Effect of Preparation and Cooking on Contaminant Distributions in Crustaceans: PCBs in Blue Crab

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Changes in the distribution of PCBs in blue crab caused by boiling or steaming were quantitated on the basis of the best estimate of residue in each crab's tissue. The relationships between total cooking losses and cooking losses of claw and body muscle were developed ($R^2 > 0.95$). The relationship of parts per million of PCBs in raw body muscle (0.349 ppm) to that of raw claw (0.227 ppm) ($N = 13$) was determined ($R^2 = 0.87$). Frozen crabs were boiled with and without the hepatopancreas and steamed without the hepatopancreas; all cooking procedures reduced PCBs by >20%. There were no significant differences in claw cooking losses (23.3–25.4% losses). Removing the hepatopancreas increased PCB loss from body muscle of boiled crab (36.4% loss when boiled with hepatopancreas removed, 31.0% with hepatopancreas). When the hepatopancreas was removed, boiling resulted in greater PCB losses from body muscle than steaming (36.4 vs 33.9%). Cooking water contained 80% of the PCBs lost from the crabs.

INTRODUCTION

Polychlorinated biphenyls (PCBS) are widespread, stable, environmental contaminants that pose a threat to humans due to possible biological harmful effects. In the United States, PCBs were sold as Aroclor compounds with the last two digits representing the percentage of chlorine. While there is no clear-cut evidence that low levels of PCBs in humans cause specific health effects, results from enzyme induction and animal toxicity studies indicate that exposure to PCBs should be minimized (Cordle et al., 1982).

Because these neutral organic chemicals resist chemical and biological breakdown, they enter the food chain, accumulating especially in the lipid tissues of organisms, concentrating as they pass from one trophic level to the next. Aquatic environments, in particular enclosed lakes, are particularly susceptible to this because of the airborne movement of PCBs and deposition into water. Highly industrialized and populated coastal states often have significant levels of chemical pollutants in the sediments of their bays and coastal waters, which are important commercial sources of crustaceans such as blue crabs.

Many states have issued advisories concerning consumption of certain species of fish and shellfish to limit human exposure to potential harmful effects from consumption of PCBs. Most people consume seafood from a wide range of locations, and therefore the potential danger from consuming one contaminant in harmful levels is reduced. The sport or commercial fishermen and their families who consume large amounts of fish or shellfish from one location are at a greater risk than the general population, if this location is one with significant contamination.

The biological assimilation of PCBs and general values of PCB levels in crab have been reported by several researchers. Young (1982) summarized that levels of PCBs in crab were 0.19 mg/kg, calculated on the basis of Aroclor 1254, in organisms taken off Palos Verdes Peninsula, CA. Comprehensive monitoring of PCB levels found in the inner New York bight were shown by Reid et al. (1982) to be 0.09–0.11 ppm in rock crab harvested off the northern New Jersey coastal area. PCB levels found were not consistently related to the levels in sediments or to areas of contamination input. More recently, Wenner (1986) reported that sand crabs collected from Santa Monica Bay, Oceanside, and San Clemente, CA, sites had levels of 0.03–0.38 ppm of PCBs. Rock crab caught off the northeastern U.S. coast were found by Farrington and Boehm (1987) to have 0.043–0.15 ppm of PCBs. Hauge et al. (1990) reported crabs from the northeastern waters of New Jersey to have mean PCB levels of 0.33 ppm in muscle (maximum muscle PCBs were 0.40 ppm, $N = 5$) and 5.38 ppm in the hepatopancreas (maximum hepatopancreas PCBs were 8.27 ppm, $N = 5$). On the basis of 18 crabs, these same authors reported PCBs in combined muscle and hepatopancreas to average 1.84 ppm (maximum PCBs were 3.86 ppm).

Preparation and cooking techniques have resulted in loss of PCBs and other organic toxicants from certain species of fish (Zabik et al., 1978, 1979; Ambruster et al., 1988; Sanders and Hayes, 1988). Trotter et al. (1989) reported PCBs were an average 27% lower after blue fish were cooked and the oil drippings and skin were discarded. In a study by Zabik (1974) that evaluated PCB levels in chicken, stewing or pressure cooking chicken pieces reduced PCBs by 50–70%, while half of the organochlorine residue transferred to the cooking media. This may result in residues contaminating foods such as rice or pasta cooked in this type of broth (Funk et al., 1972).

