**Distribution and Depth Profiles of Polychlorinated Dibenzo-p-Dioxins,
Polychlorinated Dibenzofurans, and Polychlorinated Biphenyls in Sediment
Collected from Offshore Waters of Central Vietnam**

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ABSTRACT

Concentrations of PCBs and OCPs were measured in 35 surface sediment samples collected from offshore waters of Central Vietnam. The mean concentrations of PCBs, HCHs, and DDTs in surface sediments were 86.5, 37.0, and 44.5 pg g^{-1} , respectively. Additionally, nine PCDDs, eleven PCDFs, and twelve dl-PCBs were also examined in 19 sediment core samples collected from five locations. Concentration of PCDDs, PCDFs, and dl-PCBs ranged from 200 to 460, 0.39 to 2.9, and 1.6 to 22 pg g^{-1} , respectively. OCDD was detected at the highest concentration, ranged from 100 to 300 pg g^{-1} . Generally, the concentrations of PCDD/Fs at shallower depths were higher, meanwhile the depth profiles of dl-PCBs in sediment cores were different than the depth profiles of PCDD/Fs. The results suggest that the pollution of PCBs might be from many different sources leading to the variation between depths.

Keywords: PCDD/Fs, dl-PCBs, PCBs, OCPs, Sediment cores, Vietnam

Following the Stockholm Convention (2001), Vietnam government has issued a banned decree of the production and use of persistent organic pollutants (POPs) in general, including organochlorine pesticides (OCPs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzodifurans (PCDFs), polychlorinated biphenyls (PCBs), and dioxin-like polychlorinated biphenyls (dl-PCBs) (Signatory of the Stockholm Convention Citaion, 2016). PCDD/Fs are chemicals generated unintentionally, while dl-PCBs were used for the purpose as additives in various industrial products. The toxicity of these chemicals was reported in many conferences, seminars, and scientific papers. Generally, OCPs, PCBs, PCDD/Fs, and dl-PCBs constitute five groups of relevant persistent organic pollutants with enhanced chronic toxicity.

The occurrence of OCPs and PCBs in surface sediments and soils collected from inlands in Vietnam has been reported in several earlier studies (Nhan et al., 1998; 2001; Minh et al., 2006; 2007a,b; Toan et al., 2007b; Shiozaki et al., 2009; Romano et al., 2013). The PCBs concentrations were measured in soil samples ranging from 14800 to 190000 pg g^{-1} (Toan et al., 2007a), in sediment of the canals up to 40000 pg g^{-1} (Nhan et al., 2001), and in sediment of the sewer system ranging from 1300 to 384000 pg g^{-1} (Hoai et al., 2010) from Hanoi, Vietnam. The mean concentrations of HCHs and DDTs in surface soils in agricultural areas from Hanoi Vietnam were

8030 and 89900 pg g^{-1} , respectively (Toan et al., 2007b). Further, Nhan et al., (1999) determined the concentration of HCHs, DDTs, and PCBs in sediments collected from the coast of the north of Vietnam ranged 1200-33700 pg g^{-1} , 6200-10400 pg g^{-1} , and 470-28100 pg g^{-1} , respectively.

In Vietnam, the aftermath of war, agricultural, and industrial production activities have resulted in a wide dispersion and distribution of POPs over time. The occurrence of these compounds in soil and sediment samples has been reported in some previous studies (Minh et al., 2003). The total concentration of 5 PCDDs and 5 PCDFs were found in soil collected from dumping sites in Hanoi ranging from 100 to 24000 pg g^{-1} (mean: 3100 pg g^{-1}) and 15-26000 pg g^{-1} (mean: 2900 pg g^{-1}), respectively (Kunisue et al., 2002). For sediment samples collected from Can Gio, Hue, and Hanoi, the total concentration of PCDDs and PCDFs were measured at respective level of 350-980 pg g^{-1} and 26-140 pg g^{-1} (Kishida et al., 2010).

However, there are very few studies on the distribution of PCDD/Fs, and dl-PCBs in sea sediment samples in Vietnam. The total concentration of PCDDs and PCDFs in sediment samples collected from Central Vietnam coastal lagoons ranged from 192 to 2910 pg g^{-1} (Piazza et al., 2010).

In this study, the occurrence of PCBs and OCPs in surface sediments and PCDD/Fs, and dl-PCBs was examined in sediment cores collected from offshore waters of central Vietnam. Understanding depth profiles of PCDD/Fs and dl-PCBs may provide insights into the fate and transport of these toxic chemicals in coastal offshore water, and help elucidating history of contamination.

