

Contamination Status of Dioxins in Sediments from Saigon River Estuary, Vietnam

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Abstract—Concentrations of dioxins in surface sediments and a sediment core from the coast of southern Vietnam were determined. In surface sediments, concentrations of both PCDD/DFs and coplanar-PCBs were higher in inland than in offshore samples. However, proportion of PCDFs in total PCDD/DFs was higher in inland than in the marine area samples, and it can be presumed that some combustion source might exist in inland acting as a source of PCDD/DFs to this region. On the other hand, coplanar-PCBs were specifically high in particular locations of inland and marine area, indicating that scattered hotspots may be present both in inland and the marine areas. Various technical PCBs can be suspected as pollution sources depending on the isomer profiles of different commercial mixtures. In core sediment analysis, no temporal trend either in total concentration or isomer profile was observed. 2,3,7,8-TCDD, which was present in chemical defoliants, was not detected in any of the layers analyzed. 2,3,7,8-TCDD which is present in chemical defoliants might have diffused in the ocean or remain in deeper layers than in the depth of from which the sample for the present study was collected.

Abbreviations Used: PCDD, polychlorinated dibenzo-*p*-dioxin; PCDF, polychlorinated dibenzofuran; PCB, polychlorinated biphenyl; TEF, toxic equivalent factor; I-TEQ, toxic equivalent calculated using TEF proposed by NATO in 1988; WHO-TEQ, toxic equivalent calculated using TEF proposed by WHO in 2005

INTRODUCTION

Dioxins (PCDDs, PCDFs, coplanar-PCBs) are some of the Persistent Organic Pollutants (POPs) drawing great public concern due to their high persistency, toxicity and bioaccumulation potency. Dioxins originate from many sources such as industrial activity and combustion process. It is also known that some agricultural chemicals contain dioxins as impurities.

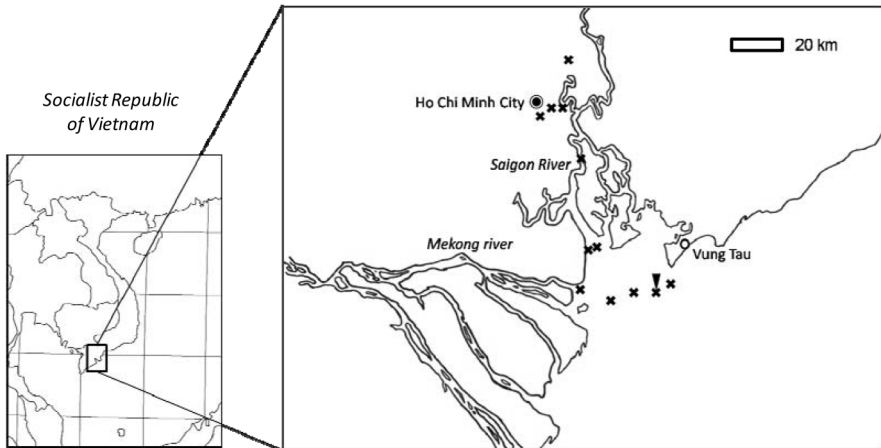


Fig. 1. Sampling sites in southern Vietnam are shown in the right map. Surface sediment sampling sites are shown by cross-marks and the core sediment sampling site is shown by a triangle.

In the Socialist Republic of Vietnam, the present study area, chemical pollution caused by rapid economic development is of great concern. In Vietnam, bulk wastes are dumped into dumping sites without appropriate processing. It is already reported that dioxins are produced by combustion of waste at such sites in Vietnam (Minh *et al.*, 2003).

Furthermore, Vietnam was affected by the widespread spraying of the chemical defoliants Agent Orange during the Vietnam conflict (Stellman *et al.*, 2003) containing the most toxic dioxin congener (2,3,7,8-TeCDD) as impurity; as a result wide areas of Southern and Northern Vietnam were found to be contaminated by 2,3,7,8-TeCDD. This historical pollution by dioxins is still continuing as a big problem even now. Many studies reported that some places in Vietnam are highly polluted by dioxins derived from Agent Orange (Schechter *et al.*, 1995, 2002, 2003; Dwernychuk *et al.*, 2002; Mai *et al.*, 2007). The contamination might be expanding from such contaminated sites to other areas on a wide scale. In contaminated areas, markedly high concentrations of 2,3,7,8-TeCDD were detected in soils and biota (Dwernychuk *et al.*, 2002; Mai *et al.*, 2007), the concentration of which is useful as an indicator of the extent of contamination derived from the chemical defoliants.