The primary purpose of this study was to quantitate the distribution of PCBs in raw blue crab claw and body muscle and to quantitate changes in PCBs during boiling or steaming. Since blue crabs are cooked whole, the potential for residue transfer from highly contaminated organs such as the hepatopancreas (Hauge et al., 1990) to muscle exists. The second objective of this study was to make a comparison of PCBs in the claw and body muscle from crabs boiled with and without the hepatopancreas removed. It was hoped that data generated from this study could be used to formulate guidelines to consumers for

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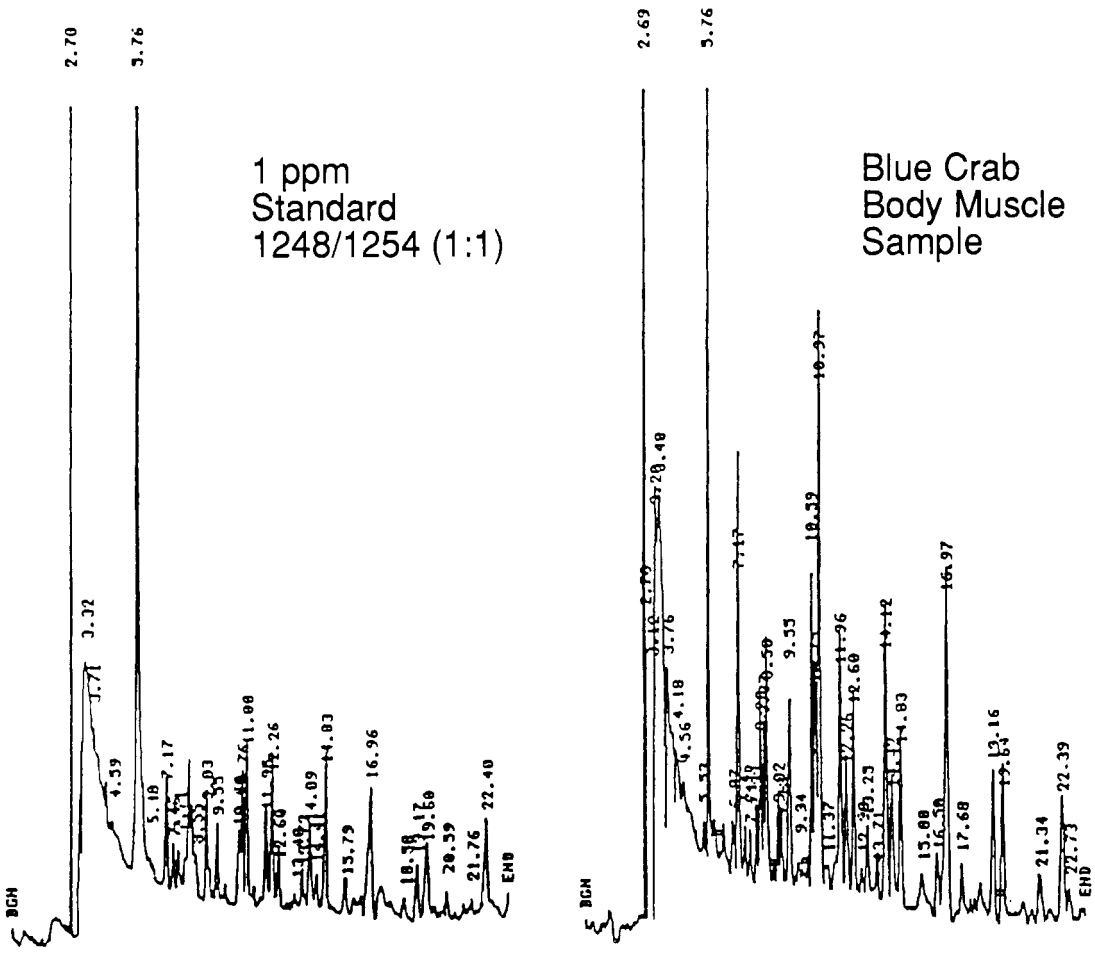

Figure 1. Sample chromatograms of PCB standard and crab body muscle.

preparation/cooking of blue crab to maximize PCB reduction.

PROJECT DESIGN AND METHODS

Materials. All solvents and chemicals were of analytical grade. All glassware and cooking equipment were washed and rinsed with distilled water and then acetone and hexane. Glassware also was baked at 177 °C overnight before use. Crabs for the cooking loss study were shipped live from a commercial fishery in Boston, MA, and then blast frozen at −29 °C. Crabs for the PCB ratio and the cooking studies were provided frozen by P. Hauge, New Jersey Department of Environmental Protection and Energy, Division of Science and Research. The crabs were collected in an area of northern New Jersey where no commercial crabbing takes place (Berrys Creek, tributary of the Hackensack River).

PCB Analysis. Extraction and cleanup of samples for PCB analysis were performed using the procedure outlined by Ribick et al. (1982) as modified by Giesy et al. (1986). An internal standard, 0.50 μg of 2,4,6-trichlorobiphenyl (no. 30), was added to a 2–10-g sample, depending upon the available muscle sample size. To dry the muscle, an amount of anhydrous Na_2SO_4 (stored at 130 °C) equal to 4 times the sample weight was mixed into the sample. The resultant dry powder was extracted with 200 mL of dichloromethane at a flow rate of 3–5 mL/min in a 2 cm i.d. glass column. The volume of solvent was reduced under vacuum with a Model 110 Rotovapor at 31 °C, and the volume was adjusted to 8.0 mL with a 1:1 (v/v) mixture of hexane and dichloromethane.