Using the HQ14-11-78, 273 Regiment Military Zone 3, Vietnam ship (450 tons payload), sediment samples were collected from offshore between Nghe An to Thua Thien-Hue in central Vietnam (Figure 1). Coordinates of survey stations was determined by the SPS351 DGPS (Trimble, USA) set on the ship and connected to reference station was set at Thang Binh district (Quang Nam province). Sampling depth position was determined by the depth gauge F2000 (Japan) and corrected for national elevation system (0 m of continent) at Hon Dau (Hai Phong province). The ocean hoers collects sediment samples from surface to 20 cm depth.

Surficial sediment samples were collected by grab samples (from surface to 20 cm depth of sediments). Sediment core samples were collected by the gravity discharge tube gravity corer (10 cm in diameter), with lengths of cores from 20 to 160 cm. After taking up the core samples was transferred to a teflon tube, cut by a plastic knife into 40 cm intervals and moved the outer layers (0.5 cm in thickness). Both types of surficial sediments and discharge tube samples were wrapped

immediately in polyethylene bags. Then samples were immediately stored in coolboxes and moved to laboratories. Nineteen sediment samples were collected from 5 cores and assigned sample number of 236, 400, 465, 658, and 821. All sediment samples were air-dried and sieved with 2 mm sieve before analysis.

PCBs and OCPs in surface sediment samples were analyzed according to the method described by Minh et al. (2006) with some modifications. All glassware was washed in the following order: acetone, toluene, n-hexane, and backed at 400 °C for 12 h. A 25 g sediment sample was mixed with 150 mL acetone in a conical flask. The flask was shaken vigorously for 60 min in an electric shaker and sediment solution was filtered into a separating funnel containing 600 mL water and 100 mL n-hexane. The funnel was shaken for 20 min and kept in a stand for 8 hours to entirely separate the aqueous from the n-hexane layers. The aqueous layer was discarded, and the n-hexane layer was washed three times with 100 mL water per wash. The volume of n-hexane in the final solution was measured for calculating recovery from the initial 100 mL, and then concentration by Kuderna-Danish (KD) apparatus to approximately 10 mL, followed by further concentration by gentle nitrogen stream to 5 mL. The 5 mL solution was transferred to a multilayer column packed with silica gel, H₂SO₄-absorbed silica gel and AgNO₃-absorbed silica gel. Three layers in the column were packed in the following order: 0.5 g Na₂SO₄, 0.5 g silica gel, 2 g H₂SO₄-absorbed silica gel, 0.5 g silica gel, 2 g AgNO₃-absorbed silica gel, and 0.5 g Na₂SO₄. After transferring the sample solution into the multilayer column, the elution was made by passing 250 mL of 5% dichloromethane in hexane through the column. The collected mixture was concentrated by KD and blown down by nitrogen to exactly 5 mL. Four ml of this solution was collected by pipette for further cleanup by gel-permeation chromatography and separated by Florisil (Wako Chemicals, USA) chromatography column to obtain PCBs and OCPs fractions as previously described (Minh et al. 2003; 2007a,b). PCBs, DDTs, HCHs were quantified by a gas chromatography–electron capture detection (GC-ECD, Shimadzu, Japan) using DB-1 fused silica capillary column (30 m x 0.25 mm I.D. x 0.25-μm film thickness). The column oven temperature was programmed from 70 °C (1 min) to 160 °C at a rate of 20 °C min⁻¹, held for 10 min, then increased to 270 °C at a rate of 2 °C min⁻¹, and held for 20 min. The PCBs (including: PCB-28, PCB-52, PCB-101, PCB-118, PCB-138, PCB-143, PCB-180, and PCB-209), HCHs (α-, β-, δ-, γ-HCHs), and DDTs (p,p'-DDE, p,p'-DDD, o,p'-DDT, and p,p'-DDT) standards and internal standards used for quantification were purchased from Wellington, Ontario, Canada. Recovery of PCBs, HCHs, and DDTs obtained by this procedure were

79-107%, 82-102%, and 81-110%, respectively. The limited of quantification (LOQ) for PCBs was 2.0 ng g⁻¹, while for HCHs and DDT were 0.5 ng g⁻¹.