As shown above, recent and historical pollution of dioxins contamination exist in Vietnam. However, studies on dioxins contamination in Vietnam are very meager, especially on the extent of pollution in the marine environment, which is the final sink of pollutants including dioxins (Sakurai *et al.*, 2000; Sakurai, 2003). Dioxins are accumulated and remain in marine sediments for a long time due to their high adsorptive property and persistency. Therefore, in this study, concentration of dioxins in river and marine sediments was determined to

Table 1. Details of the surface and core sediment samples. SG13, SGR-04, SGR-08, SGC-05, SGC-06, TN-1 and -2 of surface sediments are river sediments and others are marine sediments.

Sample ID	Moist. (%)	TOC (%)	Location	Date
Surface sediment				
SG-13	42.6	1.6	N10,36/E106,46	04.5.15
SGR-04	45.8	1.3	N10,45/E106,42	04.5.18
SGR-08	56.0	2.9	N10,50/E106,42	04.5.19
SGC-05	47.1	2.9	N10,45/E106,41	04.5.20
SGC-06	53.9	3.8	N10,45/E106,41	04.5.21
TN-1	26.5	0.1	N10,13/E106,50	04.5.14
TN-2	38.4	1.3	N10,15/E106,45	04.5.15
VT-01	31.0	0.71	N10,14/E106,55	05.7.10
VT-03	29.3	0.27	N10,22/E106,49	05.7.10
VT-04	43.6	0.84	N10,23/E106,49	05.7.10
VT-05	51.4	1.1	N10,14/E107,02	05.7.11
VT-06	47.1	0.72	N10,15/E107,05	05.7.11
Core sediment				
0–2 cm	46.2		N10,14/E107,02	05.7.11
4–6 cm	47.4		N10,14/E107,02	05.7.11
8–10 cm	45.8		N10,14/E107,02	05.7.11
12–14 cm	46.8		N10,14/E107,02	05.7.11
16–18 cm	39.2		N10,14/E107,02	05.7.11
20–21 cm	44.2		N10,14/E107,02	05.7.11
23–24 cm	41.6		N10,14/E107,02	05.7.11
26–27 cm	47.8		N10,14/E107,02	05.7.11
29–30 cm	50.3		N10,14/E107,02	05.7.11
51–52 cm	49.0		N10,14/E107,02	05.7.11
68–69 cm	51.0		N10,14/E107,02	05.7.11
75–76 cm	50.4		N10,14/E107,02	05.7.11
80–85 cm	45.3		N10,14/E107,02	05.7.11
95–100 cm	49.4		N10,14/E107,02	05.7.11

understand the contamination levels of dioxins in Vietnam coast. The objectives of this study are to elucidate the spatial distribution of dioxins from inland to open ocean and to verify the existence of dioxins derived from the chemical defoliants in coastal sediments.

MATERIALS AND METHODS

Surface sediment samples from 0 to 2 cm were collected using Ekman-Birge type bottom sampler along the course of Saigon River and the estuary of Mekong River in southern Vietnam during 2004 and 2005 (Fig. 1). A core sediment sample from 0 to 100 cm depth was also collected by using gravity corer from the coastal area near Vung Tau city in 2005 (also shown in Fig. 1). After sampling, the core was cut into layers of 2~5 cm. Dioxin analyzes were carried out on selected layers of the core. Detailed information about surface and core sediment samples is

Table 2. Concentrations (pg/g dry wt.) of PCDD/DFs and coplanar-PCBs in surface sediment samples.