Lipids were removed from the extract by gel permeation chromatography (GPC). Five milliliters of the extract was loaded quantitatively onto an automated GPC apparatus equipped with a column packed with 60 g of SX-3 Bio-Beads. The 1:1 hexane and dichloromethane mobile phase was pumped through the column at 5 mL/min. A 140-mL fraction was collected after a 170-mL dump cycle. The volume of solvent of the collected fraction was reduced using a Zymark TurboVap evaporator at 31 °C. The sample was quantitatively transferred with hexane to an acid/silica gel column. This 1.0-cm column was prepared with 1.0 g of Na_2SO_4, 5.0 g of silica gel, 1 g of H_2SO_4 (40% w/w basis) treated silica gel, and 1 g of Na_2SO_4. After the column was rinsed with 20 mL of hexane, the sample was quantitatively transferred in hexane to the column. The sample collection was begun after the 5 mL of 0.5% toluene in hexane and was added to the column. An additional 45 mL of the toluene/hexane solvent was added to elute the sample. To the eluant was added 0.5 mL of isooctane, and its volume was then reduced. The sample was quantitatively transferred to 2-mL sample vials with volume reduction via a gentle stream of purified nitrogen after each transfer and rinse. The final volume was 0.5 mL.

Concentrations of total PCBs were determined by gas chromatography (GC) with electron capture detection (GC-ECD). A Perkin-Elmer Model 8500 GC was equipped with a ^{63}Ni detector operated at 340 °C and a split injector at 235 °C. A DB-5 column, 30 m × 0.24 mm i.d., with 0.25-μm film thickness was used with helium, carrier gas, flow rate of 1 mL/min, and nitrogen, makeup gas, at a flow rate of 20 mL/min. The Perkin-Elmer oven was held at 215 °C for a 25-min run time.

Data Calculations, Assumptions, and Equations. PCB levels were calculated from total area of all peaks from 7.0 to 22.5 min minus the area of the DDE peak using the linear equation of the PCB standards and were corrected for recovery of the internal standard (2,4,6-trichlorobiphenyl no. 30) using area integration performed by the Perkin-Elmer software. The PCB congener pattern from the crab best correlated with a 1:1 ratio of Aroclor 1248 and 1254 (Figure 1).

A 50-μg sample of 2,4,6-trichlorobiphenyl (no. 30) was added to each sample as an internal standard. Recoveries of the internal standard were as follows: ratio study, 85.77 ± 5.79%; boiled crab, 77.63 ± 5.54%; steamed crab, 79.40 ± 3.16%.

The detection limit was determined to be 0.01 ppm of a 1:1 mixture of Aroclor 1248/1254 by analyzing the mixture as

compared with hexane using five replications. The mean of the peak height generated by the 0.01 ppm standard was greater than 2.5 times that of the noise. The quantitation limit was set at 5 times the detection limit. All blanks contained levels of PCBs less than the method detection limit and thus were considered acceptable. The R^2 value for standard curves which were run with every set of gas chromatograph runs was always greater than 0.99. PCB standards included 0.01, 0.1, 1, and 10 ppm of Aroclor 1248/1254 (1:1 mixture).

Precision of analysis was determined by running 10% of the crab body muscle samples in duplicate. No claw samples were run in duplicate due to the small sample size. Variability in the duplicate samples based on the lower parts per million level in each pair averaged 2.01% with a standard deviation of 1.12 (range 0.76–4.35%, $N = 9$). PCBs were measured in the raw claw and raw body muscle for the ratio study. In addition, PCBs were quantitated in a raw claw, a cooked claw, and cooked body muscle for the cooking studies as well as in the broth from the boiling study only. PCBs in the raw body muscle of the cooked crab were estimated from the PCBs in the claw using the ratio of PCBs in the raw body muscle/claw relationship. PCBs were expressed as parts per million of wet muscle, parts per million of dry weight as well as micrograms in the raw muscle, cooked muscle, and broth (boiling study). The latter data were used to calculate percentage losses.

Basic Assumption.

estimated ppm of PCBs raw right claw = ppm of PCBs raw left claw (1)

Calculations.

estimated ppm of PCBs in raw body muscle = (ppm of PCBs in raw claw) × (the relationship of ppm of PCBs in raw body muscle to ppm of PCBs in raw claw) (2)

estimated raw claw weight (g) = (cooked claw weight (g)) × (the relationship of claw cooking loss to total cooking loss) (3)

estimated raw body muscle weight (g) = (cooked body muscle weight) × (the relationship of body muscle cooking loss to total cooking loss) (4)

μg of PCBs in raw claw = (ppm of PCBs in raw claw) × (estimated raw claw weight) (5)

μg of PCBs in cooked claw = (ppm of PCBs in cooked claw) × (cooked claw weight) (6)