The methods for PCDD/Fs and dl-PCBs are those described by MOE, Government of Japan (2000) with slight modifications. A sediment sample of 8 grams, with 0.5 g of active copper were mixed in a filter cup. Samples were Soxhlet extracted with 140 mL toluene for 16 h. The extracted solution was evaporated to 2 mL. Then the solution was transferred to a tube (30 mL), after 20 mL toluene solvent was added exactly. The solution was separated to two equal parts. Each part was spiked 1 mL of 0.2 ng mL⁻¹ internal standard solution. Toluene solvent was changed with n-hexane. The cleanup step was performed by multilayer column (length: 40 cm; inner diameter: 2 cm). The multilayer column was prepared in the following sequence: Na₂SO₄ (2 g), silica gel (0.9 g), silica gel 2% KOH (3 g), silica gel (0.9 g), silica gel 44% H₂SO₄ (4.5 g), silica gel 22% H₂SO₄ (6 g), silica gel (0.9 g), silica gel 10% AgNO₃ (3 g), silica gel (0.9 g), and Na₂SO₄ (6 g). The sample was introduced to the cleanup column, eluted with 150 mL of n-hexane and the eluate was evaporated to 2 mL. The target compounds were cleaned up on the active carbon column (Kanto Chemical Co. Inc, Japan). The first step (F1) was eluted by 40 mL of mixture of n-hexane and dichloromethane (v:v, 3:1). The second step (F2) for PCDD/Fs analysis was eluted by 60 mL toluene. A half of the F2 solution was evaporated and changed solvent by n-hexane. Final solution volume was concentrated by a gentle stream of nitrogen to 50 µL for PCDD/Fs analysis. The mixture of the F2 half and F1 was evaporated, changed solvent by n-hexane, and concentrated by a gentle stream of nitrogen to 50 µL for PCBs analysis. Finally, sample solutions were injected to GC/MS high resolution for analysis, and the injected volume was 5.0 µL.

PCDD/Fs and dl-PCBs were performed on an Agilent Technology 7890 GC interfaced with a high resolution mass spectrometer (HRMS). The analysis method based on the standard methods of Hiyoshi Corporation (Shiga, Osaka, Japan).

Our efforts to minimize the contamination of PCDD/Fs and dl-PCBs, all glassware was cleaned by acetone, toluene, and n-hexane, and baked at 300 °C before using. The solvents were dispensed directly from new bottles. The calibration curve was linear over a concentration that ranged from 1.0 to 2000 pg mL⁻¹ for PCDDs and ranged from 0.5 to 100 pg mL⁻¹ for both of PCDFs and dl-PCBs.

The limited of detection (LOD) of method for PCDDs/Fs and dl-PCBs ranged 0.08-0.2 pg g⁻¹ and 0.03-0.2 pg g⁻¹, respectively. Similarly, the limited of quantification (LOQ) for PCDD/Fs and

dl-PCBs ranged 0.19-0.9 pg g⁻¹, and 0.11-0.5 pg g⁻¹, respectively. For concentrations below the LOQ, a value of one-half the LOQ was assigned for the statistical analysis.

All sediment samples were dried at 60 °C in an oven. The sediment content of total organic carbon (TOC) was measured by a SSM-5000A solid sample module combined with a TOC-Vesh total organic carbon analyzer (Shimadzu, Japan). The TOC value was determined by the difference in total carbon (TC) and inorganic carbon (IC) analysis values.

The estimated procedure for dating of the sedimentation core is based on several previous publications with minor modifications (Wang et al., 2008; Combi et al., 2013). The ²¹⁰Pb activities in sediment subsamples were determined by analysis of the α-radioactivity of its decay product ²¹⁰Po, on the assumption that the two are in equilibrium. The Po was extracted, purified, and self-plated onto silver disks at 75–80 °C in 0.5 M HCl solution, with ²⁰⁹Po used as yield monitor and tracer in quantification. Counting was conducted by computerized multichannel α-spectrometer with gold–silicon surface barrier detectors. Supported ²⁰¹Po was obtained by indirectly determining the α-activity of the supporting parent ²²⁶Ra, which was carried by co-precipitated BaSO₄. A constant initial ²¹⁰Pb concentration model was applied to give average sedimentation rates for the sedimentary cores.

