

Assessing Fisheries as Vectors for Toxic Materials from the Environment to Humans.

An assessment of potential health risks posed by shellfish collected in estuarine waters near Pensacola, Florida.

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ABSTRACT

As part of an environmental health study of northwest Florida, we conducted an initial screening level assessment of contaminants in blue crabs (*Callinectes sapidus*) and oysters (*Crassostrea virginica*) collected in bays and bayous in the Pensacola, FL area. Tissue samples were analyzed for mercury, arsenic, cadmium, chromium, copper, lead, nickel, selenium, tin, zinc, 17 dioxin/furan compounds, and 12 dioxin-like PCB congeners (PCB-77, PCB-81, PCB-105, PCB-114, PCB-118, PCB-123, PCB-126, PCB-156, PCB-157, PCB-167, PCB-169, and PCB-189). Contaminant levels were compared to Screening Values (SV) calculated using the U.S. EPA recommendations for establishing consumption advisories. Four different consumption rates were used in the derivation of the SVs.

We identified five chemicals of concern (dioxins/furans/PCBs, arsenic, mercury, cadmium, and zinc) in either crab muscle, crab hepatopancreas, total crab tissue, or oysters based

on exceedence of one or more SVs. We also assessed health risks (non-carcinogenic and carcinogenic) that may arise as a result of consumption of these shellfish species. Dioxins/PCBs accounted for 85-99%, 60-90%, 27-94%, and 53-99% of the total excess cancer risks for crab hepatopancreas, total edible crab tissue, crab muscle, and oysters, respectively. The relative contributions of dioxins/furans and dioxin-like PCBs to the TEQs and resultant risks varied with location, as evident from analysis of the crab hepatopancreas samples. Dioxins/furans were a greater contributor in samples from Bayou Chico and Perdido Bay, whereas PCBs were dominant in Bayou Grande and Western Escambia Bay. The locations that exceeded SVs and had the highest carcinogenic or non-carcinogenic health risks were generally located in urbanized waterbodies (Bayou Texar, Bayou Grande, and Bayou Chico) or downstream of known contaminated areas (Western Escambia Bay). Oysters collected from commercial oyster beds in Escambia and East Bays, and crabs collected from East, Blackwater and Perdido Bays generally had the lowest levels of contaminants. Despite accounting for only 15% of the total tissue, inclusion of hepatopancreas in a crab meal increased contamination to levels above many SVs, and therefore, direct or indirect consumption of hepatopancreas from crabs in the Pensacola Bay system should be discouraged. Further investigation is warranted to determine whether consumption advisories should be issued for shellfish from specific locations in the Pensacola Bay system.

Keywords: blue crabs, oysters, PCBs, dioxins, metals

INTRODUCTION

The U.S. Environmental Protection Agency reported that, for 2002, 32.9% of the nation's lake acreage, 15.3% of the total river miles, 100% of the Great Lakes and their connecting water bodies, and 71% of coastal waters, including 100% of the Gulf Coast were under consumption advisories for fish (U.S. EPA, 2003). Although 39 chemicals were responsible for the advisories, mercury, PCBs, chlordane, dioxins, and DDT accounted for the majority (96%) of consumption restrictions. These chemicals are bioaccumulated in the tissues of aquatic organisms at concentrations many times higher than concentrations in the water, and are passed up the food chain to fish where they may be concentrated to levels that cause physiological impairment in human consumers. Although a number of the monitored chemicals are no longer used or manufactured in the United States, studies have shown that they continue to accumulate in a variety of foods, including shellfish (Jensen and Bolger, 2001). For example, over 90% of human exposure to organochlorine compounds occurs through diet, primarily through seafood and meat (Smith and Gangolli, 2002). Segments of the human population with increased toxic exposure risk include consumers of commercially harvested seafood, recreational fishers, and citizens that rely on harvestable species for subsistence.

The Pensacola Bay region is located at the tip of the Florida Panhandle near the Florida-Alabama border. Although historically the area supported a rich and diverse ecology and productive fishery, the effects of many decades of point and nonpoint source pollution, habitat destruction, industrial activities, and development have impaired the health and productivity of the estuarine waters in the region (Thorpe et al., 1997). The area is home to a number of historical and potential contaminant sources including paper mills, a coal-burning power plant,

industrial complexes, military facilities, multiple Superfund sites, sewage treatment plant outfalls, storm water discharges, atmospheric deposition, septic tanks, golf courses and agriculture in the watershed. Significant quantities of fish and shellfish are harvested both commercially and recreationally in Northwest Florida. Although mercury levels have been routinely monitored by the State of Florida, especially for freshwater fisheries, screening of seafood for other contaminants within the state, especially along the Gulf of Mexico has been limited.

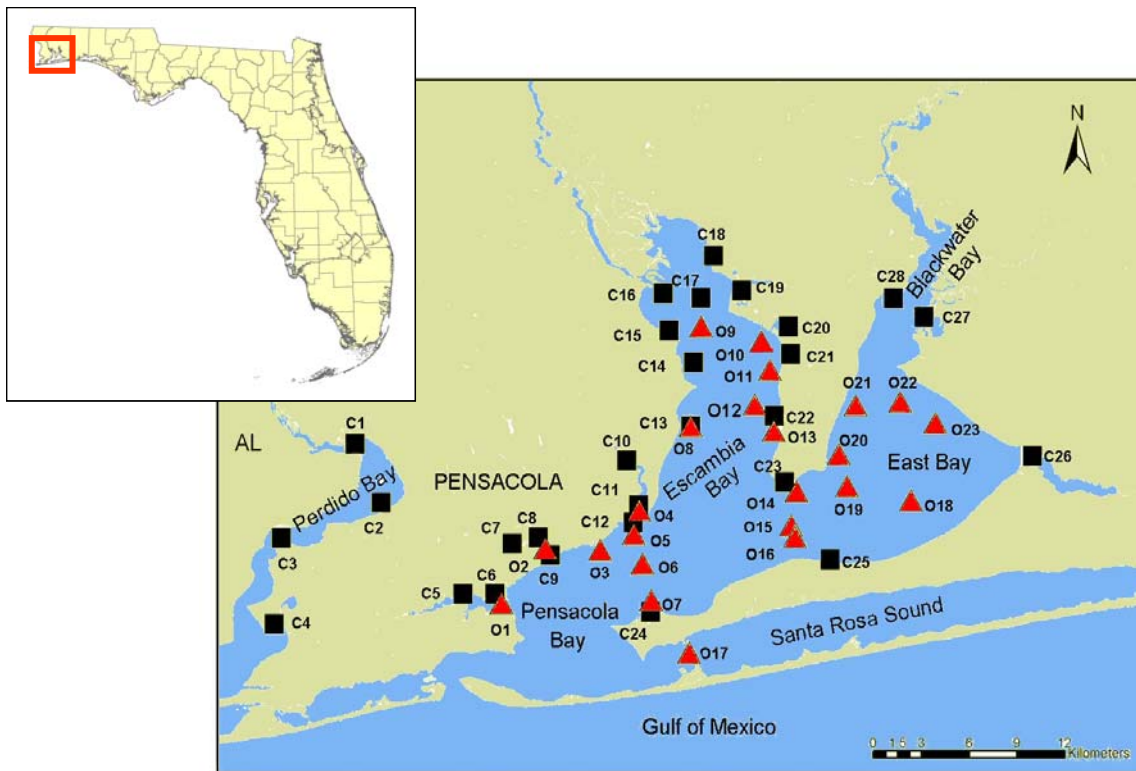


Figure 1. Pensacola Bay area blue crab and oyster sampling locations.

■ = crab sampling station, ▲ = oyster sampling station.

In the present study, we report the results of a screening survey of contaminants in eastern oyster (*Crassostrea virginica*) and blue crab (*Callinectes sapidus*) samples collected at multiple sites in the Pensacola Bay area. These two species are widely consumed along coastal regions of the United States. In 2003, commercial harvest levels for oysters and blue crabs in the two Florida counties (Escambia and Santa Rosa) that make up the Pensacola region totaled 9,140.5 and 60,956.6 kg, respectively (FWCC, 2004). Because they are sessile filter-feeders, oysters bioconcentrate chemicals from the water column and thus are indicative of the types and concentrations of contaminants in the surrounding water. In contrast, blue crabs spend much of their lives in and on the sediments, where they feed predominantly on other benthic organisms and thus are more indicative of sediment contamination levels. The objectives of this study were

to determine whether these shellfish in the Pensacola Bay region carry significant body burdens of toxic chemicals, identify chemicals of concern exceeding screening values, and identify “hotspot” locations of concern where elevated levels of contamination are found. Following the model established by the U.S. EPA in 2000, we analyzed the oyster and crab tissues for metals, including mercury, polychlorinated dibenzo-p-dioxins (PCDD)/ dibenzofurans (PCDF), and dioxin-like polychlorinated biphenyl (PCB) congeners, and used these data to characterize the degree of health risk associated with consuming oysters and crabs from the Pensacola Bay system.

METHODS

Study Area

The Pensacola Bay system and its smaller neighbor, Perdido Bay, are located at the far western tip of the Florida Panhandle, on the border with Alabama (Figure 1). The Pensacola Bay watershed drains 18,100 km² of Florida and southern Alabama, and is comprised of five major estuaries - Pensacola, Escambia, Blackwater and East Bays, and Santa Rosa Sound (Thorpe et al., 1997). The estuaries receive drainage from four major rivers (Escambia, Yellow, Blackwater and East Rivers) and many smaller tributaries and bayous. Perdido Bay is a small estuarine system that is fed by freshwater from the Perdido River and several smaller tributaries, and has a drainage area of 3,100 km² (U.S. EPA, 1999).