μg of PCBs in raw body muscle = (estimated ppm of PCBs in raw body muscle) × (estimated raw body muscle weight) (7)

μg of PCBs in cooked body muscle = (ppm of PCBs in cooked body muscle) × (cooked body muscle weight) (8)

μg of PCBs lost = (μg of PCBs in raw body muscle + 2 [μg of PCBs in raw claw]) − (μg of PCBs in body muscle + 2 [μg of PCBs in cooked claw]) (9)

μg of PCBs in broth = (ppm of PCBs in broth) × (weight of broth) (10)

Patterns of Weight Loss Due to Cooking. Crustaceans pose a particular challenge for quantitation of residue reduction because they are typically cooked whole from the live state. Since individual variation from crustacean to crustacean may be greater than the residue loss or transfer during cooking, quantitating loss must be based on the best estimate of residues in the individual crab's tissues. For the basic study design, the left claw of the blue crab was removed prior to cooking and was used to determine raw muscle PCB data. The remainder of the crab was cooked, and the right claw muscle and the muscle from the body cavity were used to obtain data for losses due to changes in weight and PCB level. In this study, the term whole crab will refer to the crabs which were left whole with the exception of removal of the left claw, unless stated otherwise.

The initial phase of this study involved determination of cooking weight loss patterns. Fourteen commercial male blue crabs of similar weight (175–237 g) were paired according to weight. In each pair one crab was used to obtain raw tissue data, while the other was used to obtain the cooked crab data for the following: whole body total weight loss, hepatopancreas, claw muscle, and body muscle. To use the same procedure that was going to be used in subsequent cooking studies, one claw was removed from each crab to be cooked. These crabs weighed an average of 185 g (range 155–214 g) and were cooked 30 min/lb (average cooking time, 12 min 30 s; range 10 min 15 s to 14 min 10 s) in 6 L of deionized boiling water. Water to crab ratio (w/w) averaged 32.4 (range 28.0–38.7). The crab then was cooled on ice for 10 min, drained for 5 min, opened, wrapped in gauze, drained for an additional 5 min, and reweighed. Details of the dissection procedure and handling of the crab tissue are given by Zabik et al. (1991). Percentage changes in weight with cooking were calculated.

Development of PCB Ratios. For the left claw muscle to be used to estimate the raw PCBs in the right claw muscle and the body muscle, a PCB ratio study (body muscle/left claw) was conducted using male crabs collected from a noncommercial area ($N = 13$). It was assumed that the raw left claw muscle PCB level could be used to estimate that of the right raw claw muscle. The ratio of PCBs in the body muscle to the left claw muscle was then determined to obtain a relationship equation to estimate the raw body muscle PCB values for the PCB cooking study.

Boiling Whole Crab with the Hepatopancreas Retained. Nine frozen noncommercial male blue crabs were boiled whole after the raw left claw was removed and retained for determination of PCBs in the raw muscle. Crab size was recorded before the crab was cooked for 30 min/lb on the basis of the weight without the left claw as described by Zabik et al. (1991). The average crab weight was 141 g (range 110–172 g); the crabs were cooked an average of 9 min 19 s (range 7 min 7 s to 11 in 22 s). The ratio of water to crab (w/w) averaged 43.2 (range 34.8–54.3). Total PCBs in the remaining cooking water were determined after analysis of the crab tissue was completed. For this, approximately 100 mL of cooking water was frozen at −25 °C in glass jars and stored until analyzed.

Boiling Crab with the Hepatopancreas Removed. The hepatopancreases of eight frozen male noncommercial blue crabs were removed prior to boiling for this portion of the study as described by Zabik et al. (1991). Boiling and handling of the raw left claw, cooked body muscle, right cooked claw muscle, and cooking media were treated as previously described. Crab weight averaged 128 g (range 8 min 28 s) (range 5 min 48 s to 11 min 17 s). The ratio of water to crab (w/w) averaged 50 (range 35.1–68.3).

Steaming Crab with the Hepatopancreas Removed. Ten additional male blue crabs were obtained from the same noncommercial area as previously described and were cooked by steaming. The procedure used to prepare the crab for the steaming study in which the crab hepatopancreas was removed was the same as that used for boiling the blue crab. A slight variation in the procedure included bringing 2 L of deionized water to a rolling boil and placing the prepared blue crab on a wire rack suspended a few centimeters above the water level. Steamed crabs weighed an average of 99 g (range 77–149 g) and were cooked an average of 6 min 32 s (range 5 min 5 s to 9 min 50 s). The water to crab ratio (w/w) was 21 (range 13.4–26.0).

Statistics. Analysis of variance and Tukey's honestly significant difference test as outlined by Gill (1978) were conducted. The relationships between total cooking losses and cooking losses of the body muscle and claw as well as the relationship of the parts per million of PCBs in the body muscle to parts per million of PCBs in the claw were determined using PlotIT (Eisensmith, 1985).