In this research, eight PCB congeners, four HCHs, and four DDTs were found in 35 surface sediment samples. The concentrations of PCBs, HCHs, and DDTs ranged between 36.2-158 pg g⁻¹ (mean/median: 86.5/83.2 pg g⁻¹), 20.7-53.9 pg g⁻¹ (mean/median: 37.0/35.7 pg g⁻¹), and 15.1-79.1 pg g⁻¹ (mean/median: 44.5/44.5 pg g⁻¹), respectively (Table 1). From North (sample ID1) to South (sample ID35) in central Vietnam coastal surficial sediments, the concentrations of PCBs and HCHs were similar throughout the study area. In contrast, DDTs showed slightly higher concentrations in the southern area in comparison to the northern area (Figure 1). Among the HCHs, γ-HCH occurred at the highest concentration from 12.5 to 28.2 pg g⁻¹ (respective 35.1 to 46.8% of total HCHs). Similarly, p,p'-DDT was found at the highest levels and ranged from 52 to 75% weight of DDTs.

The concentration of PCBs, HCHs, and DDTs in surface sediments collected from offshore waters in central were much lower than in surface sediment and soil collected from inland in Vietnam (Minh et al., 2006; 2007a,b; Toan et al., 2007a,b; Hoai et al., 2010). Similarly, the respective concentrations of HCHs and DDTs in surface sediments collected from offshore waters in central Vietnam were from 50 to 300 times lower than in sediment samples from Daya Bay, South China (Wang et al., 2008). The HCHs and DDTs concentrations in surface sediments of the Bohai

Sea, China ranged 160-3170 pg g⁻¹ and 240-5670 pg g⁻¹, respectively, and those values were higher much than in this survey (Hu et al., 2009).

All surface sediment samples collected from offshore central Vietnam had measurable concentrations of PCBs, HCH, and OCPs. Nonetheless, measured concentrations of PCBs, HCHs, and OCPs reported here are almost always lower than other earlier studies. This pattern of chemical distribution can be explained by dispersion of the chemicals in the coastal environment, as well as the distance away from land-based source emissions.

The total concentration of PCDDs (including: 1,3,6,8-TeCDD; 1,3,7,9-TeCDD; 2,3,7,8-TeCDD; 1,2,3,7,8-PeCDD; 1,2,3,4,7,8-HxCDD; 1,2,3,6,7,8-HxCDD; 1,2,3,7,8,9-HxCDD; 1,2,3,4,6,7,8-HpCDD; and OCDD) ranged from 200 to 460 pg g⁻¹ in 19 sediment core samples (Table 2, Figure 2). Comparison with an earlier study, the total concentration of PCDD/Fs in sediment cores collected from Thua Thien - Hue (Central Vietnam coastal lagoons) ranged 192 to 2910 pg g⁻¹ (Piazza et al., 2010) which were 2 to 5 times higher than the results reported here. Kishida et al. (2010) reported the total PCDDs in sediment collected from Can Gio, Thua Thien - Hue, and Hanoi ranging from 350 to 980 pg g⁻¹, and there was also higher concentration in sediments than reported here.

Among 9 PCDD congeners, OCDD was measured at the highest concentration ranging from 100 to 300 pg g⁻¹ (median: 210 pg g⁻¹), followed by 1,2,3,4,6,7,8-HpCDD (ranged: 12.0 to 27.0 pg g⁻¹), and 1,2,3,7,8,9-HxCDD (ranged: 1.2 to 2.7 pg g⁻¹). Meanwhile, 2,3,7,8-TeCDD were determined at the lowest frequency (3/19 samples, equal to 15.8%) and the concentration ranged from not detected to 0.76 pg g⁻¹ (Figure 3). Generally, the PCDD congener concentration in sediment cores tends to increasing follow the amount of chlorine atoms in molecular structures.

The toxic equivalency factor (TEF) and toxic equivalent (TEQ) concept has been developed to facilitate risk assessment and regulatory control. The TEF approach uses an underlying assumption of additivity associated with the chemicals that takes into account chemical structure and behavior. The TEF expresses the toxicity of PCDDs, PCDFs, and PCBs in terms of the most toxic form of dioxin, 2,3,7,8-TCDD (TEF value: 1). While the reported TEQ value provides toxicity information about the mixture of chemicals (Van den Berg et al., 1998; 2006). The TEQ values were calculated by based on the mean measured concentration and the TEF of individual congeners by the World Health Organization (Van den Berg et al., 2006). The WHO-TEQ values are very different for each

of PCDDs. The WHO-TEQ value was highest for 1,2,3,7,8-PeCDD (0.521 pg-TEQ g⁻¹), followed by 1,2,3,7,8,9-HxCDD (0.232 pg-TEQ g⁻¹), and 1,2,3,4,6,7,8-HpCDD (0.231 pg-TEQ g⁻¹).