Sample Collection

Sampling locations were spread throughout the various estuaries and bayous draining into Pensacola Bay and on the Florida (east) side of Perdido Bay (Figure 1). Samples were collected from locations identified by biologists and local crabbers/oystermen. In general, based on the EPA guidance for a screening study, we analyzed one composite sample for each target organism at each location.

We collected oysters (*C. virginica*) by using tongs or by hand between March 2003 and July 2004 from 23 locations (Table 1, Figure 1). Sampling locations were classified into three groups - bridges that span the major bays (locations O5-7, O9, and O14-17), commercial oyster beds in Escambia and East Bays (locations O10-13 and O18-23, respectively), and urbanized waterbodies (locations O1-4). Oysters were not collected from Perdido Bay because harvestable populations could not be identified. Upon collection, oysters shell length was measured and the samples were placed on wet ice for transport to the laboratory. Oyster tissues were prepared by severing the adductor muscle, prying open the shell, and removing the soft tissue. A minimum of 10 oysters was composited for each location and shipped to the analytical facilities for homogenization and analyses.

Blue crabs (*C. sapidus*) were collected between June 2003 and June 2004 from 28 locations, using baited commercial crab traps deployed for 24-72 hours. Sampling locations were grouped as follows: Perdido Bay (locations C1-4), urbanized bayous (locations C5-12 and C24), western Escambia Bay (locations C13-17), eastern Escambia Bay (locations C18-22), and East/Blackwater Bay (locations C23 and C25-28). Between 10 and 15 traps were deployed at each location. Crabs over 10.2 cm in carapace width were selected and the sex of the collected crabs was determined. Although blue crabs are known to migrate within an estuary, male

migration areas are generally smaller than those of females (Ju and Harvey, 2002) and therefore, where possible, females were not included in the analyses. Samples were transported to the laboratory on wet ice. Tissue from seven to 15 crabs was composited for each location. Crab muscle and hepatopancreas were analyzed separately. Crabs were prepared by separating the carapace from the body and removing the hepatopancreas using forceps. All other internal organs were also removed and discarded. Edible muscle tissue, including claw meat, was extracted by splitting each thorax in half and processing through a cleaned compression device (Crab Master™). The extracted tissues were then homogenized using a stainless steel hand-held homogenizer and shipped to the analytical facilities for further homogenization and analyses.

Contaminant analysis

All tissue samples were analyzed for the following contaminants: mercury, arsenic (total), cadmium, chromium, copper, lead, nickel, selenium, tin, zinc, 17 dioxin/furan compounds, and 12 dioxin-like PCB congeners (PCB-77, PCB-81, PCB-105, PCB-114, PCB-118, PCB-123, PCB-126, PCB-156, PCB-157, PCB-167, PCB-169, and PCB-189). All metal and mercury analyses were performed by the Florida Department of Health, Bureau of Laboratory Services (Jacksonville, FL) using Inductively Coupled Plasma - Mass Spectrometry (ICPMS; EPA method SW 846-6020) and cold vapor atomic absorption (CVAA; EPA method 245.6), respectively. The majority of oyster samples was analyzed for dioxins/furans and PCBs by Triangle Laboratories, Inc. (Durham, NC). Crab samples and four oyster samples were analyzed for dioxins/furans and PCBs by Alta Analytical Perspectives (Wilmington, NC). Dioxins/furans and PCBs in all samples were analyzed by high-resolution gas chromatography coupled with high-resolution mass spectrometry (HRGC-HRMS) using U.S. EPA methods 1668

and 8290B, respectively. Quality assurance/quality control (QA/QC) measures included analysis of method blanks, duplicate samples, matrix spikes, and laboratory control samples or standard reference materials.

All chemical concentrations are reported on a wet weight basis. A conversion factor of 15% was used to compare concentrations to dry-weight values reported in the literature. For comparison, the concentration of a chemical found below the detection limit was analyzed as both zero (ND=0) and one-half the detection limit (ND=DL/2). Risk calculations were made using ND=DL/2 for contaminants in a sample that were below the detection limit. However, if a chemical was not detected in any sample for a given target species, it was assumed to not be present and thus was not evaluated. Duplicate samples from a specific location were averaged to obtain one concentration for that site.

Assessment of Tissue Contaminant Levels

Tissue contaminant levels were assessed using Screening Values (SV) based on the U.S. Environmental Protection Agency's (EPA) *Guidance For Assessing Chemical Contaminant Data For Use In Fish Advisories: Fish Sampling and Analysis* (U.S. EPA, 2000). The SVs are concentrations of chemicals in fish and shellfish tissue that are of potential public health concern and that are used as threshold values against which tissue levels of the contaminants can be compared (U.S. EPA, 2000). Exceedance of these SVs is an indication that more intensive site-specific monitoring and/or evaluation of human health risk should be conducted. Because a quantitative fish consumption survey has not been previously conducted in the Pensacola area, four different fish consumption rates (CR) were compared in the present study for the adult population. The CR values were based on EPA estimates of the average consumption of fish by

recreational fishers (17.5 g·day⁻¹ uncooked weight) and subsistence fishers (142.4 g·day⁻¹), and of the average adult meal size (8 oz) if it was consumed weekly (32 g·day⁻¹). We also evaluated a CR estimate of 46 g·day⁻¹, which is based on the results of a fish and shellfish consumption study conducted throughout Florida by Degner et al. (1994).

Because of the unlikely scenario that an entire meal would consist of crab hepatopancreas alone, we also provide calculations that are based on the consumption of all edible tissues (body muscle, claw, and hepatopancreas). These estimates of contaminant levels in total edible crab tissue were based on the assumption that hepatopancreas accounts for less than 20% of total edible tissue in blue crabs (Tsai et al., 1984; NJDEP, 2002). To account for the proportions of tissue types, we used an estimate of 15% of total edible mass for hepatopancreas and 85% for muscle/claw. Therefore, estimates for whole crab were calculated as follows: $(C_{\text{hep}} * 0.15) + (C_{\text{mus}} * 0.85)$, where C_{hep} = concentration in hepatopancreas and C_{mus} = concentration in crab muscle.

Based on the EPA guidelines, a 70 kg body weight for adults, a 10⁻⁵ risk level for carcinogens, and a 70-year exposure duration were used (U.S. EPA, 2000). Cancer Slope Factors (CSF) and oral reference doses (RfD) used in the calculation of SVs were obtained from the U.S. EPA (U.S. EPA, 2000; U.S. EPA, 2002). Table 1 summarizes the SVs used in the present assessment and delineates the respective CSFs and RfDs used in the calculation. The EPA has suggested that in cases where both a carcinogenic and non-carcinogenic SV is available (e.g. arsenic), the lower of the two SVs (generally, the SV for carcinogenic effects) should be used for screening. We assessed the hazards posed by dioxins/furans and dioxin-like PCBs using World Health Organization Toxic Equivalency Factors (TEFs) (Van den Berg et al., 1998), which were summed for each sample to give a Toxic Equivalency Quotient (TEQ) and compared against the

derived SVs. In the present report, we use TEQ_{DFP} to refer to TEQs calculated using concentrations of both dioxins/furans and dioxin-like PCBs, TEQ_{DF} to refer to TEQs calculated for dioxins/furans only, and TEQ_P to refer to TEQs calculated for dioxin-like PCBs only.

Table 1. Tissue contaminant screening values (SV) based on a 70 kg body weight for adults, a 10⁻⁵ risk level for carcinogens, and 70-year exposure duration.

Chemical	RfD (mg/kg-day)	CSF (mg/kg-d)	SV Units	SV - Recreational ^a		SV - Subsistence ^b		SV - Florida ^c		SV - 8 oz. ^d	
				Non-Carcin.	Carcin.	Non-Carcin.	Carcin.	Non-Carcin.	Carcin.	Non-Carcin.	Carcin.
Arsenic (inorganic)	3.00E-04	1.5	mg·kg ⁻¹	1.2	0.027	0.15	0.003	0.46	0.010	0.66	0.015
Cadmium	1.00E-03	-	mg·kg ⁻¹	4	-	0.49	-	1.52	-	2.19	-
Chromium	3.00E-03	-	mg·kg ⁻¹	12	-	1.47	-	4.56	-	6.56	-
Mercury	1.00E-04	-	mg·kg ⁻¹	0.4	-	0.05	-	0.15	-	0.22	-
Nickel	2.00E-02	-	mg·kg ⁻¹	80	-	9.83	-	30.42	-	43.75	-
Selenium	5.00E-03	-	mg·kg ⁻¹	20	-	2.46	-	7.61	-	10.94	-
Tributyltin	3.00E-04	-	mg·kg ⁻¹	1.2	-	0.15	-	0.46	-	0.66	-
Zinc	3.00E-01	-	mg·kg ⁻¹	1200	-	147.47	-	456.32	-	656.25	-
Dioxins/Furans *	-	1.56E+05	pg·g ⁻¹	-	0.256	-	0.032	-	0.098	-	0.140

* Based on WHO-TEQ values and includes 12 dioxin-like PCBs.

^a Based on consumption rate of 17.5 g·day⁻¹.

^b Based on consumption rate of 142.4 g·day⁻¹.

^c Based on consumption rate of 46 g·day⁻¹.

^d Based on consumption rate of 32 g·day⁻¹.

