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ORGANOCHLORINE PESTICIDES IN SEAFOOD PRODUCTS FROM SOUTHERN CHINA AND HEALTH RISK ASSESSMENT

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Abstract—Seafood consumption is an important route of human exposure to organic contaminants. Residual levels of organochlorine pesticides (OCPs), including DDTs, hexachlorocyclohexanes (HCHs), heptachlor, aldrin, α-endosulfan, β-endosulfan, dieldrin, endrin, endrin aldehyde, endrin ketone, methoxychlor, endosulfan sulfate, and heptachlor epoxide, were determined in a wide variety of seafood products collected from 11 coastal cities in southern China in June and October 2005. The results indicated that OCPs were predominated by DDTs and HCHs. The concentrations of other OCP components generally were low and were detectable in a small number of seafood samples only, probably reflective of the generally low levels of these OCPs in the study region and low bioaccumulation potentials in the species under investigation. Risk assessment against various standards clearly showed that seafood products were highly contaminated by DDTs and may pose health threat to local residents and the consumers all over the world. Furthermore, other OCP components, such as dieldrin and heptachlor, also impose lifetime cancer risk, especially to residents of coastal regions who often consume more seafood than those living inland. Therefore, continual monitoring of OCPs in various environment compartments, including biota and abiota, urgently is needed to mitigate effectively the impact of OCPs, particularly DDTs, on human health and the ecological environment.

Keywords—Organochlorine pesticide Dichlorodiphenyltrichloroethane Hexachloroxcylohexane Seafood product Health risk

INTRODUCTION

Organochlorine pesticides (OCPs), such as DDT and their metabolites, dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethylene (DDE) (sum of *o,p′*- and *p,p′*-DDT, DDD, and DDE is designated as DDTs), and hexachlorocyclohexanes ([HCHs]; including α-HCH, the major constituent [60%] of the technical mixture; β-HCH, with the highest toxicity and accumulation potential for mammals; and γ-HCH, the only insecticidal isomer; sum of them represents more than 85% of the technical mixture), are ubiquitous in the environment and may continue to pose health threat to both wildlife and human beings, due to their persistency, bioaccumulative ability, and potential toxicity. In China, OCPs widely had been used in agriculture and sanitation for several decades until the official ban on their usage in 1983. The amounts of HCHs and DDTs produced in China were estimated at 4.9 and 0.4 million metric tons, accounting for 33 and 20%, respectively, of the total global production [1]. In the Pearl River Delta of southern China, the amount of OCPs used was approximately 76,000 to 100,000 tons annually from 1972 to 1982, with an application rate of 1.8 to 2.7 kg per metric acre in the agricultural zones [2]. More recent data showed that the average annual application of OCPs reached 37.2 kg per hectare from 1980 to 1995, four times higher than the country's average [3].

The last two decades have witnessed an explosive economic growth in Guangdong Province, a coastal region of southern China (Fig. 1). Rapid industrialization, urbanization, and conversion of massive agricultural lands to commercial use have accelerated environmental deterioration, especially in the Pearl River Delta and the adjacent coastal region. Although production and usage of DDTs and HCHs officially have been banned in China since 1983, considerably high levels of both DDTs and HCHs recently have been detected in water, sediment, and biota [4–6]. Furthermore, new sources of DDT may be present in this area [7,8].

China has been the world's largest producer and exporter of fishery products since 2002. The main trade partners include Japan, Korea, Canada, the United States, and the European Union. In 2005, the exporting quantity of fishery products reached 3.153 million metric tons, accounting for 10% of the total global exporting volume (http://fishery.aweb.com.cn/news/2006/4/13/10241115.shtml). Seafood products, such as shrimps, crabs, and shellfish, are farmed extensively in the coastal region of southern China, which has become an important production zone to support exporting activities. For example, 15% of the global exporting volume for shrimps is provided by China, among which 60% is from Zhanjiang (Fig. 1) of southern China (http://www.china-fisheries.com/market/display.asp?id=4710). In general, fish and seafood account for only a small portion of human diet, but it represents a major route of human exposure to organic contaminants [9,10]. Given the importance of China's seafood products to the human health globally, information regarding the state of OCP contamination in seafood products urgently is needed to gauge the impact of OCPs on consumers all over the world.