	SG-13	SGR-04	SGR-08	SGC-05	SGC-06	TN-1	TN-2	VT-01	VT-03	VT-04	VT-05	VT-06
2378-T4CDD	0.12	3.2	1.5	1.1	6.5	0.25	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
12378-P5CDD	0.63	0.90	0.90	1.2	1.7	0.11	0.20	<0.4	<0.4	<0.4	<0.4	<0.4
123478-H6CDD	0.90	2.5	3.0	2.1	4.1	<0.5	0.30	<0.5	1.5	3.0	2.4	1.9
123678-H6CDD	1.2	2.1	3.9	3.7	6.8	0.4	0.50	1.5	1.5	4.6	2.1	2.3
123789-H6CDD	3.9	3.8	5.1	4.5	6.1	0.5	1.0	2.3	1.3	5.6	4.4	4.3
1234678-H7CDD	34	58	87	85	130	7.0	14	40	23	85	44	40
O8CDD	500	730	1100	850	1300	170	390	320	220	580	340	310
2378-T4CDF	0.53	1.8	1.8	4.0	5.6	0.13	0.26	<0.2	<0.2	<0.2	<0.2	<0.2
12378-P5CDF	0.28	0.40	1.0	3.6	5.6	0.13	0.12	<0.2	<0.2	<0.2	<0.2	<0.2
23478-P5CDF	0.17	0.80	0.80	2.3	3.2	0.15	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
123478-H6CDF	<0.3	1.7	2.7	3.0	5.6	0.20	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
123678-H6CDF	0.20	1.4	0.80	2.8	1.1	0.20	0.20	<0.3	<0.3	<0.3	<0.3	<0.3
123789-H6CDF	<0.3	0.70	<0.3	2.1	0.7	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
234678-H6CDF	<0.3	0.50	1.2	2.2	3.1	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
1234678-H7CDF	1.9	9.5	20	19	33	0.64	0.65	<0.6	<0.6	2.0	<0.6	<0.6
1234789-H7CDF	0.20	0.70	1.3	2.4	3.4	0.21	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
O8CDF	2.1	26	73	130	220	1.2	1.0	<1.5	<1.5	4.5	0	0
T4CDDs	9.5	23	21	27	46	2.0	5.3	3.0	2.2	8.1	1.9	1.5
P5CDDs	16	24	22	29	40	1.5	6.4	0	5.1	18	15	13
H6CDDs	110	96	110	100	140	11	30	63	41	96	85	80
H7CDDs	240	200	250	250	310	24	71	120	73	240	140	120
O8CDD	500	730	1100	850	1300	170	390	320	220	580	340	310

	SG-13	SGR-04	SGR-08	SGC-05	SGC-06	TN-1	TN-2	VT-01	VT-03	VT-04	VT-05	VT-06
T4CDFs	4.9	27	29	69	93	2.2	2.8	8.7	2.0	22	2.1	0.90
P5CDFs	2.1	15	24	69	92	1.2	1.0	<0.2	<0.2	1.4	<0.2	<0.2
H6CDFs	1.2	19	23	33	48	3.3	0.9	<0.3	<0.3	<0.3	<0.3	<0.3
H7CDFs	3.8	23	51	42	74	1.3	1.3	<0.6	<0.6	3.4	<0.6	<0.6
O8CDF	2.1	26	73	130	220	1.2	1.0	<1.5	<1.5	4.5	<1.5	<1.5
ΣPCDD/Fs	890	1200	1700	1600	2400	220	510	510	340	970	580	530
#77-TeCB	4.3	32	42	140	400	5.3	4.0	11	3.4	14	1.7	2.1
#81-TeCB	0.1	0.90	1.6	5.3	16	0.14	0.11	<2.0	<2.0	1.3	<2.0	<2.0
#126-PeCB	0.2	2.3	2.9	8.1	23	0.31	0.30	<1.0	<1.0	<1.0	<1.0	<1.0
#169-HxCB	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7
#105-PeCB	24	160	160	470	2000	72	53	1300	11	62	4.2	7.1
#114-PeCB	1.5	4.3	4.1	26	89	2.6	1.9	60	<0.3	3.4	<0.3	<0.3
#118-PeCB	67	430	410	1300	4700	210	150	2600	26	160	9.6	13
#123-PeCB	1.3	7.5	8.0	25	71	1.8	1.2	48	<0.2	3.1	<0.2	<0.2
#156-HxCB	4.8	75	65	240	690	65	54	430	5.1	28	2.2	3.1
#157-HxCB	1.2	26	23	84	190	16	12	100	<0.4	6.3	<0.4	<0.4
#167-HxCB	1.9	35	34	100	250	22	18	130	<0.4	14	<0.4	<0.4
#189-HpCB	0.29	11	8.8	30	56	3.4	2.9	15	<0.2	6.9	<0.2	<0.2
Σnon-ortho-PCBs	5	35	47	150	440	6.0	4.0	11.0	3.4	15	1.7	2.1
Σmono-ortho-PCBs	100	750	720	2300	8000	400	290	4683	42	280	16.0	23
Σco-PCBs	110	790	770	2500	8400	400	300	4700	46	300	18	25