The total concentration of PCDFs (including: 1,2,7,8-TeCDF; 2,3,7,8-TeCDF; 1,2,3,7,8-PeCDF; 2,3,4,7,8-PeCDF; 1,2,3,4,7,8-HxCDF; 1,2,3,6,7,8-HxCDF; 1,2,3,7,8,9-HxCDF; 2,3,4,6,7,8-HxCDF; 1,2,3,4,6,7,8-HpCDF; 1,2,3,4,7,8,9-HpCDF; OCDF) in sediment samples ranged from 0.39 to 2.9 pg g⁻¹. The concentration of two TeCDF congeners and two PeCDF congeners ranged from 0.36-1.4 pg g⁻¹ and 0.11-0.74 pg g⁻¹, respectively. Among 11 PCDFs, many individual PCDFs were not detected in any sediment samples from offshore such as 1,2,3,7,8,9-HxCDF, 1,2,3,4,7,8,9-HpCDF, and OCDF. Meanwhile, 1,2,3,4,6,7,8-HpCDF was found at the highest frequency, ten per nineteen samples were detected (equal to 47.4%) and the concentrations was up to 0.55 pg g⁻¹. In general, the frequency and concentration of the occurred PCDFs in sediment from offshore waters were lower than from inlands in Vietnam reported by other studies (Kunisue et al., 2002; Shiozaki et al., 2009; Kishida et al., 2010).

The WHO-TEQ values was calculated for individual PCDF congener, those values were approximately 10 times lower than for PCDDs. The WHO-TEQ value of 2,3,4,7,8-PeCDF was at the highest level (0.0418 pg-TEQ g⁻¹). Meanwhile, this values for 1,2,3,7,8,9-HxCDF and 2,3,4,6,7,8-HxCDF were the same (0.03 pg-TEQ g⁻¹), followed by 1,2,3,6,7,8-HxCDF (0.015 pg-TEQ g⁻¹).

The total concentration of dl-PCBs (including: 3,3',4,4'-TeCB (#77); 3,4,4',5-TeCB (#81); 2,3,3',4,4'-PeCB (#105); 2,3,4,4',5-PeCB (#114); 2,3',4,4',5-PeCB (#118); 2',3,4,4',5-PeCB (#123); 3,3',4,4',5-PeCB (#126); 2,3,3',4,4',5-HxCB (#156); 2,3,3',4,4',5'-HxCB (#157); 2,3',4,4',5,5'-HxCB (#167); 3,3',4,4',5,5'-HxCB (#169); 2,3,3',4,4',5,5'-HpCB (#189)) in nineteen sediment samples collected offshore from central Vietnam, ranged from 1.6 to 22 pg g⁻¹. These results are 1000 times lower than another earlier study, the measured dl-PCBs concentrations in sediment from Saigon River Estuary, Vietnam ranged from 18 to 8400 pg g⁻¹ (Shiozaki et al., 2009). However, the dl-PCBs were found in offshore sediment at the lower levels what compared with in sediments from the inlands and the coast from Vietnam in several previous reports (Minh et al., 2003; Kishida et al., 2010; Piazza et al., 2010).

Among dl-PCBs, PCB-118 was found at the most abundant (freq. 100%) and measured at the highest concentration ranging from 1.0 to 14.0 pg g⁻¹ (median: 1.8 pg g⁻¹), followed by PCB-105 (freq. 100%; median: 0.99 pg g⁻¹), and PCB-156 (freq. 63.2%; median: 0.235 pg g⁻¹).

The WHO-TEQ values of individual dl-PCBs were generally lower than those values for individual PCDD and PCDF congeners. The WHO-TEQ values of PCB-126 was at the highest level (0.025 pg-TEQ g⁻¹), followed by PCB-169) (0.0075 pg-TEQ g⁻¹).