Large-scale farming and increasing market demand of sea-

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Fig. 1. Map of the sampling site in the coastal region of southern China.

food products should spur more attention to the health consequences via seafood consumption, because historical discharge and possible new sources of OCPs are likely to impact adversely the quality of seafood products. The present study aimed to survey extensively a large number of seafood products from the coastal region of southern China (Fig. 1) for OCP contamination. The data acquired enabled us to perform risk assessments related to consumption of the target seafood products and to identify potential health risk. Furthermore, the data also should be helpful for environmental management authorities to balance the utilization of natural marine resources, protection of the eco-environment, and production of seafood products.

MATERIALS AND METHODS

Materials

Pesticide mixture standards (Supelco, Bellefonte, PA, USA), polychlorinated biphenyls (PCBs) standards (Accustandards, New Haven, CT, USA), and *o,p′*-DDE, *o,p′*-DDD, and *o,p′*-DDT (Accustandards) were used for identification and quantification. Surrogate standards of 2,4,5,6-tetrachloro-*m*-xylene were obtained from Ultra Scientific (North Kingstown, RI, USA). SX-3 Bio-Beads used in gel permeation chromatograph were purchased from Bio-Rad Laboratories (Hercules, CA, USA). All organic solvents were redistilled in a glass system before use. Silica (80–100 mesh) and alumina (100–200 mesh) were extracted with methanol:dichloride methane (1:1) for 72 h before use. Sodium sulfate was baked at 450°C and stored in sealed containers. Purified water was prepared with a redistilling apparatus (SZ-II, Shanghai, China).

Sample collection

A wide variety of seafood products, including six species of shrimps, two species of crabs, and fourteen species of shellfish, were collected from local fishery product markets in 11 coastal cities of southern China, namely, Dongguan, Foshan, Guangzhou, Jiangmen, Maoming, Shantou, Shanwei, Yangjiang, Zhuhai, Zhanjiang, and Zhongshan (Fig. 1), in June and October 2005. Sample types were selected based on the geographical distribution, commercial availability, and potentials to accumulate a wide range of pollutants. Upon collection, samples were stored in polyethylene bags, kept in ice, and brought back to the laboratory immediately. They were stored at −20°C until analyzed.

Sample preparation

Frozen samples were thawed and rinsed individually with purified water to remove possible impurities. Subsequently, the edible parts from approximately 20 to 30 specimens of the same species collected from each location were pooled and homogenized. Samples were freeze-dried with a freeze dryer (ALPHA1–4, Martin Christ, Osterode, Germany) for 48 h, and then were ground into powders and stored at −20°C for chemical analysis.

An aliquot (~5 g dry wt) of each sample was spiked with surrogate standards 2,4,5,6-tetrachloro-*m*-xylene (TMX), PCB 67, and PCB 191, and was Soxhlet extracted for 48 h with 200 ml of acetone:*n*-hexane (1:1, v:v). The extract was concentrated to approximately 5 ml with a Zymark Turbo Vap II (Hopkinton, MA, USA) at 30°C. A portion (10%) of the extract was taken out for gravimetrical determination of lipid content, and the rest was subject to a gel permeation chromatograph, a glass column packed with 40 g of SX-3 Bio-Beads (Bio-Rad). The column, loaded with an extract, was eluted with 50% dichloromethane in *n*-hexane for lipid removal. The fraction from 110 to 280 ml containing OCPs was collected and concentrated. The subsequent cleanup and fractionation was performed with a multilayer alumina/silica column packed, from the bottom to top, with neutral alumina (6 cm, 3% deactivated), neutral silica gel (12 cm, 3% deactivated), and anhydrous sodium sulfate (1 cm). The column was prewashed with 5 ml of *n*-hexane, and, as the solvent reached the top layer, the defatted sample was added and eluted slowly with 70 ml of *n*-hexane:dichloromethane (7:3, v:v). The effluent

Table 1. Concentrations of DDTs and hexachlorocyclohexanes ([HCHs], ng/g wet wt) in seafood products