Table I. Percent Cooking Weight Losses in Whole Body, Hepatopancreas, Claws, and Body Muscle between Pairs of Blue Crabs of Similar Weight[a]

tissue	cooking loss,[b] %	tissue	cooking loss,[b] %
total crab	25.1 ± 4.4	claw muscle	38.1 ± 12.8
hepatopancreas	86.4 ± 4.7	body muscle	24.4 ± 7.5

[a] Frozen crabs allowed to thaw before preparation. [b] Mean and standard deviation, $N = 7$.

RESULTS AND DISCUSSION

Establishment of Patterns of Weight Loss Due to Cooking among Individual Tissues of Blue Crab. Mean weight for seven blue crab pairs used to determine cooking losses was 211.9 g (range 175.5–248.1 g). The weight of the left and right claws of a single blue crab, as well as the left or right claws of the blue crabs paired by weight and size, differed enough to result in large variations for claw cooking loss data. The data in Table I show a standard deviation of ≥12% for the cooking loss data for the claw when raw and cooked claw weight of the paired crabs were compared. The ability of blue crabs to regenerate lost claws results in crabs which may have one small claw that is in the process of growing and one full-size claw. This could account for these large claw size variations. A large weight loss of the hepatopancreas (86.36 ± 4.74%) resulted from boiling the crab. Cooking weight losses of the body muscle were 24.44 ± 7.51% and were similar to total losses (25.05 ± 4.39%). The cooking weight loss of total crab and body muscle as well as claw cooking weight loss results presented in Table I were used to determine the following relationships (Eisensmith, 1985):

$$\%\ \text{total cooking loss} = 0.976 \times (\%\ \text{body muscle cooking losses}) \qquad R^2 = 0.955 \quad (11)$$

$$\%\ \text{total cooking loss} = 0.620 \times (\%\ \text{claw cooking losses}) \qquad R^2 = 0.951 \quad (12)$$

Development of PCB Ratios. The size of the crabs used to determine the ratio of PCBs in the raw tissues averaged 14.0 cm (range 12.2–16.3 cm). Mean weight was 167.5 g (range 110.2–246.5 g).

Recoveries of the internal standard in the PCB ratio study averaged 85.77% (range 73.20–97.22%). The parts per million expressed on either a wet or dry weight basis showed expected biological variability (Table II), yet the ratio of PCBs in body muscle to PCBs in the claw muscle was much more consistent. The average ratio for PCBs expressed on a wet weight basis was 1.54 ± 0.30 and on a dry weight basis was 1.57 ± 0.35. This points out that the body muscle consistently carries a greater PCB burden than the claw muscle. Since the ratio of PCBs expressed on a solids basis showed greater variability than the ratio expressed on a wet weight basis, only parts per million of PCBs expressed on a wet weight basis was calculated for the subsequent cooking studies. The relationship for PCBs expressed as parts per million wet weight basis in the body muscle to that in the claw was derived using PlotIT (Eisensmith, 1985) with an R^2 of 0.866:

$$\text{ppm of PCBs in body muscle} = 1.604 \times (\text{ppm of PCBs in claw}) \quad (13)$$

Cooking Studies—Levels of PCBs in Blue Crab Boiled Whole and Boiled or Steamed with the Hepatopancreas Removed Prior to Cooking. While the blue crabs which were cooked whole in the boiling study had greater average weights (159.9 ± 22.3 g) and sizes (13.6 ± 0.9 cm) than the two groups of crabs used for the studies in which crabs were boiled (142.4 ± 39.5 g; 13.1 ± 1.2 cm) or steamed (138.2 ± 32.5 g; 13.1 ± 1.3 cm) with the hepatopancreas removed, values did not differ by more than 1 standard deviation. The large standard deviations found for the crab weights are typical of those found for biological specimens.

For all three cooking studies, the left claw of each crab was removed and the left claw muscle analyzed for PCBs. These results were used to estimate PCB levels in raw tissues from the right claw by assuming that the PCB levels are equal to that of the left claw (eqs 1 and 2). Also, the PCB levels in the raw body muscle were estimated by inserting the relationship in eq 13 into eq 2. Raw tissue weights for the right claw and body muscle were estimated from the cooked tissue weights (eqs 3 and 4), using the cooking weight loss factors developed from eqs 11 and 12.

The results of the PCB analyses for the raw left claw, the cooked right claw, and the cooked body muscle are given in Table III. These values are expressed as parts per million of wet tissue. The estimated values for the parts per million of PCBs in the raw body muscle calculated using eqs 2 and 13 are also given in Table III. These values ranged from an average of 0.269 ppm for the crabs that were boiled with the hepatopancreas to 0.434 for the crabs that were steamed without the hepatopancreas. These are similar to the parts per million of PCBs found for the body muscle of blue crabs quantitated for the ratio study (Table II). The latter blue crabs were harvested from the same area at the same time (boiling studies) or harvested from the same area at a later time (steaming study).