Risk Calculations

To further evaluate the human health risks associated with consumption of shellfish species in the Pensacola Bay region, we determined the excess cancer risk (ECR) over a lifetime for each sample using the methods described by the U.S. EPA (2002). The potential cancer risk is estimated as an incremental increase in the probability of an individual developing cancer over a lifetime as a result of exposure to a carcinogen (U.S. EPA, 2002). The excess cancer risk for all carcinogens was summed to provide an estimate of total risk posed by exposure to multiple carcinogens. We also determined species-specific non-cancer hazard risks for each contaminant at each location (U.S. EPA, 2002). In these analyses, an exposure threshold is assumed to exist

below which adverse effects are unlikely to occur, and thus the average daily dose is compared to the reference dose to obtain a hazard quotient (HQ). A total Hazard Index (HI) is calculated by summing all HQ for a particular location across all health effects. If the HI exceeds 1, there is an indication of potential non-carcinogenic health effects, and the greater the magnitude above 1, the greater the level of concern (U.S. EPA, 2002). If the total HI was greater than 1.0, HQs for chemicals with similar target organs or health endpoints (mechanisms of toxicity) were summed to identify potential non-cancer effects (U.S. EPA, 2002). For this risk assessment, consumption rate and exposure duration were varied to estimate exposure under various scenarios.

Consumption rates were as described above. Body weight for adults was assumed to be 70 kg, the average body weight for all adults in the general public (U.S. EPA, 2000; U.S. EPA, 2002). Exposure duration, the length of time over which exposure occurs, was assumed to be nine years (the median number of years individuals remain at one residence), 30 years (the national 90th percentile for the length of time an individual stays at one residence), or 70 years (lifetime exposure duration) for adults (U.S. EPA, 2000; U.S. EPA, 2002).

Table 2. Contaminant concentrations in crab muscle samples from various locations in the Pensacola Bay area. ID designations correspond to locations on Figure 1.

ID	Location	As	In. As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Sn	Zn	TEQ _{DFP} (pg·g ⁻¹)	
		mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	ND=DL/2
C1	Perdido-11 Mile Creek	0.90	0.009	(0.10)	0.79	4.40	(0.45)	0.13	(0.27)	0.90	(0.64)	22.0	0.27	0.14
C2	Perdido Bay - Upper	1.20	0.012	(0.18)	0.98	5.10	(0.78)	0.14	(0.47)	1.00	(1.10)	25.0	0.27	0.16
C3	Perdido Bay - Lillian Bridge	1.10	0.011	(0.13)	0.82	4.00	(0.55)	0.24	(0.33)	1.00	(0.78)	24.0	0.11	0.08
C4	Perdido Bay -Tarkiln	2.80	0.028	(0.14)	0.67	5.90	(0.64)	0.13	(0.38)	1.00	(0.91)	28.0	0.17	0.15
C5	Bayou Grande Upper	1.10	0.011	(0.12)	0.49	5.90	(0.51)	0.12	(0.31)	0.84	(0.73)	20.0	0.65	0.64
C6	Bayou Grande	1.50	0.015	(0.16)	(0.27)	7.70	(0.69)	0.14	(0.41)	0.60	(0.10)	29.0	0.58	0.55
C7	Bayou Chico Upper	2.00	0.020	(0.15)	(0.26)	11.00	(0.64)	0.07	(0.38)	0.53	(0.09)	40.0	0.84	0.84
C8	Bayou Chico Bridge	3.30	0.033	(0.15)	0.28	6.70	(0.67)	0.14	(0.40)	0.67	(0.96)	29.0	0.71	0.70
C9	Bayou Chico Mouth	8.30	0.083	(0.12)	(0.21)	12.00	(0.52)	0.15	(0.31)	0.73	(0.07)	43.0	0.47	0.46
C10	Bayou Texar Upper	0.73	0.007	(0.14)	0.29	11.00	(0.60)	0.22	(0.36)	0.81	(0.86)	26.0	0.60	0.59
C11	Bayou Texar Mid	0.69	0.007	(0.15)	(0.26)	8.15	(0.65)	0.15	0.29	0.51	(0.10)	34.5	0.33	0.32
C12	Bayou Texar Mouth	1.32	0.013	(0.09)	0.17	8.95	(0.45)	0.17	(0.27)	0.50	(0.06)	34.0	0.23	0.19
C13	Gaberonne	2.20	0.022	(0.16)	0.37	14.00	(0.70)	0.21	(0.41)	0.57	(0.10)	54.0	0.87	0.59
C14	Devils Point	0.57	0.006	(0.17)	0.40	7.80	(0.75)	0.14	(0.45)	0.66	(1.10)	32.0	0.34	0.13
C15	Escambia Bay NW	0.84	0.008	(0.15)	0.42	9.90	(0.63)	0.19	0.41	0.68	(0.90)	36.5	0.75	0.74
C16	Mackey Cove	0.54	0.005	(0.15)	(0.27)	4.20	(0.68)	0.15	(0.40)	0.51	(0.95)	24.0	0.38	0.23
C17	Escambia Channel	0.50	0.005	(0.16)	(0.27)	8.40	(0.68)	0.19	0.87	0.58	(0.99)	36.0	0.76	0.65
C18	Escambia Bay NE	0.69	0.007	(0.14)	(0.26)	11.00	(0.64)	0.13	0.60	0.51	(0.92)	33.0	0.28	0.18
C19	Mulat Bayou	0.55	0.006	(0.14)	0.52	6.40	(0.61)	0.08	(0.37)	0.65	(0.87)	35.0	0.44	0.42
C20	Indian Bayou	0.47	0.005	(0.13)	(0.23)	6.10	(0.58)	0.17	(0.35)	0.49	(0.08)	26.5	0.46	0.44
C21	Trout Bayou	0.56	0.006	(0.11)	0.36	8.10	(0.46)	0.23	0.3	0.58	(0.66)	25.0	0.46	0.44
C22	Escambia Bay SE	1.75	0.018	(0.14)	(0.235)	9.65	(0.59)	0.13	0.47	0.29	(0.84)	29.0	0.67	0.17
C23	Garcon Point	3.70	0.037	(0.14)	(0.25)	3.90	(0.62)	0.23	(0.37)	0.59	(0.89)	14.0	0.13	0.08
C24	Hoffman Bayou	2.07	0.021	(0.14)	0.49	4.33	(0.61)	0.15	(0.36)	0.47	(0.87)	22.0	0.32	0.28
C25	Redfish Point	2.50	0.025	(0.11)	0.72	7.60	(0.50)	0.16	(0.30)	1.00	0.77	20.0	0.26	0.21
C26	East River	2.40	0.024	(0.14)	0.52	7.50	(0.63)	0.11	(0.38)	1.10	(0.90)	27.0	0.33	0.24
C27	Yellow River	0.55	0.006	(0.18)	(0.33)	4.40	(0.81)	0.15	(0.49)	0.68	(1.20)	24.0	0.54	0.07
C28	Blackwater Bay	0.70	0.007	(0.14)	0.26	9.30	(0.59)	0.21	(0.35)	0.84	(0.84)	28.0	0.33	0.04

Table 3. Contaminant concentrations in crab hepatopancreas samples from various locations in the Pensacola Bay area. ID designations correspond to locations on Figure 1.

ID	Location	As	In. As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Sn	Zn	TEQ _{DFP} (pg·g ⁻¹)	
		mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	ND=DL/2
C1	Perdido-11 Mile Creek	3.00	0.060	(0.14)	0.55	6.10	(0.62)	0.05	(0.37)	2.00	(0.88)	17.0	8.1	8.1
C2	Perdido Bay - Upper	2.40	0.048	0.01	1.10	7.20	(0.49)	0.02	(0.3)	1.80	(0.70)	18.0	8.7	8.7
C3	Perdido Bay - Lillian Bridge	2.60	0.052	0.19	1.10	5.20	(0.62)	0.22	(0.37)	1.90	(0.89)	17.0	12.3	12.3
C4	Perdido Bay -Tarkiln	8.15	0.163	0.20	0.92	7.60	(0.64)	0.13	0.56	1.85	(0.91)	21.5	7.2	7.2
C5	Bayou Grande Upper	2.00	0.040	0.98	0.60	28.00	(0.30)	0.14	(0.18)	1.60	0.75	19.0	16.6	16.6
C6	Bayou Grande	3.80	0.076	4.60	0.29	58.00	(0.59)	0.06	(0.35)	1.60	(0.08)	46.0	28.2	28.2
C7	Bayou Chico Upper	2.50	0.050	0.24	(0.22)	95.00	(0.58)	0.02	(0.35)	0.98	(0.08)	46.0	38.6	38.6
C8	Bayou Chico Bridge	5.00	0.100	0.67	0.64	52.00	(0.71)	0.05	(0.43)	1.30	(1.00)	43.0	30.5	30.5
C9	Bayou Chico Mouth	9.60	0.192	2.30	0.32	99.00	(0.54)	0.06	(0.33)	1.30	(0.08)	48.0	17.8	17.8
C10	Bayou Texar Upper	2.30	0.046	4.00	0.44	88.00	(0.65)	0.08	(0.39)	1.80	(0.93)	14.0	13.4	13.4
C11	Bayou Texar Mid	2.30	0.046	0.65	0.30	40.00	(0.56)	0.05	(0.34)	1.10	(0.08)	34.0	25.3	25.3
C12	Bayou Texar Mouth	3.30	0.066	1.30	0.32	32.00	(0.30)	0.10	0.21	1.10	(0.04)	48.0	17.0	17.0
C13	Gaberonne	3.30	0.066	1.90	0.50	53.00	(0.71)	1.10	(0.43)	1.20	(0.10)	45.0	32.8	32.7
C14	Devils Point	1.90	0.038	0.67	0.55	56.00	(0.64)	0.25	(0.38)	2.30	(0.91)	19.0	16.3	16.3
C15	Escambia Bay NW	1.75	0.035	1.80	0.76	76.00	(0.64)	0.07	0.69	1.75	(0.92)	26.0	14.4	14.3
C16	Mackey Cove	1.80	0.036	0.89	0.38	64.00	(0.59)	0.06	(0.36)	1.80	(0.85)	21.0	9.3	9.2
C17	Escambia Channel	1.60	0.032	0.66	0.28	41.00	(0.67)	0.05	1.40	1.20	(0.95)	37.0	18.7	18.7
C18	Escambia Bay NE	2.40	0.048	0.63	(0.28)	22.00	(0.69)	0.04	(0.42)	1.50	(0.99)	33.0	14.5	14.5
C19	Mulat Bayou	1.50	0.030	1.40	0.58	20.00	(0.65)	0.52	(0.39)	1.10	(0.93)	13.0	8.1	8.0
C20	Indian Bayou	2.05	0.041	0.91	0.34	10.95	(0.65)	0.06	0.47	1.65	(0.54)	22.0	14.8	14.7
C21	Trout Bayou	2.10	0.042	1.20	0.77	11.00	(0.66)	0.08	(0.4)	1.30	(0.94)	18.0	20.8	19.2
C22	Escambia Bay SE	4.00	0.080	0.64	0.20	32.00	(0.62)	0.04	1.30	1.60	(0.88)	43.0	14.7	14.7
C23	Garcon Point	2.90	0.058	1.60	0.39	46.00	(0.69)	0.08	0.55	1.50	(0.99)	16.0	3.1	3.1
C24	Hoffman Bayou	3.40	0.068	0.90	0.76	68.00	(0.65)	0.05	(0.39)	1.27	(0.93)	33.7	12.4	12.4
C25	Redfish Point	4.20	0.084	0.95	0.65	42.00	(0.70)	0.07	(0.42)	2.00	1.1	28.0	17.4	17.3
C26	East River	4.40	0.088	0.51	0.60	7.00	(0.48)	0.13	(0.29)	2.10	(0.69)	16.0	9.7	9.7
C27	Yellow River	1.70	0.034	1.10	0.31	26.00	(0.72)	0.06	(0.44)	1.50	(1.00)	20.0	3.3	3.3
C28	Blackwater Bay	2.10	0.042	0.82	0.51	22.00	(0.77)	0.04	1.3	1.70	(1.10)	32.0	4.1	4.1