	HCHs			DDTs		
Species	Range	AVE[a]	Median	Range	AVE	Median
Crabs						
Scylla serrata[b]	0.18–6.82	1.54	0.60	0.52–44.9	14.3	7.79
S. serrata[c]	0.04–2.33	0.60	0.17	0.83–19.4	7.38	5.51
Ovalipes punctatus[b]	0.26–0.61	0.42	0.42	6.27–56.3	35.6	49.3
O. punctatus[c]	0.12–0.97	0.38	0.29	1.71–36.1	15.1	9.99
Shrimps						
Metapenaeus ensis	0.09–0.40	0.20	0.18	0.10–1.28	0.37	0.20
Proambarus clarkii	0.08–0.19	0.11	0.09	0.34–1.73	0.91	0.78
Macrobrachium rosenbergi	0.03–0.43	0.22	0.20	0.13–5.12	1.42	0.75
Penaeus japonicus	0.11–0.42	0.28	0.30	0.20–14.4	6.67	5.35
Penaeus monodon	0.09–0.53	0.34	0.15	0.30–5.71	1.60	1.20
Squilla oraloria	0.14–0.39	0.28	0.19	2.40–52.3	20.3	16.9
Shellfish						
Haliotis diversicolor	0.17–0.96	0.40	0.33	0.05–43.8	7.77	0.31
Solen grandis	0.14–0.49	0.25	0.23	0.08–12.5	4.54	3.53
Scapharca subcrenata	0.09–1.07	0.30	0.23	1.32–50.0	8.81	3.41
Tegillarca granosa	0.21–0.78	0.39	0.35	1.63–83.5	14.0	4.93
Argopectens irradias	0.08–0.50	0.29	0.27	0.11–3.43	1.68	1.34
Patinopecten yessoensis	0.07–0.54	0.27	0.27	0.08–22.8	8.62	8.20
Pinna pectinata Linnaeus	0.13–0.31	0.19	0.16	1.32–90.4	15.2	5.30
Meretrix meretrix	0.05–7.00	1.07	0.36	0.95–39.9	12.2	9.01
Cyclina sinensis	0.22–2.22	0.67	0.36	1.45–45.2	10.7	5.20
Venerupis variegata	0.14–0.99	0.45	0.44	2.27–121.8	34.1	29.2
Perna uiridis	0.11–1.17	0.51	0.46	3.95–506.8	70.9	23.6
Sinonovacula constricta	0.03–1.57	0.52	0.38	11.7–315.0	116.2	65.7
Crassostrea gigas	0.31–3.68	1.13	0.72	65.7–619.7	210.3	179.7

[a] AVE = Arithmetic mean values.
[b] Male.
[c] Female.

was concentrated, quantitatively transferred into a 2-ml vial, and further concentrated to the final volume of 100 μl under a gentle nitrogen stream. An internal standard, PCB 82, was added to the extract prior to instrumental analysis.

Instrumental analysis

Instrumental analysis was carried out with a Hewlett-Packard ([HP], Avondale, PA, USA) 5890 gas chromatograph and a 5973 mass spectrometer operating in the selective ion monitoring mode. A 30 m × 0.25 mm (i.d.) × 0.25 μM (film thickness) DB–5 fused silica capillary column was used for chromatographic separation. The column temperature was programmed from 80°C (held for 1 min) to 200°C at a rate of 12°C/min, followed by an increase at a rate of 1°C/min to 220°C, and the temperature was further ramped at a rate of 15°C/min to 290°C (held for 10 min). Ultrahigh purity helium (99.999%) was employed as carrier gas at a constant pressure of 10 psi. Splitless injection of 1-μl sample was performed with a 10-min solvent delay time. Injector and detector temperatures were set at 280°C and 300°C, respectively. Mass spectra were acquired in the electron impact mode with an impact voltage of 70 eV. Data acquisition and processing were performed with a DOS-based HP ChemStation system.