Hauge et al. (1990) had reported that in 1986–1987 the body muscle of blue crabs from New Jersey had an average of 0.33 ppm, with the highest value in the five samples analyzed being 0.40 ppm. The average parts per million level in the raw body muscle of the crabs which were boiled either with or without the hepatopancreas was estimated to be slightly less than this value, i.e., 0.31 or 0.27 ppm, respectively. For these crabs, the raw claws had been analyzed and contained mean PCB values of 0.19 and 0.17 ppm, respectively. The raw claw PCB values from the second lot of crab obtained from New Jersey had a mean of 0.27 ppm so that the estimated PCB value of the raw body muscle was 0.43 ppm, which is higher than the highest value reported by Hauge et al. (1990). Three of the 13 crabs analyzed for the ratio study (Table II) also had analyzed PCB values for body muscle greater than the maximum values reported earlier (Hauge et al., 1990), even though the mean value for parts per million of PCBs in the body muscle was similar.

During the boiling process, 86% of the hepatopancreas is lost when the crab is boiled whole (Table I). High levels of PCBs in the hepatopancreas of the blue crab have been found (Hauge et al., 1990), which are more than an order of magnitude higher than levels in crab muscle for crabs from northeastern New Jersey. The parts per million level of PCBs in the cooked body muscle of the crab boiled with the hepatopancreas was slightly greater than the parts per million level of PCBs in the cooked body muscle of crabs boiled after the hepatopancreas had been removed. Therefore, it is possible that during boiling of a crab with the hepatopancreas intact some of the PCBs are redistributed throughout the body muscle in addition to any loss into the cooking medium.

To calculate loss of PCBs during cooking by boiling with or without the hepatopancreas or steaming without the hepatopancreas, micrograms of PCBs in each raw and cooked tissue were calculated using eqs 5–8. These values also are included in Table III. The percentage PCB loss

Table II. PCB Content[a] in Raw Left Claw (LC) and Body Muscle (BM) of Blue Crabs Used for the Ratio Study (BM/LC)

		ppm		ratio	
crab	tissue	wet wt	dry wt	wet wt	dry wt
1	BM	0.192	0.941	1.78	1.89
	BM	0.184	0.903	1.71	1.82
	LC	0.108	0.497		
2	BM	0.280	1.776	1.33	1.24
	LC	0.210	1.432		
3	BM	0.237	1.669	1.44	1.27
	LC	0.165	1.315		
4	BM	0.145	0.743	1.96	2.11
	LC	0.074	0.352		
5	BM	0.319	1.526	1.34	1.53
	LC	0.239	0.997		
6	BM	0.445	2.350	1.88	1.80
	LC	0.237	0.302		
7	BM	0.129	0.708	1.28	1.43
	LC	0.101	0.495		
8	BM	0.617	3.341	2.02	2.17
	LC	0.306	1.538		
9	BM	0.247	1.411	1.42	1.55
	LC	0.174	0.909		
10	BM	0.223	1.169	1.45	1.71
	LC	0.154	0.685		
11	BM	0.367	1.565	1.22	1.09
	LC	0.302	1.441		
12	BM	0.379	1.973	1.22	1.14
	BM	0.370	1.927	1.19	1.11
	LC	0.312	1.730		
13	BM	1.095	4.911	1.92	1.64
	LC	0.570	2.986		
av BM PCBs		0.349 ± 0.243	1.794 ± 1.100		
av LC PCBs		0.227 ± 0.130	1.206 ± 0.69		
av wet wt ratio				1.54 ± 0.30	
av dry wt ratio					1.57 ± 0.35

[a] Quantitated as 1:1 1248/1254.

Table III. Effect of Cooking on PCB Levels in the Claw and Body Muscle of Whole Blue Crab

		PCBs				
		ppm wet tissue		μg per muscle		
muscle tissue	N	raw	cooked	raw	cooked	μg % loss[a,b]
		Boiled with Hepatopancreas				
claw	8	0.192 ± 0.065	0.222 ± 0.065	1.70[c] ± 0.70	1.26[d] ± 0.45	24.98a ± 5.68
body muscle	8	0.307[e] ± 0.104	0.278 ± 0.098	7.10[f] ± 4.00	4.87[g] ± 2.63	31.02b ± 2.68
whole (2 × claw) + body muscle	8					29.03e ± 2.97
		Boiled without Hepatopancreas				
claw	7	0.168 ± 0.074	0.187 ± 0.080	1.26 ± 0.49	0.94 ± 0.38	25.38a ± 2.07
body muscle	7	0.269 ± 0.119	0.218 ± 0.090	6.13 ± 2.95	3.91 ± 1.89	36.38c ± 2.07
whole	7					33.10f ± 1.78
		Steamed without Hepatopancreas				
claw	10	0.270 ± 0.039	0.260 ± 0.044	1.27 ± 0.23	0.98 ± 0.18	23.25a ± 1.64
body muscle	10	0.434 ± 0.063	0.336 ± 0.060	5.89 ± 0.88	3.89 ± 0.60	33.88d ± 3.10
whole	10					30.63e ± 2.20