Table 4. Estimated contaminant concentrations in total edible crab tissue samples from various locations in the Pensacola Bay area. ID designations correspond to locations on Figure 1.

ID	Location	As	In. As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Sn	Zn	TEQ _{DFF} (pg g ⁻¹)	
		mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	mg·kg ⁻¹	ND=DL/2
C1	Perdido-11 Mile Creek	1.22	0.017	<DL	0.75	4.66	<DL	0.12	<DL	1.07	<DL	21.25	1.44	1.33
C2	Perdido Bay - Upper	1.38	0.017	0.08	1.00	5.42	<DL	0.12	<DL	1.12	<DL	23.95	1.54	1.44
C3	Perdido Bay - Lillian Bridge	1.33	0.017	0.08	0.86	4.18	<DL	0.24	<DL	1.14	<DL	22.95	1.94	1.90
C4	Perdido Bay -Tarkiln	3.60	0.048	0.09	0.71	6.16	<DL	0.13	0.24	1.13	<DL	27.03	1.23	1.21
C5	Bayou Grande Upper	1.24	0.015	0.20	0.51	9.22	<DL	0.12	<DL	0.95	<DL	19.85	3.05	3.03
C6	Bayou Grande	1.85	0.024	0.76	0.16	15.25	<DL	0.13	<DL	0.75	<DL	31.55	4.73	4.69
C7	Bayou Chico Upper	2.08	0.025	0.10	<DL	23.60	<DL	0.06	<DL	0.60	<DL	40.90	6.50	6.50
C8	Bayou Chico Bridge	3.56	0.043	0.16	0.33	13.50	<DL	0.13	<DL	0.76	<DL	31.10	5.18	5.17
C9	Bayou Chico Mouth	8.50	0.099	0.40	0.14	25.05	<DL	0.14	<DL	0.82	<DL	43.75	3.07	3.07
C10	Bayou Texar Upper	0.97	0.013	0.66	0.31	22.55	<DL	0.20	<DL	0.96	<DL	24.20	2.52	2.51
C11	Bayou Texar Mid	0.93	0.013	0.16	0.16	12.93	<DL	0.14	0.27	0.60	<DL	34.43	4.08	4.07
C12	Bayou Texar Mouth	1.61	0.021	0.23	0.19	12.41	<DL	0.16	0.15	0.59	<DL	36.10	2.75	2.71
C13	Gaberonne	2.37	0.029	0.35	0.39	19.85	<DL	0.34	<DL	0.66	<DL	52.65	5.65	5.41
C14	Devils Point	0.77	0.011	0.17	0.42	15.03	<DL	0.16	<DL	0.91	<DL	30.05	2.74	2.56
C15	Escambia Bay NW	0.97	0.012	0.33	0.47	19.82	<DL	0.17	0.45	0.84	<DL	34.93	2.80	2.77
C16	Mackey Cove	0.73	0.010	0.20	0.17	13.17	<DL	0.14	<DL	0.70	<DL	23.55	1.72	1.58
C17	Escambia Channel	0.67	0.009	0.17	0.16	13.29	<DL	0.17	0.95	0.67	<DL	36.15	3.45	3.35
C18	Escambia Bay NE	0.95	0.013	0.15	<DL	12.65	<DL	0.12	0.54	0.66	<DL	33.00	2.41	2.33
C19	Mulat Bayou	0.69	0.009	0.27	0.53	8.44	<DL	0.15	<DL	0.72	<DL	31.70	1.58	1.56
C20	Indian Bayou	0.71	0.010	0.19	0.15	6.83	<DL	0.15	0.22	0.66	<DL	25.83	2.61	2.59
C21	Trout Bayou	0.79	0.011	0.23	0.42	8.54	<DL	0.21	0.29	0.69	<DL	23.95	3.51	3.25
C22	Escambia Bay SE	2.09	0.027	0.16	0.13	13.00	<DL	0.12	0.60	0.49	<DL	31.10	2.76	2.34
C23	Garcon Point	3.58	0.040	0.30	0.16	10.22	<DL	0.21	0.24	0.73	<DL	14.30	0.58	0.53
C24	Hoffman Bayou	2.27	0.028	0.19	0.53	13.88	<DL	0.14	<DL	0.59	<DL	23.75	2.13	2.10
C25	Redfish Point	2.76	0.034	0.19	0.71	12.76	<DL	0.15	<DL	1.15	0.82	21.20	2.82	2.78
C26	East River	2.70	0.034	0.14	0.53	7.43	<DL	0.11	<DL	1.25	<DL	25.35	1.73	1.66
C27	Yellow River	0.72	0.010	0.24	0.19	7.64	<DL	0.14	<DL	0.80	<DL	23.40	0.96	0.56
C28	Blackwater Bay	0.91	0.012	0.18	0.30	11.21	<DL	0.18	0.34	0.97	<DL	28.60	0.90	0.65

Table 5. Contaminant concentrations in oyster samples from various locations in the Pensacola Bay area. ID designations correspond to locations on Figure 1.

ID	Location	As	In. As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Sn	Zn	TEQ _{DFF} (pg g ⁻¹)	
		mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	mg kg ⁻¹	ND=DL/2
O1	Bayou Grande	1.80	0.018	0.61	(0.33)	56.0	(0.83)	0.017	(0.49)	(0.53)	(1.2)	1000	4.21	4.19
O2	Bayou Chico Bridge	1.15	0.012	0.15	(0.03)	44.5	(0.08)	0.040	(0.045)	0.24	(0.01)	850	5.90	5.62
O3	Bayfront Auditorium	1.40	0.014	(0.10)	0.14	13.0	(0.42)	0.060	(0.25)	(0.27)	0.09	190	1.86	1.68
O4	Bayou Texar	0.97	0.010	0.17	(0.14)	6.7	(0.34)	0.050	(0.2)	(0.22)	0.59	290	1.35	0.92
O5	Pensacola Bay Bridge North	1.90	0.019	(0.08)	(0.13)	1.5	(0.33)	0.051	(0.2)	(0.27)	0.05	62	1.54	1.20
O6	Pensacola Bay Bridge Mid	2.60	0.026	0.11	(0.13)	5.8	(0.32)	0.06	(0.19)	(0.4)	0.05	130	0.43	0.24
O7	Pensacola Bay Bridge South	2.30	0.023	(0.06)	(0.11)	1.3	(0.28)	0.055	(0.17)	0.21	(0.04)	21	0.73	0.26
O8	Gaberonne	0.12	0.001	(0.17)	(0.30)	10.5	(0.73)	0.028	0.69	(0.48)	0.14	165	1.42	1.40
O9	I-10 Bridge Mid	1.60	0.016	(0.09)	(0.16)	4.9	(0.39)	0.051	(0.23)	(0.25)	0.14	200	1.82	1.56
O10	Escambia Bay 7	2.50	0.025	0.43	0.71	6.7	(0.24)	0.025	(0.14)	0.95	0.07	190	0.58	0.50
O11	Escambia Bay 1	2.20	0.022	0.36	0.46	6.3	(0.26)	0.020	(0.15)	0.61	(0.04)	130	0.46	0.27
O12	Escambia Bay 5	2.80	0.028	0.32	0.41	10.0	(0.23)	0.018	(0.14)	0.72	(0.03)	200	0.62	0.23
O13	Escambia Bay 8	2.50	0.025	0.59	0.33	24.0	(0.23)	0.016	(0.13)	1.30	(0.03)	340	0.56	0.12
O14	Garcon Point Bridge North	1.10	0.011	0.28	0.11	2.6	(0.28)	(0.056)	(0.17)	0.21	(0.04)	1000	1.14	0.85
O15	Garcon Point Bridge Mid	2.00	0.020	(0.08)	(0.14)	4.2	(0.35)	0.074	(0.21)	(0.23)	(0.05)	1200	0.90	0.61
O16	Garcon Point Bridge South	1.90	0.019	(0.09)	(0.15)	3.0	(0.37)	0.070	(0.24)	(0.25)	(0.05)	440	0.93	0.69
O17	Bob Sikes Bridge Mid	2.20	0.022	0.10	0.23	5.6	(0.29)	0.05	(0.17)	0.28	(0.04)	110	1.19	0.84
O18	East Bay 13	2.20	0.022	0.44	0.46	7.4	(0.19)	0.011	(0.11)	0.86	0.04	150	0.37	0.21
O19	East Bay 2	2.90	0.029	0.59	0.84	8.5	(0.24)	0.006	(0.14)	0.87	(0.19)	120	0.31	0.18
O20	East Bay 3	2.10	0.021	0.50	0.51	9.5	(0.20)	0.017	0.20	0.80	0.09	190	0.29	0.16
O21	East Bay 5	2.10	0.021	0.44	0.53	6.9	(0.22)	0.024	(0.13)	0.79	0.12	160	0.33	0.17
O22	East Bay 8	2.30	0.023	0.35	0.5	8.1	(0.22)	0.030	(0.12)	0.91	0.12	190	0.29	0.17
O23	East Bay 9	1.73	0.017	0.50	0.67	8.0	(0.45)	0.020	(0.27)	0.94	0.30	170	1.14	1.08