The distributions of PCDD/Fs and dl-PCBs in sediment samples were surveyed in five cores. The depth profiles were different between cores. However, the concentration of PCDD/Fs at three shallower depths was higher (core No.236, 658, and 821) (Figure 4). Generally our preliminary results suggest that depth profiles of PCDD/Fs reflect trends of recent growth of industry in recent years (1990s) in Vietnam. Depth profiles of dl-PCBs in sediment cores were markedly different than those of PCDD/Fs. For core No.485, 658, and 821, profiles of dl-PCBs were similar to PCDD/Fs, in which the concentration of PCDD/F and PCBs were higher at shallower depths. Meanwhile, the dl-PCBs concentrations at two shallower depths were lower other depths (core No. 236, 400). The results suggest that the pollution of PCBs might be from different sources leading to the variation between depths.

The occurrences of PCDD/Fs and dl-PCBs in sediment cores collected from offshore waters in Vietnam are very limited. Shiozaki et al. (2009) reported PCDD/Fs and dl-PCBs in surface and sediment core along coasts of Saigon River and Mekong River, southern Vietnam, and revealed higher concentrations of PCDD/Fs in cores at various depth from 0 - 30 cm. Concentrations of PCDD/Fs in Saigon and Mekong River sediment cores ranged from 220 - 670 pg/g dry wt. (mean: 425 pg/g dry wt.), which were slightly higher than those observed in the present study (mean: 380 pg/g dry wt.; range: 200 - 460 pg/g dry wt.). PCDD/Fs residues in sediment cores in offshore waters from middle of Vietnam were in the range of those reported in surface sediment from Can Gio mangrove forests in southern Vietnam and lakes from Hanoi Metropolitan area, and lower than those in lagoons from Hue City, middle of Vietnam (Kishida et al., 2010).

Comparison of depth profiles of PCDD/Fs in sediment cores from the previous studies revealed somewhat similar patterns. Piazza et al. (2010) demonstrated that the depth profiles in sediment cores collected from Central Vietnam coastal lagoon was only minor changes over time in PCDD/Fs input and composition. Further, Ikenaka et al. (2005) reported the maximum concentrations of PCDD/Fs, and dl-PCBs in sediment cores collected from Lake Suwa, Japan were respectively 25.2 and 19.0 pg g⁻¹ at the depth of 30-35 cm. The PCDD/Fs and dl-PCBs were found at the higher concentration in surface layer sediment of two cores from semi-enclosed bay in Korea (Moon et al., 2009).

The human activity was the main cause of the contribution of POPs pollutants into environments. The process of waste disposal by burning and the agricultural activity also distributed the emission of PCDD/Fs, dl-PCBs, PCBs, and OCPs into the environment. For OCPs (including: HCH and DDTs) has been banned from use in Vietnam in many years ago, but due to the illegal trading and consumption activities so they still penetrate into different environments such as soil, water and sediments.

In summary, our results indicate widespread occurrence of PCDD/Fs, dl-PCBs, PCBs and OCPs in offshore waters sediments in the central Vietnam. The levels were generally in lower range as compared to the previous investigations. Vertical profiles of these contaminants generally showed higher levels in shallower depths, reflecting the recent industrial growth in Vietnam. Further studies in sediment cores from different coastal areas are needed to trace the history and predict the future trends of contamination caused by anthropogenic hazardous POPs.

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Table 1: Spatial distribution of the total of PCBs and OCPs in surface sediment (pg g⁻¹ dry weight)

No.	Sample ID	PCBs	HCHs	DDTs	No.	Sample ID	PCBs	HCHs	DDTs
1	BD-1	36.2	34.5	25.2	20	BD-20	76.7	46.1	43.2
2	BD-2	104	32.2	31.1	21	BD-21	87.7	42.7	53.8
3	BD-3	74.1	43.7	29.0	22	BD-22	72.0	41.8	50.0
4	BD-4	58.8	35.2	41.4	23	BD-23	85.8	35.2	58.2
5	BD-5	85.0	42.0	60.1	24	BD-24	84.1	28.0	44.9
6	BD-6	85.3	53.9	46.5	25	BD-25	78.3	32.4	59.2
7	BD-7	139	45.2	35.6	26	BD-26	68.2	41.0	35.5
8	BD-8	106	22.3	22.9	27	BD-27	81.9	45.4	47.6
9	BD-9	83.2	46.0	44.0	28	BD-28	61.4	35.7	48.2
10	BD-10	89.4	28.0	31.2	29	BD-29	91.1	43.3	47.7
11	BD-11	84.9	32.2	58.3	30	BD-30	64.9	32.1	44.3
12	BD-12	158	41.2	27.7	31	BD-31	105	26.7	78.1
13	BD-13	75.0	37.1	15.1	32	BD-32	89.8	44.5	53.7
14	BD-14	73.3	32.7	36.7	33	BD-33	68.0	37.7	66.4
15	BD-15	67.7	31.8	39.0	34	BD-34	75.2	33.0	58.4
16	BD-16	127	35.2	29.4	35	BD-35	126	20.7	79.1
17	BD-17	114	45.0	27.2		Mean	86.5	37.0	44.5
18	BD-18	65.4	25.1	44.5		Median	83.2	35.7	44.5
19	BD-19	83.2	43.9	45.5					