[a] Averages with different letters are significantly different, $p < 0.05$, for comparison of cooking methods for a single tissue, i.e., claw, body muscle, or whole (15). [b] Values for whole crab calculated using eq 9. [c] Calculated using eq 5 (using 1, 3, 12). [d] Calculated using eq 6. [e] Calculated using eq 2 (using 13). [f] Calculated using eq 7 (using 2, 4, 11, 13). [g] Calculated using eq 8.

in the whole crab was based on the change in micrograms of PCBs in two claws plus that of the body muscle, which was calculated using eq 9 (Table III). Calculating PCB losses based on micrograms in the raw and cooked sample is more accurate than just comparing the level of PCBs expressed as parts per million wet or dry tissue since cooking losses and, particularly, losses of moisture and fat are not consistant for various cooking methods.

Analyses of variance for the effect of cooking method on the loss of PCBs from the claw, from the body muscle, and from the whole crab established significant differences for losses from the body muscle and whole crab only. Losses for the claw ranged from an average of 23.25% for the crabs that were steamed without the hepatopancreas to 25.38% for the crabs that were boiled without the hepatopancreas. This shows that more than one-fifth of the PCBs in the raw crab were lost by all cooking methods.

Crabs boiled with the hepatopancreas intact lost 31.0% of the PCBs in the body muscle. Removing the hepatopancreas before cooking resulted in significantly greater cooking losses (Table III), with boiling producing significantly greater ($p < 0.05$) losses (36.4%) than steaming (33.9%). The same significant differences were found for the comparison of the PCB losses from the whole crab, although the percentages lost were slightly lower than for the body muscle. This could be due to the significantly ($p < 0.05$) higher cooking losses from crabs which were boiled (19.37 ± 8.61%) as compared to those which were

Table IV. Mean and Standard Deviation for PCB Content of Cooking Medium for Crabs Boiled Whole and after the Hepatopancreas Was Removed[a]

boiling condition	total PCBs lost from crab, μg	PCBs recovered in broth, μg	% loss recovered in broth
with hepatopancreas	2.68 ± 1.64	2.12 ± 1.34	78.2 ■ 2.5
hepatopancreas removed	2.53 ■ 1.18	2.06 ± 0.99	80.9 ■ 2.0

[a] Equations 9 and 10 were used to calculate micrograms of PCBs lost and micrograms of PCBs recovered in the broth.

steamed (12.21 ± 4.97%). Cooking losses from the crabs which were boiled intact were 21.24 ± 7.67% and did not differ significantly ($p > 0.05$) from those of crabs boiled with the hepatopancreas removed. Nevertheless, cooking reduced the PCBs in the body muscle of the blue crab by more than 30% so that this loss should be taken into account in evaluating the potential hazard of ingesting blue crab from any contaminated waters.

The greater percentage of PCB losses in the body muscle of crabs that were boiled after removal of the hepatopancreas, as compared with losses in crabs that were steamed after removal of the hepatopancreas, may be due to the contact of the crabs with the large amount of boiling water (6 L). There is less opportunity for loss of PCBs from the body muscle into the steaming cooking water.

The percentage loss of PCBs found for the current study is similar to that reported in other studies. Roasting ciscowets from Lake Superior resulted in an average loss of 34% PCBs; microwaving these fish gave a 26% loss, while broiling gave a 53% average loss (Zabik et al., 1979). In contrast to the loss found for the high-fat ciscowets, minimal losses of PCBs were found from carp harvested from Saginaw Bay, Lake Huron (Zabik et al., 1982). Somewhat higher losses of PCBs have been found for stewing or pressure cooking of chickens (Zabik, 1974) as well as roating of turkey rolls (Zabik, 1990), but both of these studies used considerably longer cooking times than is appropriate for cooking crab.

Levels of PCBs in Cooking Medium. The PCB contents of the cooking medium from crabs boiled whole and with the hepatopancreas removed prior to cooking were 0.039 ± 0.024 and 0.031 ± 0.015 ppm, respectively. Analysis of variance showed no difference in total average mass of micrograms of PCB lost for the crabs (2.68 ± 1.64 and 2.53 ± 1.18 μg, respectively) (Table IV). Also, no differences in the total mass of PCBs in the cooking broth occurred for crabs boiled whole and with the hepatopancreas removed (2.12 ± 1.34 and 2.06 ± 0.99 μg, respectively). High recoveries of the PCBs lost from the cooked crab were found in the broth, 78.2 ± 2.5 and 80.9 ± 2.0%, for crabs cooked whole and with the hepatopancreas removed, respectively. It is possible that some part of the PCBs recovered from the cooking medium is due to the PCBs in the crab from portions which were not analyzed (shell, body fluids, body organs, etc.).