RESULTS

Tables 2, 3, 4, and 5 present summaries of contaminant concentrations in crab muscle, crab hepatopancreas, total edible crab tissues, and oyster tissues, respectively. Five chemicals or chemical groups (dioxins/furans/PCBs, arsenic, mercury, cadmium, and zinc) exceeded at least one of their respective SVs (recreational, subsistence, Florida, or 8 oz) in crab muscle, crab hepatopancreas, whole crab, or oysters.

Metals

Tissue samples were analyzed for mercury, arsenic (total), cadmium, chromium, copper, lead, nickel, selenium, tin, and zinc. None of the samples exceeded sample detection limits for lead, and cadmium levels were below detection limits in all crab muscle samples. The majority of crab muscle and hepatopancreas sample concentrations fell below their respective detection limits for nickel and tin (Tables 2 and 3). Of the samples that were above their respective detection limits for nickel, none exceeded any of the calculated SVs. None of the samples exceeded the SVs for chromium or selenium, regardless of consumption rate. A SV could not be calculated for total tin or copper due to a lack of RfD or CSF values.

Table 6 presents the number of samples that exceeded calculated screening values for the remaining contaminants. EPA consensus toxicity values for organic or total arsenic are not available and therefore the calculated SVs could not be directly compared to the total arsenic measured in the present study. To allow for comparison to inorganic arsenic SVs, we estimated the levels of inorganic arsenic by applying a conversion factor to the total arsenic levels measured in each sample. A separate analysis of a limited number of crab and oyster samples from the Pensacola region revealed that inorganic arsenic levels were generally below 1% of

total arsenic in crab muscle and oysters, and below 2% for crab hepatopancreas (unpublished data). Therefore, for screening purposes we estimated the concentrations of inorganic arsenic in our tissue samples, using 1% of total arsenic as a conversion factor for crab muscle and oysters and 2% for crab hepatopancreas.

Table 6. Number of samples that exceeded the four calculated screening values

Screening Value	Tissue	As (inorg.)	Cd	Hg	Zn	Dioxins*
Subsistence	Crab Muscle (n=28)	28	<DL	28	0	28 [28]
	Hepatopancreas (n=28)	28	23	23	0	28 [28]
	Total Edible Crab Tissue (n=28)	28	2	28	0	28 [28]
	Oyster (n=23)	22	4	9	17	23 [23]
Florida	Crab Muscle (n=28)	15	<DL	16	0	28 [24]
	Hepatopancreas (n=28)	28	6	4	0	28 [28]
	Total Edible Crab Tissue (n=28)	26	0	12	0	28 [28]
	Oyster (n=23)	22	0	0	3	23 [23]
8 oz	Crab Muscle (n=28)	11	<DL	4	0	28 [23]
	Hepatopancreas (n=28)	28	3	4	0	28 [28]
	Total Edible Crab Tissue (n=28)	16	0	2	0	28 [28]
	Oyster (n=23)	18	0	0	3	23 [22]
Recreational	Crab Muscle (n=28)	5	<DL	0	0	28 [14]
	Hepatopancreas (n=28)	28	2	2	0	28 [28]
	Total Edible Crab Tissue (n=28)	9	0	0	0	28 [28]
	Oyster (n=23)	2	0	0	1	23 [15]

* Based on WHO-TEQ values calculated using $ND=DL/2$ and includes 17 dioxins and furans and 12 dioxin-like PCBs.

Values in brackets are based on WHO-TEQs calculated using $ND=0$.

Dioxins and PCBs

The two most toxic dioxin congeners, 2,3,7,8-TCDD and 1,2,3,7,8-PeCDD, were detected in 100% of the crab hepatopancreas samples. However, these congeners represented only a small fraction of the total amount of dioxins/furans in the samples. OCDD and 1,2,3,4,6,7,8-HpCDD were the most prevalent congeners in most samples (Table 7). All dioxin-like PCB congeners were detected in all crab samples, although PCB-169 and PCB-189 were not

Table 7. Percent contribution of dioxin/furan congeners to the total dioxin/furan concentrations in crab muscle, hepatopancreas, and oysters.

	Crab Muscle		Hepatopancreas		Oysters	
	mean	range	mean	range	mean	range
2378-TCDD	1.6%	0.0% - 7.0%	1.3%	0.0% - 3.0%	0.5%	0.0% - 1.3%
12378-PeCDD	5.2%	1.0% - 17.0%	3.8%	1.0% - 7.0%	0.7%	0.2% - 1.8%
123478-HxCDD	1.8%	0.0% - 6.0%	2.0%	0.0% - 4.0%	0.8%	0.3% - 1.9%
123678-HxCDD	5.9%	1.0% - 18.0%	5.6%	1.0% - 13.0%	2.0%	0.4% - 5.4%
123789-HxCDD	3.8%	0.0% - 12.0%	3.7%	1.0% - 8.0%	2.2%	0.4% - 6.0%
1234678-HpCDD	9.5%	1.0% - 19.0%	10.9%	2.0% - 23.0%	7.7%	3.3% - 12.9%
OCDD	38.7%	4.0% - 72.0%	24.7%	5.0% - 64.0%	76.6%	56.8% - 84.9%
2378-TCDF	6.1%	1.0% - 30.0%	8.7%	2.0% - 22.0%	4.7%	0.7% - 11.5%
12378-PeCDF	1.7%	0.0% - 7.0%	3.7%	1.0% - 11.0%	0.6%	0.1% - 2.7%
23478-PeCDF	2.5%	0.0% - 12.0%	3.3%	0.0% - 11.0%	0.7%	0.2% - 2.9%
123478-HxCDF	1.7%	0.0% - 6.0%	1.0%	0.0% - 2.0%	0.5%	0.0% - 2.4%
123678-HxCDF	3.6%	0.0% - 11.0%	7.6%	0.0% - 21.0%	0.3%	0.0% - 0.8%
123789-HxCDF	100%<DL		97%<DL		95%<DL	
234678-HxCDF	100%<DL		0.5%	0.0% - 3.0%	0.3%	0.0% - 1.3%
1234678-HpCDF	13.4%	1.0% - 34.0%	23.0%	0.0% - 60.0%	0.4%	0.1% - 1.3%
1234789-HpCDF	97%<DL		97%<DL		100%<DL	
OCDF	4.3%	0.0% - 12.0%	0.1%	0.0% - 1.0%	1.5%	0.2% - 5.2%

recovered from many oyster samples. PCB-118 was the most prevalent congener in all samples, followed by PCB-156.

TEQ_{DFP} for crab muscle samples ranged from 0.11 to 0.88 pg·g⁻¹ for ND=DL/2 and 0.04 to 0.84 pg·g⁻¹ for ND=0. TEQ_{DFP} values for crab hepatopancreas samples were 20-70 times higher than their corresponding crab muscle samples, and all hepatopancreas samples and total crab tissue estimates exceeded the SVs, regardless of consumption rate or TEQ calculation method used. Table 6 presents the number of samples that exceeded the SVs calculated for dioxins/furans and dioxin-like PCBs.

The percent contribution of PCBs and dioxins/furans to TEQ_{DFP} varied extensively by sampling location (Tables 8 and 9). The identification of a dominant contributor to the TEQ_{DFP} values was made more difficult in crab muscle and oyster samples due to the preponderance of samples in which congener concentrations fell below the detection limit. However, clear patterns could be identified in several locations. For example, crab hepatopancreas samples suggested

Table 8. Sample group means for contaminants that exceeded SVs in crab muscle and hepatopancreas.