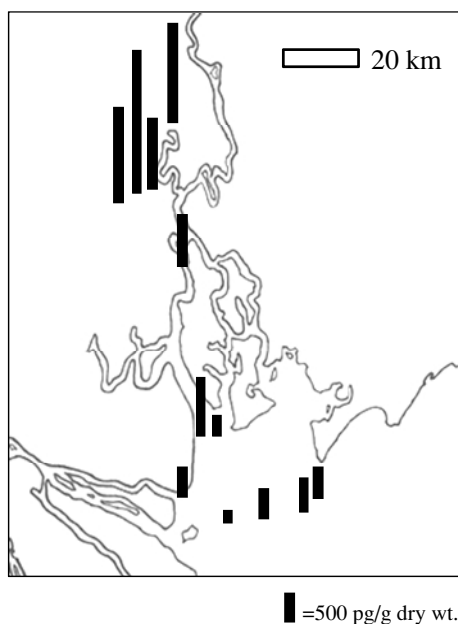


Fig. 2. Distribution of PCDD/DFs in the sediments of the study area.

shown in Table 1. All the samples were stored in the Environmental Specimen Bank (*es*-BANK), Ehime University, Japan at -25°C until chemical analysis.

All samples were air-dried and sieved with 2 mm sieve before analysis. About 10 grams of sieved sediment samples were extracted using toluene in a Soxhlet apparatus for 16 hours. One-third of the extract was used for dioxin analysis to which $^{13}\text{C}_{12}$ -labeled PCDD/DFs and coplanar-PCBs were added as clean-up spike. After adding the clean-up spike, extracts were treated with sulfuric acid and passed through multilayer silica-gel column for clean-up. Then, the eluate was passed through activated alumina-gel column and carbon dispersed silica-gel column for fractionation. First fraction contains mono-*ortho* PCBs and the 2nd fraction contains non-*ortho* PCBs and PCDD/DFs. After fractionation, syringe spike ($^{13}\text{C}_{12}$ -labeled PCDD/DFs and coplanar-PCBs) were added to both the fractions, and injected to high resolution gas chromatography-high resolution mass spectrometer (HRGC-HRMS; Agilent 6890-JOEL JMS-700D) for quantification.

For quantification of total organic content (TOC) in sediments, 1 gm sieved sediment sample was ground in agate mortar and treated with hydrochloric acid to remove inorganic carbon. The remaining (organic) carbon content was analyzed by elemental analyzer and TOC was calculated.

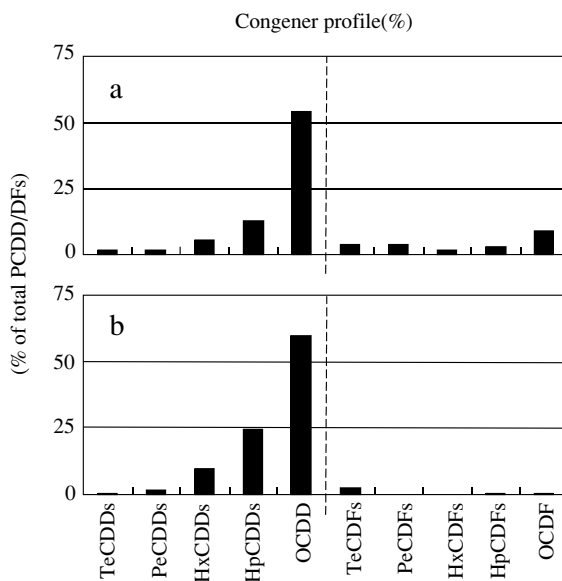


Fig. 3. Congener profiles of PCDD/DFs in sediment samples. (a) SGC-06 and (b) VT-04 are shown as representatives of river and marine sediments, respectively.

RESULTS AND DISCUSSION

Surface sediment

PCDD/DFs were detected in all surface sediment samples analyzed in this study. The total concentration ranged from 250 to 1800 pg/g dry weight (mean: 650 pg/g dry weight). The PCDD/DFs concentrations of each location are listed in Table 2.