Quality assurance/quality control

The residues of OCPs in the samples were identified on the basis of retention time and ion fragment profiles compared against authentic standards, whereas quantitation was conducted using a multipoint internal calibration method. The correlation coefficients (r) for all calibration curves were greater than 0.996. The limits of detection of 21 OCP components were defined as signal-to-noise ratio > 3, ranging from 0.01 to 0.05 ng/g wet weight. For each batch of 12 field samples, a procedural blank, a spiked blank, a pair of spiked matrix sample/duplicate, and a sample replicate were processed. The recoveries of the surrogate standards added to all samples were 59.8 ± 12.5% for TMX, 85.4 ± 15.4% for PCB 67, and 91.3 ± 17.3% for PCB 191. Recoveries of 21 OCP components in six spiked blank ranged from 68.2 ± 17.2% for aldrin to 102.7 ± 17.4% for methoxychlor. No target compounds were found in procedural blanks, and the final concentrations were not corrected with surrogate recoveries.

RESULTS AND DISCUSSION

Concentrations of DDTs and HCHs

A total of 212 seafood products collected from 11 coastal cities of south China in 2005 were analyzed for 21 OCPs residues, including DDT and its metabolites (including *o,p′*- and *p,p′*-DDT, DDD, and DDE), HCH isomers (including α-, β-, γ-, and δ-HCHs), heptachlor, aldrin, α-endosulfan, β-endosulfan, dieldrin, endrin, endrin aldehyde, endrin ketone, methoxychlor, endosulfan sulfate, and heptachlor epoxide. The analytical results indicate that OCPs were predominated by DDTs and HCHs. Both groups of compounds were detected in all the samples. Concentration data of DDTs and HCHs in seafood products, including concentration range, average, and median values, are presented in Table 1.

Among the different species, the highest residual levels of DDTs were found in *Crassostrea gigas* (median concentration: 179.7 ng/g wet wt), *Sinonovacula constricta* (median concentration: 65.7 ng/g wet wt), *Venerupis variegata* (median concentration: 29.2 ng/g wet wt), and *Perna uiridis* (median concentration: 23.6 ng/g wet wt). The lowest residual level of DDTs was detected in *Metapenaeus ensis*, with a median concentration of 0.20 ng/g wet weight, and the concentration range is two to three orders of magnitude lower than that with *C. gigas*. These results suggest that bioaccumulation of DDTs in seafood products was highly species-specific, probably due to different ecological characteristics for different aquatic species such as feeding habits and habitats [11]. On the other hand, DDTs residues also were considerably sampling location dependent. The concentrations of DDTs in each species generally varied over one or two orders of magnitude.

Dichlorodiphenyltrichloroethane is known to biodegrade to DDE under aerobic conditions and to DDD under anaerobic conditions. Therefore, the ratio of DDT/(DDE + DDD) can be used as an indicator of possible new sources. In the present study, DDT compositions in seafood products varied considerably with individual samples. The DDT/(DDE + DDD) values ranged from 0 to 4.8 with an arithmetic mean of 0.7. This suggested that biodegradation of DDT occurred in the study area. On the other hand, possible new inputs of DDT could not be excluded entirely, because more than 20% of the samples had DDT/(DDE + DDD) higher than one. The presence of possible new sources of DDTs in the study areas, which has been demonstrated in previous studies [12,13], could be responsible for this large variability. However, the likelihood of dicofol being a new important source of DDTs in China [14] remains debatable, because *o,p'*-DDT (and therefore *o,p'*-DDD and DDE as the metabolites), which was the main starting material to produce dicofol, was found as a much less significant constituent in our samples. Therefore we cannot conclusively regard dicofol as the main source of new DDT inputs in the study area.

Hexachlorocyclohexanes were also ubiquitous in seafood products, but the residual levels were considerably lower than those of DDTs. Despite the low residual levels, the variability of HCH levels with species and sampling locations was basically the same as that of DDTs. Historically, the usages of technical HCHs were much more than those of DDTs in China. Nevertheless, the results of the present study that the residual levels of HCHs in seafood products were lower than those of DDTs are consistent with the results obtained from the previous studies investigating the levels of OCPs in vegetable soil and small cetaceans in the same study region [15,16]. The discrepancy between the usages of HCHs and DDTs and their accumulative levels in seafood products may be due to the difference in physicochemical and biochemical properties between HCHs and DDTs, wherein HCHs have higher biodegradability and lower lipophilicity compared to DDTs.