A. Crab muscle

Group	As	Cu	Hg	TEQ _P		TEQ _{DF}		TEQ _{DFP}	
	(total)			ND=DL/2	ND=0	ND=DL/2	ND=0	ND=DL/2	ND=0
Perdido Bay	1.50 (0.90 - 2.8)	4.9 (4.0 - 5.9)	0.16 (0.13 - 0.24)	0.07 (0.05 - 0.09)	0.07 (0.05 - 0.09)	0.14 (0.06 - 0.21)	0.07 (0.03 - 0.1)	0.21 (0.11 - 0.27)	0.13 (0.08 - 0.16)
Urban Bayous	2.30 (0.69 - 8.3)	8.4 (4.3 - 12.0)	0.15 (0.07 - 0.22)	0.28 (0.13 - 0.46)	0.28 (0.13 - 0.46)	0.25 (0.06 - 0.58)	0.23 (0.02 - 0.57)	0.53 (0.23 - 0.84)	0.51 (0.19 - 0.84)
W. Escambia	0.92 (0.50 - 2.20)	8.9 (4.2 - 14.0)	0.18 (0.14 - 0.21)	0.43 (0.13 - 0.69)	0.38 (0.13 - 0.58)	0.19 (0.16 - 0.21)	0.09 (0 - 0.19)	0.62 (0.34 - 0.87)	0.47 (0.13 - 0.74)
E. Escambia	0.84 (0.47 - 1.75)	8.3 (6.1 - 11.0)	0.15 (0.08 - 0.23)	0.23 (0.15 - 0.3)	0.23 (0.15 - 0.3)	0.23 (0.12 - 0.52)	0.10 (0.02 - 0.21)	0.46 (0.28 - 0.67)	0.33 (0.17 - 0.44)
East Bay	1.98 (0.6 - 3.7)	6.5 (3.9 - 9.3)	0.17 (0.11 - 0.23)	0.09 (0.04 - 0.14)	0.09 (0.04 - 0.14)	0.23 (0.07 - 0.47)	0.04 (0 - 0.11)	0.32 (0.13 - 0.54)	0.13 (0.04 - 0.24)

Values for metals are in mg·kg⁻¹ wet weight and values for TEQs are in pg·g⁻¹.
Values in parentheses represent concentration ranges.

B. Crab hepatopancreas

Group	As	Cd	Cu	Hg	TEQ _P	TEQ _{DF}	TEQ _{DFP}
	(total)				ND=DL/2	ND=DL/2	ND=DL/2
Perdido Bay	4.03 (2.40 - 8.15)	0.12 (0.01 - 0.2)	6.5 (5.2 - 7.6)	0.11 (0.02 - 0.22)	3.78 (3.3 - 4.3)	5.35 (4.0 - 8.0)	9.08 (7.2 - 12.3)
Urban Bayous	3.8 (2.00-9.60)	1.74 (0.24 - 4.6)	62.2 (28.0 - 99.0)	0.07 (0.02 - 0.14)	13.56 (7.7 - 24.7)	8.67 (3.4 - 21.1)	22.20 (12.4 - 38.6)
W. Escambia	2.07 (1.60-3.30)	1.18 (0.66 - 1.9)	58.0 (41 - 76)	0.31 (0.05 - 1.10)	14.64 (7.8 - 25.8)	3.68 (1.5 - 7.0)	18.30 (9.3 - 32.8)
E. Escambia	2.41 (1.50-4.00)	0.96 (0.63 - 1.4)	19.2 (11.0 - 32.0)	0.15 (0.04 - 0.52)	9.72 (6.3 - 11.5)	4.86 (1.8 - 9.3)	14.58 (8.1 - 20.8)
East Bay	3.06 (1.70-4.40)	1.00 (0.51 - 1.6)	28.6 (7.0 - 46.0)	0.08 (0.04 - 0.13)	3.40 (1.7 - 6.9)	4.12 (1.3 - 10.5)	7.52 (3.1 - 17.4)

that TEQ_{DFP} for western Escambia Bay stations and Bayou Grande were dominated by PCBs, whereas dioxins/furans were a greater contributor to TEQ_{DFP} for Bayou Chico and Perdido Bay samples.

Table 9. Sample group means of contaminants that exceeded SVs in oysters.

Group	As	Cd	Cu	Hg	Zn	TEQ _p		TEQ _{DF}		TEQ _{DFP}	
	(total)					ND=DL/2	ND=0	ND=DL/2	ND=0	ND=DL/2	ND=0
Urban	1.33 (0.97-1.80)	0.25 (0.05 - 0.61)	30.1 (6.7 - 56.0)	0.042 (0.017 - 0.06)	582.5 (190 - 1000)	1.76 (0.71 - 3.38)	1.75 (0.7 - 3.38)	1.58 (0.57 - 3.75)	1.35 (0.15 - 3.47)	3.33 (1.35 - 5.90)	3.10 (0.92 - 5.62)
Bridges	1.95 (1.10-2.60)	0.06 (0.03 - 0.11)	3.8 (1.3 - 5.8)	0.055 (0.028 - 0.074)	309.0 (21 - 1200)	0.65 (0.19 - 1.30)	0.64 (0.16 - 1.30)	0.44 (0.24 - 0.53)	0.14 (0.07 - 0.26)	1.08 (0.43 - 1.82)	0.77 (0.24 - 1.56)
Oyster Beds	2.33 (1.73-2.90)	0.45 (0.32 - 0.59)	9.5 (6.3 - 24.0)	0.019 (0.006 - 0.03)	184.0 (120 - 340)	0.22 (0.06 - 0.74)	0.17 (0.03 - 0.73)	0.27 (0.16 - 0.41)	0.14 (0 - 0.35)	0.50 (0.29 - 1.14)	0.31 (0.12 - 1.08)

Values for metals are in mg kg⁻¹ wet weight and values for TEQs are in pg g⁻¹

Table 10. Hazard indices (HI) and cancer risks associated with consumption of crab hepatopancreas from the Pensacola Bay region.

Station ID	HI				Cancer Risk 70 year				Cancer Risk 30 year				Cancer Risk 9 year			
	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.
C1	0.3	2.8	0.9	0.6	3.4E-04	2.8E-03	8.9E-04	6.2E-04	1.5E-04	1.2E-03	3.8E-04	2.7E-04	4.4E-05	3.5E-04	1.1E-04	8.0E-05
C2	0.3	2.3	0.7	0.5	3.6E-04	2.9E-03	9.4E-04	6.6E-04	1.5E-04	1.3E-03	4.0E-04	2.8E-04	4.6E-05	3.8E-04	1.2E-04	8.4E-05
C3	0.8	6.9	2.2	1.5	5.0E-04	4.1E-03	1.3E-03	9.1E-04	2.1E-04	1.7E-03	5.6E-04	3.9E-04	6.4E-05	5.2E-04	1.7E-04	1.2E-04
C4	0.7	5.7	1.9	1.3	3.4E-04	2.8E-03	9.0E-04	6.3E-04	1.5E-04	1.2E-03	3.9E-04	2.7E-04	4.4E-05	3.6E-04	1.2E-04	8.1E-05
C5	0.8	6.3	2.0	1.4	6.6E-04	5.4E-03	1.7E-03	1.2E-03	2.8E-04	2.3E-03	7.5E-04	5.2E-04	8.5E-05	6.9E-04	2.2E-04	1.6E-04
C6	1.5	12.2	3.9	2.7	1.1E-03	9.2E-03	3.0E-03	2.1E-03	4.8E-04	3.9E-03	1.3E-03	8.8E-04	1.5E-04	1.2E-03	3.8E-04	2.7E-04
C7	0.3	2.0	0.7	0.5	1.5E-03	1.2E-02	4.0E-03	2.8E-03	6.5E-04	5.3E-03	1.7E-03	1.2E-03	2.0E-04	1.6E-03	5.2E-04	3.6E-04
C8	0.5	4.3	1.4	1.0	1.2E-03	1.0E-02	3.2E-03	2.2E-03	5.3E-04	4.3E-03	1.4E-03	9.6E-04	1.6E-04	1.3E-03	4.1E-04	2.9E-04
C9	1.0	8.4	2.7	1.9	7.7E-04	6.2E-03	2.0E-03	1.4E-03	3.3E-04	2.7E-03	8.6E-04	6.0E-04	9.9E-05	8.0E-04	2.6E-04	1.8E-04
C10	1.4	11.2	3.6	2.5	5.4E-04	4.4E-03	1.4E-03	9.9E-04	2.3E-04	1.9E-03	6.1E-04	4.2E-04	7.0E-05	5.7E-04	1.8E-04	1.3E-04
C11	0.4	3.6	1.2	0.8	1.0E-03	8.2E-03	2.6E-03	1.8E-03	4.3E-04	3.5E-03	1.1E-03	7.9E-04	1.3E-04	1.1E-03	3.4E-04	2.4E-04
C12	0.8	6.1	2.0	1.4	6.9E-04	5.6E-03	1.8E-03	1.3E-03	2.9E-04	2.4E-03	7.7E-04	5.4E-04	8.8E-05	7.2E-04	2.3E-04	1.6E-04
C13	3.4	27.8	9.0	6.3	1.3E-03	1.1E-02	3.4E-03	2.4E-03	5.6E-04	4.5E-03	1.5E-03	1.0E-03	1.7E-04	1.4E-03	4.4E-04	3.1E-04
C14	1.0	8.2	2.6	1.8	6.6E-04	5.4E-03	1.7E-03	1.2E-03	2.8E-04	2.3E-03	7.5E-04	5.2E-04	8.5E-05	6.9E-04	2.2E-04	1.6E-04
C15	0.8	6.7	2.2	1.5	5.7E-04	4.7E-03	1.5E-03	1.1E-03	2.5E-04	2.0E-03	6.5E-04	4.5E-04	7.4E-05	6.0E-04	1.9E-04	1.4E-04
C16	0.5	4.3	1.4	1.0	3.8E-04	3.1E-03	1.0E-03	7.0E-04	1.6E-04	1.3E-03	4.3E-04	3.0E-04	4.9E-05	4.0E-04	1.3E-04	9.0E-05
C17	0.4	3.6	1.2	0.8	7.4E-04	6.0E-03	1.9E-03	1.4E-03	3.2E-04	2.6E-03	8.4E-04	5.8E-04	9.5E-05	7.8E-04	2.5E-04	1.7E-04
C18	0.4	3.3	1.1	0.7	5.8E-04	4.7E-03	1.5E-03	1.1E-03	2.5E-04	2.0E-03	6.6E-04	4.6E-04	7.5E-05	6.1E-04	2.0E-04	1.4E-04
C19	1.8	14.6	4.7	3.3	3.3E-04	2.6E-03	8.6E-04	6.0E-04	1.4E-04	1.1E-03	3.7E-04	2.6E-04	4.2E-05	3.4E-04	1.1E-04	7.7E-05
C20	0.6	4.5	1.5	1.0	5.9E-04	4.8E-03	1.6E-03	1.1E-03	2.5E-04	2.1E-03	6.7E-04	4.6E-04	7.6E-05	6.2E-04	2.0E-04	1.4E-04
C21	0.7	5.5	1.8	1.2	8.3E-04	6.7E-03	2.2E-03	1.5E-03	3.5E-04	2.9E-03	9.3E-04	6.5E-04	1.1E-04	8.6E-04	2.8E-04	1.9E-04
C22	0.5	3.9	1.2	0.9	6.0E-04	4.9E-03	1.6E-03	1.1E-03	2.6E-04	2.1E-03	6.8E-04	4.7E-04	7.7E-05	6.3E-04	2.0E-04	1.4E-04
C23	0.8	6.3	2.0	1.4	1.4E-04	1.2E-03	3.7E-04	2.6E-04	6.1E-05	5.0E-04	1.6E-04	1.1E-04	1.8E-05	1.5E-04	4.8E-05	3.3E-05
C24	0.6	4.6	1.5	1.0	5.1E-04	4.1E-03	1.3E-03	9.3E-04	2.2E-04	1.8E-03	5.7E-04	4.0E-04	6.5E-05	5.3E-04	1.7E-04	1.2E-04
C25	0.7	5.3	1.7	1.2	7.1E-04	5.8E-03	1.9E-03	1.3E-03	3.0E-04	2.5E-03	8.0E-04	5.6E-04	9.1E-05	7.4E-04	2.4E-04	1.7E-04
C26	0.7	5.7	1.8	1.3	4.1E-04	3.3E-03	1.1E-03	7.5E-04	1.8E-04	1.4E-03	4.6E-04	3.2E-04	5.3E-05	4.3E-04	1.4E-04	9.6E-05
C27	0.6	4.6	1.5	1.0	1.6E-04	1.3E-03	4.1E-04	2.9E-04	6.7E-05	5.5E-04	1.8E-04	1.2E-04	2.0E-05	1.6E-04	5.3E-05	3.7E-05
C28	0.5	4.1	1.3	0.9	1.6E-04	1.3E-03	4.2E-04	2.9E-04	6.9E-05	5.6E-04	1.8E-04	1.3E-04	2.1E-05	1.7E-04	5.4E-05	3.8E-05