Application of Data to Risk Assessment. Cordle and co-workers (Cordle et al., 1982) discussed data related to the risk assessment of ingestion of PCBs and arguments for establishment of either a 2 or 1 ppm tolerance for PCBs in fish and shellfish. Clearly, any tolerance established or advisories developed should consider the level of residue in the food as consumed. None of the raw crab muscle analyzed exceeded the current tolerance of 2 ppm. Moreover, only 1 of the 38 crabs analyzed had levels of PCBs in the raw tissues which exceeded 1 ppm (body muscle of crab 13 in Table II).

The EPA cites PCBs as classification B2, probable human carcinogen, in its Integrated Risk Information System (IRIS) which was last updated in 1991. The basis of this listing is hepatocellular carcinomas in three strains of rats and two strains of mice and inadequate, yet suggestive, evidence of excess risk of liver cancer in humans by ingestion and inhalation or dermal contact.

As one method to assess the risk of ingesting crab from this waterway, we back-calculated the average PCB concentration in cooked crabs that would result in a cancer risk of 10^{-6}. The EPA generally regards carcinogenic risk to be of concern at levels greater than the 10^{-4}–10^{-6} range. Using the exposure and risk assessment equations developed for the EPA (1989) Superfund program, the following relationships can be calculated:

$$\text{carcinogenic risk} = (\text{exposure intake}) \times (\text{oral slope factor})$$

$$\text{exposure intake} = \text{risk}/\text{oral slope factor}$$

If we use a conservative risk of 10^{-6} and an oral slope factor of 7.7 mg kg^{-1} day^{-1} – 1 which is obtained from the 1991 IRIS of EPA, the intake can be calculated as

$$\text{intake} = 1.3 \times 10^{-7} \text{ mg kg}^{-1} \text{ day}^{-1} \text{ PCBs}$$

The EPA (1989) relates intake to risk as

$$\text{intake (mg kg}^{-1}\text{ day}^{-1}) = (\text{CF} \times \text{IR} \times \text{FI} \times \text{EF} \times \text{ED})/(\text{BW} \times \text{AT})$$

where CF is the contaminant concentration in fish (mg/kg), IR is the ingestion rate (kg/meal), FI is the fraction ingested from contaminated source (unitless), EF is the exposure frequency (meals/year), ED is the exposure duration (years), BW is the body weight (kg), and AT is the averaging time (period over which exposure is averaged, days). Then CF can be calculated as

$$\text{CF} = (\text{intake} \times \text{BW} \times \text{AT})/(\text{IR} \times \text{FI} \times \text{EF} \times \text{ED})$$

According to Javitz (1980), the mean consumption of crab other than king is 0.254 g/day. If we use this value for the IR, an intake value of 1.3×10^{-7}, a 70-kg man for an average body weight for BW, a 70-year lifetime for carcinogenic effect × 365 days per year for AT, a value of 1.0 for FI (assumes all crabs consumed come from contaminated sources), an EF of 365 days, and an ED of 9 years [national median time (50th percentile) at one residence (EPA, 1989)], the CF would be 0.28 mg/kg PCBs or 0.28 ppm. Only the average parts per million level in the cooked body muscle of steamed crabs exceeds this value. Considering the contamination level in the body muscle of the steamed crabs, the years of exposure could be about 7.5.

One may wish to use an ED of 30 years [national upper bound time (90th percentile in one residence)], which could be considered as a reasonable maximum exposure, or 70 years, which is a conventional lifetime estimate. Moreover, an EF of 365 days is approximately 7.6 times the average fish/shellfish consumption pattern of 48 days per year (Javitz, 1980).

Since high percentages of the PCBs lost during the boiling of crab are found in the cooking water, governmental agencies may wish to establish advisories for limited reuse of cooking water. Disposal issues related to this cooking water could also be addressed.

Conclusion and Recommendations. While an effort was made in this study to obtain blue crabs from an area thought to be highly contaminated with PCBs, levels found in the edible portions of the blue crab (body muscle and claw) were all below the current level of tolerance.

However, on the basis of the results of this study, recommendations for consumers interested in reducing PCB ingestion could be made. Cooking the blue crab by boiling or steaming always reduced the PCB content of the crab tissue by greater than 20%. A preparation technique involving removal of the hepatopancreas from the top and bottom of the crab interior increased PCB loss for the body muscle. Since this additional loss was small compared to the overall PCB loss from cooking, it would only be necessary when the crabs were thought to contain very high residue levels. Those who consume large numbers of blue crab may also benefit by the further reduction in PCBs by removal of the hepatopancreas prior to cooking.

The medium used for cooking blue crabs should be discarded and not be used for preparing other foods. While cooking does reduce residues, this advantage is lost if the cooking broth is further used to prepare soups, sauces, etc. The actual average parts per million level of the cooking medium was found to be low (0.039 and 0.031 ppm, whole and without the hepatopancreas), but any further concentration of the broth or boiling of many crabs in the same volume of water could lead to potential problems.

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