The residual levels of contaminants in *Perna uiridis*, recognized as an excellent bioindicator of trace toxic contaminants levels in coastal waters and sediments due to their widespread distribution, sessile lifestyle, relatively low P_{450} activities, and high ability to sequester a wide range of chemicals [17], have been investigated extensively worldwide for different purposes [17–19]. The large data set accumulated allows us to compare the state of environmental quality among different countries and regions. The residual levels of DDTs in *P. uiridis* from the present study (3.95–506.8 ng/g wet wt with a mean of 65.7 ng/g wet wt) were not only much higher than the levels found in Demark (2.4–67 ng/g wet wt) [20], India (1.6–40 ng/g wet wt) [18], Korea (1.1–19.5 ng/g wet wt) [21], and Japan (3.5 ng/g wet wt) [17], but also higher than the levels documented in Vietnam (40 ng/g wet wt) [17] and Dalian (39.18 ng/g wet wt) and Tianjin (43.94 ng/g wet wt) of northern China [22]. The only region that reports higher levels of DDTs is Egypt, with DDTs concentrations in mussel in the range of 125 to 772 ng/g wet weight and where DDT had been used still in agriculture and vector control until recently [23]. This indicates that the coastal region of southern China is probably one of the most DDT-polluted areas in the world.

Table 2. Organochlorine pesticide residues and their occurrence in seafood products

	Residue levels (ng/g wet wt)				
	Maximum	AVE[a]	Minimum	Occurrence	Frequency (%)
Heptachlor	0.35	0.02	0.01	17	8.0
Aldrin	0.28	0.01	0.01	9	4.2
Heptachlor epoxide	0.18	0.01	0.01	9	4.2
α-Endosulfan	1.25	0.04	0.02	8	3.8
Dieldrin	0.77	0.08	0.01	25	11.8
Endrin	2.37	0.66	0.01	64	30.2
β-Endosulfan	0.29	0.00	0.02	3	1.4
Endrin aldehyde	1.25	0.43	0.01	78	36.8
Endosulfan sulfate	0.35	0.01	0.01	9	4.2
Endrin ketone	0.55	0.10	0.01	40	18.9
Methoxychlor	0.71	0.06	0.02	19	9.0

[a] AVE = Arithmetic mean values.

Concentrations of other organochlorine pesticides

Other OCP components, including heptachlor, aldrin, α-endosulfan, β-endosulfan, dieldrin, endrin, endrin aldehyde, endrin ketone, methoxychlor, endosulfan sulfate, and heptachlor epoxide, were detected in a small portion of the samples. The concentration data, including concentration ranges, occurrence, and frequency of detection, are summarized in Table 2. Because of the low frequency of detection, the data analysis was conducted in compliance with the guideline of the World Health Organization [24]. Maximum residual level was derived from the mean of the detectable values, and minimum level was estimated as half the limits of detection for the samples containing nondetectable residues. In addition, the average residue level was derived from all the samples containing detectable and nondetectable contaminants.

Endrin and its metabolites (endrin aldehyde and endrin ketone) were the main detectable residues in addition to DDTs and HCHs, with the detectable frequency of 30.2, 36.8, and 18.9%, respectively (Table 2). For the other pesticides, the occurrences in seafood products were rather low, with the frequency of detection ranging from 11.8% for dieldrin to 1.4% for β–endosulfan. In fact, these OCP compounds mostly were found in a few shellfish species, such as *P. uiridis*, *S. constricta*, and *C. gigas*, which may have high ability to accumulate OCPs, as suggested by the relatively high levels of DDTs and HCHs (Table 1). Few data are available on the occurrence of these pesticides in the environment and their historical usage. Limited information indicates that these pesticide compounds incontrovertibly have been found in surface water, pore water, surface sediment, and soil in China, although the residue levels are often quite low [4,25–29]. Recent surveys on Macau coastal water [4,29] show that the target OCPs were widespread in the aquatic environment around the Pearl River Estuary. Therefore, the low residual levels of these pesticides and their low frequency of detection may be attributed to their relatively low residual levels in the environment and/