Rec = recreational fisher consumption rate (17.5 g day⁻¹)
 Sub = subsistence fisher consumption rate (142.4 g day⁻¹)
 FL = estimated consumption rate for Florida residents (46 g day⁻¹)
 8 oz = one 8 oz. meal per week consumption rate (32 g day⁻¹)

Table 11. Hazard indices (HI) and cancer risks associated with consumption of total edible crab tissue from the Pensacola Bay region.

Station ID	HI				Cancer Risk 70 year				Cancer Risk 30 year				Cancer Risk 9 year			
	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.
C1	0.44	3.60	1.16	0.81	6.3E-05	5.1E-04	1.6E-04	1.1E-04	2.7E-05	2.2E-04	7.1E-05	4.9E-05	8.0E-06	6.5E-05	2.1E-05	1.5E-05
C2	0.50	4.04	1.31	0.91	6.7E-05	5.4E-04	1.8E-04	1.2E-04	2.9E-05	2.3E-04	7.5E-05	5.2E-05	8.6E-06	7.0E-05	2.3E-05	1.6E-05
C3	0.78	6.31	2.04	1.42	8.2E-05	6.7E-04	2.2E-04	1.5E-04	3.5E-05	2.9E-04	9.2E-05	6.4E-05	1.1E-05	8.6E-05	2.8E-05	1.9E-05
C4	0.53	4.30	1.39	0.97	6.6E-05	5.4E-04	1.7E-04	1.2E-04	2.8E-05	2.3E-04	7.4E-05	5.2E-05	8.5E-06	6.9E-05	2.2E-05	1.6E-05
C5	0.48	3.88	1.25	0.87	1.2E-04	1.0E-03	3.3E-04	2.3E-04	5.3E-05	4.3E-04	1.4E-04	9.8E-05	1.6E-05	1.3E-04	4.2E-05	2.9E-05
C6	0.61	4.93	1.59	1.11	1.9E-04	1.6E-03	5.1E-04	3.5E-04	8.3E-05	6.7E-04	2.2E-04	1.5E-04	2.5E-05	2.0E-04	6.5E-05	4.5E-05
C7	0.26	2.13	0.69	0.48	2.6E-04	2.1E-03	6.9E-04	4.8E-04	1.1E-04	9.2E-04	3.0E-04	2.1E-04	3.4E-05	2.7E-04	8.9E-05	6.2E-05
C8	0.48	3.94	1.27	0.89	2.2E-04	1.8E-03	5.7E-04	4.0E-04	9.4E-05	7.6E-04	2.5E-04	1.7E-04	2.8E-05	2.3E-04	7.4E-05	5.1E-05
C9	0.61	4.99	1.61	1.12	1.6E-04	1.3E-03	4.1E-04	2.9E-04	6.7E-05	5.5E-04	1.8E-04	1.2E-04	2.0E-05	1.6E-04	5.3E-05	3.7E-05
C10	0.77	6.24	2.02	1.40	1.0E-04	8.4E-04	2.7E-04	1.9E-04	4.4E-05	3.6E-04	1.2E-04	8.1E-05	1.3E-05	1.1E-04	3.5E-05	2.4E-05
C11	0.46	3.78	1.22	0.85	1.6E-04	1.3E-03	4.3E-04	3.0E-04	7.0E-05	5.7E-04	1.8E-04	1.3E-04	2.1E-05	1.7E-04	5.5E-05	3.9E-05
C12	0.55	4.49	1.45	1.01	1.1E-04	9.4E-04	3.0E-04	2.1E-04	4.9E-05	4.0E-04	1.3E-04	9.0E-05	1.5E-05	1.2E-04	3.9E-05	2.7E-05
C13	1.08	8.79	2.84	1.98	2.3E-04	1.9E-03	6.1E-04	4.2E-04	9.9E-05	8.1E-04	2.6E-04	1.8E-04	3.0E-05	2.4E-04	7.8E-05	5.4E-05
C14	0.55	4.47	1.44	1.00	1.1E-04	9.0E-04	2.9E-04	2.0E-04	4.7E-05	3.9E-04	1.2E-04	8.7E-05	1.4E-05	1.2E-04	3.7E-05	2.6E-05
C15	0.63	5.10	1.65	1.15	1.1E-04	9.3E-04	3.0E-04	2.1E-04	4.9E-05	4.0E-04	1.3E-04	8.9E-05	1.5E-05	1.2E-04	3.8E-05	2.7E-05
C16	0.47	3.79	1.23	0.85	7.1E-05	5.8E-04	1.9E-04	1.3E-04	3.0E-05	2.5E-04	8.0E-05	5.5E-05	9.1E-06	7.4E-05	2.4E-05	1.7E-05
C17	0.56	4.55	1.47	1.02	1.4E-04	1.1E-03	3.6E-04	2.5E-04	5.9E-05	4.8E-04	1.6E-04	1.1E-04	1.8E-05	1.4E-04	4.7E-05	3.2E-05
C18	0.41	3.30	1.07	0.74	9.9E-05	8.1E-04	2.6E-04	1.8E-04	4.2E-05	3.5E-04	1.1E-04	7.8E-05	1.3E-05	1.0E-04	3.3E-05	2.3E-05
C19	0.55	4.45	1.44	1.00	6.5E-05	5.3E-04	1.7E-04	1.2E-04	2.8E-05	2.3E-04	7.3E-05	5.1E-05	8.4E-06	6.8E-05	2.2E-05	1.5E-05
C20	0.51	4.16	1.34	0.93	1.1E-04	8.6E-04	2.8E-04	1.9E-04	4.5E-05	3.7E-04	1.2E-04	8.3E-05	1.4E-05	1.1E-04	3.6E-05	2.5E-05
C21	0.68	5.51	1.78	1.24	1.4E-04	1.1E-03	3.7E-04	2.6E-04	6.0E-05	4.9E-04	1.6E-04	1.1E-04	1.8E-05	1.5E-04	4.8E-05	3.3E-05
C22	0.42	3.43	1.11	0.77	1.2E-04	9.6E-04	3.1E-04	2.2E-04	5.1E-05	4.1E-04	1.3E-04	9.2E-05	1.5E-05	1.2E-04	4.0E-05	2.8E-05
C23	0.69	5.63	1.82	1.27	3.8E-05	3.1E-04	9.9E-05	6.9E-05	1.6E-05	1.3E-04	4.2E-05	2.9E-05	4.8E-06	3.9E-05	1.3E-05	8.8E-06
C24	0.51	4.12	1.33	0.93	9.3E-05	7.6E-04	2.5E-04	1.7E-04	4.0E-05	3.3E-04	1.1E-04	7.3E-05	1.2E-05	9.8E-05	3.2E-05	2.2E-05
C25	0.57	4.68	1.51	1.05	1.2E-04	1.0E-03	3.2E-04	2.2E-04	5.3E-05	4.3E-04	1.4E-04	9.6E-05	1.6E-05	1.3E-04	4.2E-05	2.9E-05
C26	0.47	3.84	1.24	0.86	8.0E-05	6.5E-04	2.1E-04	1.5E-04	3.4E-05	2.8E-04	9.0E-05	6.3E-05	1.0E-05	8.4E-05	2.7E-05	1.9E-05
C27	0.48	3.93	1.27	0.88	4.1E-05	3.3E-04	1.1E-04	7.5E-05	1.8E-05	1.4E-04	4.6E-05	3.2E-05	5.3E-06	4.3E-05	1.4E-05	9.7E-06
C28	0.62	5.03	1.62	1.13	4.0E-05	3.2E-04	1.0E-04	7.3E-05	1.7E-05	1.4E-04	4.5E-05	3.1E-05	5.1E-06	4.1E-05	1.3E-05	9.3E-06