The average concentrations of river and marine sediments were 1560 pg/g dry weight and 520 pg/g dry weight, respectively. Figure 2 displays the distribution of PCDD/DFs. As seen in Fig. 2, a decreasing trend of PCDD/DFs concentration from inland to marine area was observed indicating that the main sources of PCDD/DFs exist in inland, and the pollution of PCDD/DFs is spreading from inland to the ocean.

The congener profiles of PCDD/DFs were shown in Fig. 3. As the PCDD/DFs profiles were similar in both inland and marine locations, the profiles of two locations with the highest concentrations in inland and marine area are shown. It can be seen in these figures that OCDD was the dominant congener in both inland and marine areas. The contribution of OCDD in total PCDD/DFs concentration ranged from 53 to 65% in inland and from 59 to 81% in marine area. This is known to be a general pattern of sediments from non-contaminated sites (Hites, 1990; Baker and Hites, 2000; Ogura *et al.*, 2001).



Fig. 4. Distribution of coplanar-PCBs in the study area.

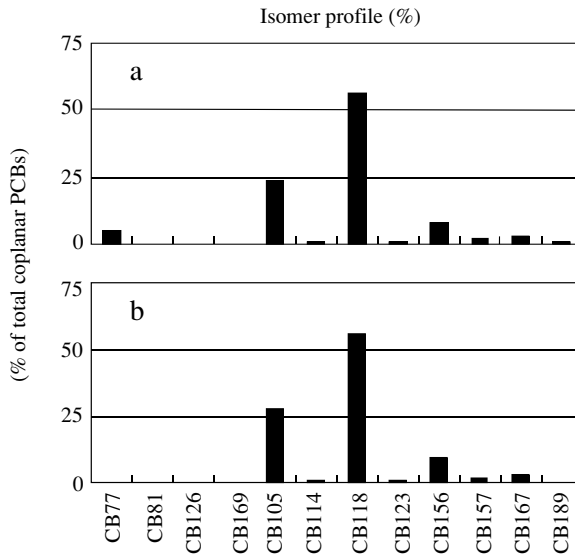


Fig. 5. Isomer profiles of coplanar-PCBs in a river sediment. The profiles of (a) SGC-06 and (b) VT-01 are shown as representatives of river and marine sediments, respectively.

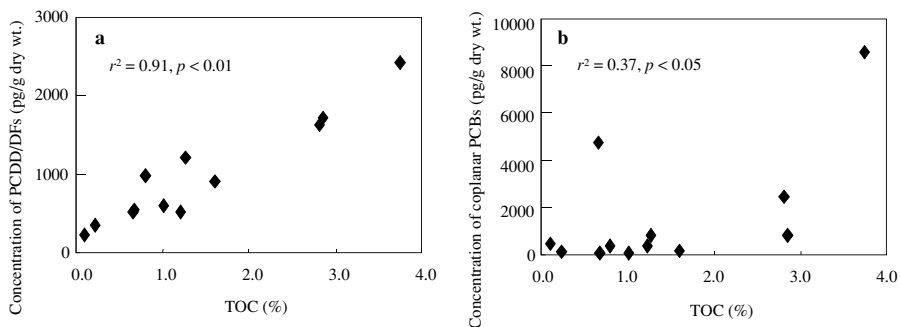


Fig. 6. Correlation between TOC and concentrations of PCDD/DFs and coplanar-PCBs in surface sediment from inland to marine area in Vietnam.

Table 3. Comparison of TEQ values obtained in this study to other areas in the world. TEQ values are calculated using I-TEF (Kurtz *et al.*, 1990) and WHO-TEF (Van den berg *et al.*, 2006). Data of other areas are referred from EU DG Environment (Finland, Germany, Italy, Netherlands, Sweden, UK, and Spain), Suarez *et al.* (2006) (US), Sakurai *et al.* (2000) (Japan), Kannan *et al.* (2007) (Korea), Müller *et al.* (2002) (Hong Kong), Liu *et al.* (2007) (China) and Schecter *et al.* (2001) (Hanoi).