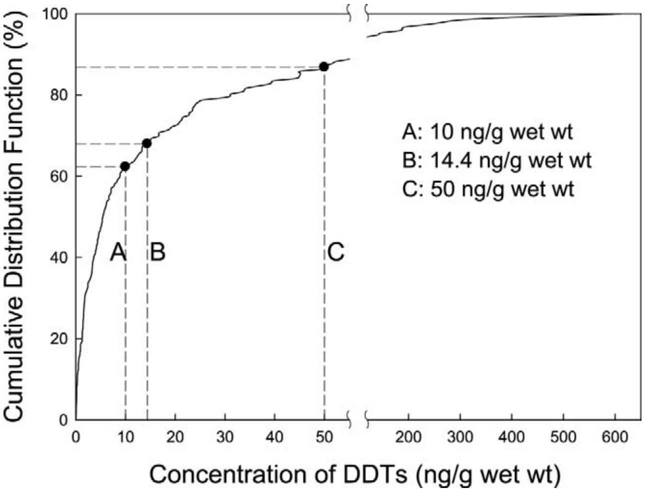

Fig. 2. Cumulative distribution function for DDTs in all the seafood products. Broken lines represent three different assessment standards: (**A**) The most stringent standard (10 ng/g wet wt) on marine biological quality enacted by the Chinese government (GB18421–2001); (**B**) fish consumption standard (14.4 ng/g wet wt) recommended by the U.S. Environmental Protection Agency; and (**C**) maximum admissible concentration (50 ng/g wet wt) established by the European Union on the basis of the lipid percentage of food.

or their relatively low potential for bioaccumulation in the species under consideration.

Health risk assessment

Numerous epidemiological evidence has established that exposure to OCPs is associated with a wide array of adverse effects on human health [30–32]. The present study provides a general overview of the OCPs residual levels in seafood products collected from the coastal region of southern China. The results show that DDTs are the predominant contaminants. Compared to the maximum admissible concentration (50 ng/g wet wt) established by the European Union on the basis of the lipid percentage of food [33], 13.2% of our samples are considered overloaded. If a relatively stricter limit for fish consumption (14.4 ng/g wet wt) recommended by the U.S. Environmental Protection Agency [34] is used, the residual levels of DDTs in 32.1% of the samples exceed the criterion. Finally, more than one third of the samples (37.1%) are regarded excessive when assessed against the most stringent standard (10 ng/g wet wt) on marine biological quality enacted by the Chinese government (GB18421–2001). All of these comparisons are shown schematically in Figure 2.

A previous study showed that the levels of HCHs in foodstuffs (including aquatic products) dramatically declined during the last 30 years [35]. In the present work, HCHs are detected widely in seafood products, but concentrations are rather low. Only one sample from Guangzhou has the residual level of HCHs (7.0 ng/g wet wt; Table 1) close to the maximum admissible concentration (10 ng/g wet wt) established by the European Union [33]. Low residual levels of HCHs suggest that HCHs are no longer an environmentally significant organic contaminant in seafood products from southern China, although the widespread distribution of HCHs still deserves further monitoring efforts to ensure the long-term safety of consumers in association with consumption of seafood products. Low persistency in the environment, high biodegradation and volatility, and absence of new input sources may be responsible for the low levels of HCHs residues in the seafood samples.

Despite the low levels and low detection frequency of other OCPs residues in seafood products, potential health risk associated with consumption of seafood products cannot be neglected. If the seafood consumption data provided by the Food and Agriculture Organization fact sheets (http://faostat.fao.org/site/346/default.aspx) are taken and the estimated daily intakes (EDIs) derived from the maximum residual levels from the present study are used, the estimated daily intakes of selected OCP components can be derived (Table 3). The EDIs of *p,p′*-DDT and dieldrin are not only higher than the cancer benchmark concentration, but also higher than the oral reference dose developed by a previous study funded by the U.S. Environmental Protection Agency [10], suggesting a perceptible health risk associated with consumption of seafood products. Besides *p,p′*-DDT and dieldrin, the EDI of heptachlor also exceeds the cancer benchmark level. These assessments imply that lifetime cancer risk remains a possibility for coastal residents who are likely to consume more seafood than those living inland. On the other hand, the EDI of each contaminant mostly comes from bivalves (Table 3). For example, 96.7% of *p,p′*-DDT is derived from bivalves, though only 3.3% of *p,p′*-DDT is associated with crustaceans. Furthermore, no heptachlor and dieldrin can be found in crustacean samples. This suggests that crustaceans were much safer than bivalves to consume based on their contributions to the EDI of organic contaminants.

