ministry of Science and Technology (MOST) and the Italian scientific institutions involved in the research, in the framework of a bilateral project. The authors thank M. Brunello for his help in some analyses and N.H. Anh for his contribution to field work. This is contribution No. 1776 from the Istituto di Scienze Marine, Bologna (Italy).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.chemosphere.2012.10.067.

References