	I-TEQ		I-TEQ	WHO-TEQ
Finland				
background	<1–100	Houston Ship Channel, US	28	25
contaminated	80000			
Germany				
background	1.2–19	Tokyo Bay, Japan	32	27
contaminated	1500			
Italy				
background	<1–10	Masan Bay, Korea	37	36
contaminated	570			
Netherlands				
background	1–10	Hong Kong	13	10
contaminated	4000			
Sweden				
background	<1–208	Bohai Sea, China	230	190
contaminated	1692			
UK				
background	2–123	Hanoi	6.6	5.8
contaminated	7410			
Spain				
urban	<1–57	This study (mean)	3.9	4.1
		This study (maximum)	16	17

Table 4. Concentrations of PCDD/DFs and coplanar-PCBs (pg/g dry wt.) in the core sediment sample.

Depth (cm)	0-2	4-6	8-10	12-14	16-18	20-21	23-24	26-27	29-30	51-52	68-69	75-76	80-85	95-100
2378-T4CDD	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
12378-P5CDD	<0.4	0.83	1.4	<0.4	<0.4	1.2	<0.4	<0.4	<0.4	0.53	0.72	0.81	0.3	0.52
123478-H6CDD	1.3	2.4	1.6	1.4	2.5	0	2.5	<0.5	2.2	1.3	0.94	1.4	1.1	1.5
123678-H6CDD	1.9	4.9	3.2	2.1	3.0	2.6	2.1	3.8	2.6	2.2	2.3	2.8	2.1	2.9
123789-H6CDD	4.3	6.7	5.4	3.5	4.4	4.4	4.5	5.5	4.5	4.5	4.5	4	2.7	4.3
1234678-H7CDD	48	80	57	43	51	52	59	60	59	39	38	38	26	36
O8CDD	380	560	400	330	400	370	410	390	460	290	320	320	190	290
2378-T4CDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
12378-P5CDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
23478-P5CDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
123478-H6CDF	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
123678-H6CDF	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
123789-H6CDF	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
234678-H6CDF	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
1234678-H7CDF	<0.6	4.0	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
1234789-H7CDF	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
O8CDF	<1.5	13	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
ΣPCDDs	440	650	470	380	460	430	480	460	530	340	370	370	220	340
ΣPCDFs	ND	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
ΣPCDD/DFs	440	670	470	380	460	430	480	460	530	340	370	370	220	340

Depth (cm)	0-2	4-6	8-10	12-14	16-18	20-21	23-24	26-27	29-30	51-52	68-69	75-76	80-85	95-100
#77-TeCB	1.4	3.7	3.6	2.7	2.7	3.0	1.9	2.3	1.4	<2.0	<2.0	<2.0	<2.0	<2.0
#81-TeCB	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
#126-PeCB	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
#169-HxCB	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7	<0.7
#105-PeCB	4.0	7.1	5.8	3.8	4.6	4.3	4.2	3.2	3.9	<2.5	<2.5	<2.5	<2.5	<2.5
#114-PeCB	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
#118-PeCB	13	15	13	12	14	9.5	12	6.0	13	<5.0	<5.0	<5.0	<5.0	<5.0
#123-PeCB	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
#156-HxCB	2.7	2.1	2.0	1.6	2.2	1.2	<0.4	0.84	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
#157-HxCB	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
#167-HxCB	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
#189-HpCB	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
non- <i>o</i> -PCBs	1.4	3.7	3.6	2.7	2.7	3.0	1.9	2.3	1.4	ND	ND	ND	ND	ND
mono- <i>o</i> -PCBs	20	24	21	17	21	15	16	10	17	ND	ND	ND	ND	ND
co-PCBs	21	28	24	20	24	18	18	12	18	ND	ND	ND	ND	ND

When the proportion of PCDFs to total PCDD/DFs in river and marine sediments were compared, the values were higher in inland than in marine area. The percentage of PCDFs to total PCDD/DFs concentration in river and marine sediments ranged from 1.6 to 22.0% and from 0.2 to 4.2%, respectively. In previous studies, it was found that the PCDFs account for a high percentage of PCDD/DFs produced in combustion processes (Oh *et al.*, 1999; Baker and Hites, 2000). Therefore, it can be suggested that some pollution sources associated to combustion processes exist in inland areas of the present study.

The total coplanar-PCBs concentration ranged from 18 to 8400 pg/g dry wt. The average concentrations in river and marine sediments were 2500 and 830 pg/g dry wt., respectively (Table 2). Similar to PCDD/DFs, the concentration in inland sediment was higher than in marine area. But the distribution of coplanar-PCBs was rather local when compared with PCDD/DFs, and the spatial decreasing trend from inland to marine area was not found (Fig. 4).