With a large amount of data about persistent organochlorine compounds in mussel from coastal waters of Asian countries [17], incorporating the consumption data from Food and Agriculture Organization fact sheets (http://faostat.fao.org/site/346/default.aspx) and population data (http://post.baidu.com/f?kz=100212531) would allow a comparison of the EDIs among the populations in the Asian-Pacific region (Table 4). Because of the large quantity of bivalves consumed and the highest DDT concentration in mussel, the EDI of DDTs via

Table 3. Comparison of the estimated daily intake (EDI) from the present study with the Cancer Benchmark Concentration (CBC) and Oral Reference Dose (Oral RfD) developed by a previous study funded by the U.S. Environmental Protection Agency [10]

Contaminant	Species	Consumption[a] (g/day)	EDI[b] (ng/kg·day)	Sum of EDI (ng/kg·day)	Oral RfD (ng/kg·day)	CBC (ng/kg·day)
p,p′-DDT	Bivalves	17.1	6.07	6.28	0.5	0.003
	Crustaceans	8.3	0.21	—	—	—
Heptachlor	Bivalves	17.1	0.04	0.04	0.5	0.00022
	Crustaceans	8.3	0	—	—	—
Dieldrin	Bivalves	17.1	0.11	0.11	0.05	0.0000625
	Crustaceans	8.3	0	—	—	—

[a] Original data were adopted from http://faostat.fao.org/site/346/default.aspx.

[b] An average weight of 60 kg, representative of the average weight of Chinese population, was used to calculate EDIs.

Table 4. Comparison of the estimated daily intake (EDI) derived from the present study with those for other countries in the Asian-Pacific region

Location	Consumption[a] ($\times 10^3$ tons/year)	DDTs concn (ng/g wet wt)	Population[b]	EDI (ng/day/capita)
Cambodia	0.78	0.33[c]	13,607,069	0.1
Indonesia	39.10	1.0[c]	241,973,879	0.4
Philippines	96.78	0.4[c]	87,857,473	1.2
Malaysia	71.06	1.4[c]	23,953,136	11.4
Japan	1,081.91	3.5[c]	127,417,244	81.4
Vietnam	84.79	40.0[c]	83,535,576	111.2
South China	8,125.69	65.7	1,306,313,812	1,119.7

[a] Data were obtained from http://faostat.fao.org/site/346/default.aspx.
[b] Data were obtained from http://post.baidu.com/f?kz = 100212531.
[c] Data of DDT concentration (excluding those from South China) were from Fung et al [19].

seafood consumption in South China is much higher than those for other countries in the Asian-Pacific region. This comparison may be superficial, because mussels cannot entirely represent the bivalves, leading to biased results. Nevertheless, it provides a preliminary assessment on the status of human exposure to DDTs via seafood consumption among different countries in the Asian-Pacific region.

CONCLUSION

A thorough search through the literature indicates that almost all previous studies monitoring OCPs residues in biota have focused on fish and other organisms with high trophic levels. The present study demonstrates that organisms at lower trophic levels also may accumulate high levels of OCPs and consequently can be a health concern to humans and the ecosystem. Further research/monitoring efforts are desirable to identify new input sources of DDTs partially responsible for the elevated DDT concentrations in seafood products. Amid the highly species-specific bioaccumulation of OCPs, additional research efforts also should focus on the species that have high bioaccumulation potentials, such as *P. uiridis*, *S. constricta*, and *C. gigas*. The present study also shows that, in addition to DDTs and HCHs, other OCPs also may pose lifetime cancer risk (Table 3), especially to residents of coastal regions who often consume more seafood products than those living inland. Therefore, it is worthwhile to continue tracing their occurrence in the environment and biota for the purpose of protecting public health.

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