Table 2: Concentration of PCDD/Fs and dl-PCBs in sediment samples collected from offshore of Central, Vietnam (pg g⁻¹)

		Core 1 (No.236)				Core 2 (No.400)				Core 3 (No.465)				Core 4 (No.658)				Core 5 (No.821)		
		D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3
PCDDs	TeCDDs	5.5	5.7	6.0	5.0	5.5	4.9	5.3	5.2	4.3	3.1	4.5	4.7	5.8	5.4	5.6	4.9	5.4	5.8	5.5
	PeCDDs	14	16	16	14	14	14	12	15	7.6	8.1	11	11	12	12	14	14	12	15	14
	HxCDDs	65	69	70	68	67	68	69	66	49	36	51	52	55	61	65	65	54	71	65
	HpCDDs	93	100	100	98	100	97	100	98	65	49	76	73	89	87	91	90	85	100	92
	OCDD	200	210	220	200	260	270	230	230	130	100	160	150	300	200	210	210	280	240	230
	Total PCDDs	380	400	410	390	450	450	420	410	260	200	300	290	460	370	390	380	440	430	410
PCDFs	TeCDFs	0.77	0.98	1.4	0.63	0.7	0.82	0.78	0.4	0.71	0.37	0.16	0.36	0.58	0.49	0.37	0.85	0.88	0.53	0.49
	PeCDFs	0.34	0.36	0.59	0.31	0.4	0.4	0.71	0.33	0.32	0.11	0.23	0.12	0.5	0.24	0.6	0.49	0.74	0.33	0.41
	HxCDFs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5	ND	ND	0.3	0.7	ND	ND
	HpCDFs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4	ND	ND	0.4	0.6	0.2	0.2
	OCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Total PCDFs	1.1	1.5	2.2	0.94	1.3	1.4	1.7	1.67	1	0.48	0.39	0.48	2	0.73	0.97	2	2.9	1.3	1.1
	Total (PCDD/Fs)	380	400	410	390	450	460	420	420	260	200	300	290	460	370	390	390	440	430	410
PCBs	Total non-ortho PCBs	ND	ND	0.7	ND	ND	ND	3.8	0.4	1	ND	ND	ND	1.3	0.3	1.5	0.2	1.5	1.1	1.3
	Total mono-ortho PCBs	1.6	1.9	7.7	1.6	2	2.5	19	3.6	7.4	1.7	2.2	2.2	22	5.3	15	3	22	9.3	12
Total dl-PCBs		1.6	1.9	8.4	1.6	2	2.5	23	4	8.4	1.7	2.2	2.2	23	5.6	16	3.2	23	10	13
Total (PCDDs+PCDFs+dl-PCBs)		380	400	420	390	450	460	440	430	270	200	310	290	490	370	400	390	460	440	420

* D1: Depth 0-40 cm (with estimated years ~1996-2012); D2: depth 40-80 cm (~1980-1996); D3: depth 80-120 cm (~1952-1980); and D4 depth 120-160 cm (~1924-1952)

** ND: Not Detected; LOD (pg g⁻¹): the limited of detection

Figure 1: Spatial distribution of the total of OCPs and PCBs in surface sediment collected from offshore waters of central, Vietnam (pg g^{-1} dry weight)

Figure 2; Distribution of PCDDs in sediment cores collected at offshore from NgheAn to ThuaThien Hue, Vietnam. No. 236 (N:18°29'33"; E:107°10'46"); No.400 (N:18°12'7";E:107°24'39"); No.465 (N:17°48'29"; E:107°9'42"); No.658 (N:17°52'15"; E:107°37'5"); No.821 (N:17°17'30"; E:107°42'52")

Figure 3: The concentration of individual PCDD congener (without OCDD) in 19 sediment core samples (pg g^{-1})

Figure 4: Total concentrations of dl-PCBs and PCDD/Fs in sediment core samples according to the depths