The locations SGC-06 and VT-01 showed the highest concentration of coplanar-PCBs in inland and marine areas, respectively. The isomer profiles of these two locations are shown in Fig. 5. In all locations, the isomer profiles of coplanar-PCBs were similar. The dominant isomer was CB118, followed by CB105 and CB156. This pattern is similar to the pattern of technical PCBs (Kim *et al.*, 2004; Ishikawa *et al.*, 2007). Therefore, it can be presumed that some potential source of technical PCBs exist in both the areas.

A significant correlation was found between the total concentration of PCDD/DFs and TOC (Pearson's correlation coefficient, $p < 0.01$, $r^2 = 0.91$, Fig. 6a). River sediments showed higher levels of both PCDD/DFs and TOC than marine sediment. As both PCDD/DFs and TOC showed linear decreasing trends from inland to marine area, it can be suggested that the major sources of PCDD/DFs exist in inland, and PCDD/DFs were re-distributed from river sediments into marine sediments depending on the levels of TOC in sediments.

Meanwhile, the correlation between the total concentrations of coplanar-PCBs and TOC was significant (Pearson's correlation coefficient, $p < 0.05$) but the contribution rate was lower than in the case of PCDD/DFs ($r^2 = 0.37$, Fig. 6b). Therefore, it can be assumed that some factors other than TOC in sediments affect the distribution of coplanar-PCBs. With regard to the distribution pattern of coplanar-PCBs, the most remarkable location is VT-01, which showed a notably higher concentration of coplanar-PCBs than other locations having the same TOC levels in the marine area. For this reason, it can be presumed that some local pollution sources exist not only in inland but also in marine area and such sources might become a factor for the specifically high concentration at VT-01. Such "Hot Spots" of contamination may exist at other places and so detailed investigations on the distribution of coplanar-PCBs are needed.

Using the I-TEF (Kutz *et al.*, 1990) and WHO-TEF (Van den Berg *et al.*, 2006), I-TEQ and WHO-TEQ values were calculated. In this study, I-TEQ and WHO-TEQ values ranged from 0.73 to 16 (mean = 3.9) and 0.73 to 17 (mean = 4.1) pg-TEQ/g dry wt, respectively. These values are lower than the values previously reported (EU DG Environment, 1999; Sakurai *et al.*, 2000; Müller *et*

al., 2002; Suarez *et al.*, 2006; Kannan *et al.*, 2007; Liu *et al.*, 2007). Meanwhile, in the northern part of Vietnam, the TEQ value from Hanoi is almost the same as the present study area (Table 3) (Schechter *et al.*, 2001). Therefore, it is suggested that the dioxin contamination in the area surveyed in this study is not so severe when compared to several areas in developed countries. However, developing countries such as Vietnam are very much lenient than developed countries in implementing legislations on control of dioxins contamination; so continuous monitoring is needed to control the possible increase in dioxin contamination in Vietnam in the future.

Core sediment

Results of the core sediment analysis are shown in Table 4. As for PCDD/DFs, both total concentrations and congener profiles showed no specific trend from surface to deeper layer. Mean concentration of the values from all the layers of the core was 630 pg/g dry wt. and the dominant congener was OCDD. On the other hand, coplanar-PCBs concentrations showed a slight decreasing trend from surface to deeper layer. This might indicate a temporal decreasing trend of coplanar-PCBs even though the decreasing trend was not significantly clear.

2,3,7,8-TCDD was not detected from all the layers of the core sediment (Table 4). Therefore, the historical contamination derived from the chemical defoliant was not evident in this area.

In the present sampling area, Saigon River and Mekong River enters into the ocean and as a result severe agitation of sediment occurs due to a major change of tidal current and development of salt wedge (Wolanski *et al.*, 1996; Hu *et al.*, 2000). Because of this, it seems that 2,3,7,8-TCDD derived from the chemical defoliant had already diffused before reaching the present sample location by re-suspension of sediments or remain in layers deeper than the depth of one meter surveyed in this study.

Dioxin contamination derived from chemical defoliants was not observed in this study, but even now very high concentrations of 2,3,7,8-TCDD is still reported in some samples such as military base soil and lake sediments from highly contaminated areas. These reservoirs might become secondary sources of dioxins in the future. So, a continuous monitoring of 2,3,7,8-TCDD levels in terrestrial soils and marine sediments are needed.

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