Rec = recreational fisher consumption rate (17.5 g·day⁻¹)
 Sub = subsistence fisher consumption rate (142.4 g·day⁻¹)
 FL = estimated consumption rate for Florida residents (46 g·day⁻¹)
 8 oz = one 8 oz. meal per week consumption rate (32 g·day⁻¹)

Table 12. Hazard indices (HI) and cancer risks associated with consumption of crab muscle from the Pensacola Bay region.

Station ID	HI				Cancer Risk 70 year				Cancer Risk 30 year				Cancer Risk 9 year			
	Rec	Sub	FL	8 oz	Rec	Sub	FL	8 oz	Rec	Sub	FL	8 oz	Rec	Sub	FL	8 oz
C1	0.5	3.8	1.2	0.8	1.4E-05	1.1E-04	3.6E-05	2.5E-05	5.9E-06	4.8E-05	1.6E-05	1.1E-05	1.8E-06	1.4E-05	4.7E-06	3.3E-06
C2	0.5	4.2	1.4	0.9	1.5E-05	1.2E-04	4.0E-05	2.8E-05	6.5E-06	5.3E-05	1.7E-05	1.2E-05	1.9E-06	1.6E-05	5.1E-06	3.6E-06
C3	0.7	6.1	2.0	1.4	8.4E-06	6.9E-05	2.2E-05	1.5E-05	3.6E-06	2.9E-05	9.5E-06	6.6E-06	1.1E-06	8.8E-06	2.9E-06	2.0E-06
C4	0.5	3.9	1.3	0.9	1.7E-05	1.4E-04	4.5E-05	3.1E-05	7.3E-06	5.9E-05	1.9E-05	1.3E-05	2.2E-06	1.8E-05	5.8E-06	4.0E-06
C5	0.4	3.3	1.1	0.8	2.9E-05	2.4E-04	7.7E-05	5.4E-05	1.3E-05	1.0E-04	3.3E-05	2.3E-05	3.8E-06	3.1E-05	1.0E-05	6.9E-06
C6	0.4	3.5	1.1	0.8	2.8E-05	2.3E-04	7.5E-05	5.2E-05	1.2E-05	9.9E-05	3.2E-05	2.2E-05	3.7E-06	3.0E-05	9.6E-06	6.7E-06
C7	0.3	2.1	0.7	0.5	4.0E-05	3.3E-04	1.1E-04	7.4E-05	1.7E-05	1.4E-04	4.5E-05	3.2E-05	5.2E-06	4.2E-05	1.4E-05	9.5E-06
C8	0.5	3.8	1.2	0.8	4.0E-05	3.3E-04	1.1E-04	7.3E-05	1.7E-05	1.4E-04	4.5E-05	3.1E-05	5.1E-06	4.2E-05	1.4E-05	9.4E-06
C9	0.5	4.3	1.4	1.0	4.9E-05	4.0E-04	1.3E-04	9.0E-05	2.1E-05	1.7E-04	5.6E-05	3.9E-05	6.3E-06	5.2E-05	1.7E-05	1.2E-05
C10	0.6	5.2	1.7	1.2	2.6E-05	2.1E-04	6.9E-05	4.8E-05	1.1E-05	9.1E-05	2.9E-05	2.0E-05	3.4E-06	2.7E-05	8.8E-06	6.1E-06
C11	0.4	3.7	1.2	0.8	1.6E-05	1.3E-04	4.1E-05	2.8E-05	6.6E-06	5.4E-05	1.7E-05	1.2E-05	2.0E-06	1.6E-05	5.2E-06	3.6E-06
C12	0.5	4.1	1.3	0.9	1.4E-05	1.1E-04	3.7E-05	2.6E-05	6.0E-06	4.9E-05	1.6E-05	1.1E-05	1.8E-06	1.5E-05	4.7E-06	3.3E-06
C13	0.7	5.3	1.7	1.2	4.2E-05	3.4E-04	1.1E-04	7.7E-05	1.8E-05	1.5E-04	4.7E-05	3.3E-05	5.4E-06	4.4E-05	1.4E-05	9.9E-06
C14	0.5	3.7	1.2	0.8	1.5E-05	1.2E-04	4.0E-05	2.8E-05	6.5E-06	5.3E-05	1.7E-05	1.2E-05	2.0E-06	1.6E-05	5.1E-06	3.6E-06
C15	0.6	4.7	1.5	1.0	3.3E-05	2.6E-04	8.5E-05	5.9E-05	1.4E-05	1.1E-04	3.7E-05	2.5E-05	4.2E-06	3.4E-05	1.1E-05	7.6E-06
C16	0.4	3.6	1.2	0.8	1.7E-05	1.4E-04	4.5E-05	3.1E-05	7.3E-06	5.9E-05	1.9E-05	1.3E-05	2.2E-06	1.8E-05	5.7E-06	4.0E-06
C17	0.6	4.6	1.5	1.0	3.1E-05	2.6E-04	8.2E-05	5.7E-05	1.3E-05	1.1E-04	3.5E-05	2.5E-05	4.0E-06	3.3E-05	1.1E-05	7.4E-06
C18	0.4	3.3	1.1	0.7	1.3E-05	1.1E-04	3.5E-05	2.5E-05	5.8E-06	4.7E-05	1.5E-05	1.1E-05	1.7E-06	1.4E-05	4.5E-06	3.2E-06
C19	0.3	2.5	0.8	0.6	1.9E-05	1.6E-04	5.1E-05	3.5E-05	8.3E-06	6.7E-05	2.2E-05	1.5E-05	2.5E-06	2.0E-05	6.5E-06	4.5E-06
C20	0.5	4.0	1.3	0.9	2.0E-05	1.6E-04	5.2E-05	3.6E-05	8.5E-06	6.9E-05	2.2E-05	1.6E-05	2.5E-06	2.1E-05	6.7E-06	4.7E-06
C21	0.7	5.4	1.7	1.2	2.0E-05	1.6E-04	5.3E-05	3.7E-05	8.7E-06	7.0E-05	2.3E-05	1.6E-05	2.6E-06	2.1E-05	6.8E-06	4.7E-06
C22	0.4	3.2	1.0	0.7	3.3E-05	2.6E-04	8.6E-05	6.0E-05	1.4E-05	1.1E-04	3.7E-05	2.6E-05	4.2E-06	3.4E-05	1.1E-05	7.7E-06
C23	0.7	5.4	1.7	1.2	1.9E-05	1.6E-04	5.0E-05	3.5E-05	8.2E-06	6.6E-05	2.1E-05	1.5E-05	2.5E-06	2.0E-05	6.4E-06	4.5E-06
C24	0.5	3.9	1.3	0.9	2.0E-05	1.6E-04	5.3E-05	3.7E-05	8.6E-06	7.0E-05	2.3E-05	1.6E-05	2.6E-06	2.1E-05	6.8E-06	4.7E-06
C25	0.5	4.5	1.4	1.0	1.9E-05	1.6E-04	5.1E-05	3.6E-05	8.3E-06	6.8E-05	2.2E-05	1.5E-05	2.5E-06	2.0E-05	6.6E-06	4.6E-06
C26	0.4	3.4	1.1	0.8	2.2E-05	1.8E-04	5.7E-05	4.0E-05	9.3E-06	7.6E-05	2.4E-05	1.7E-05	2.8E-06	2.3E-05	7.3E-06	5.1E-06
C27	0.5	3.7	1.2	0.8	2.3E-05	1.9E-04	6.1E-05	4.2E-05	9.9E-06	8.0E-05	2.6E-05	1.8E-05	3.0E-06	2.4E-05	7.8E-06	5.4E-06
C28	0.6	5.0	1.6	1.1	1.5E-05	1.3E-04	4.1E-05	2.8E-05	6.6E-06	5.4E-05	1.7E-05	1.2E-05	2.0E-06	1.6E-05	5.2E-06	3.6E-06

Rec = recreational fisher consumption rate (17.5 g·day⁻¹)
 Sub = subsistence fisher consumption rate (142.4 g·day⁻¹)
 FL = estimated consumption rate for Florida residents (46 g·day⁻¹)
 8 oz = one 8 oz. meal per week consumption rate (32 g·day⁻¹)

Table 13. Hazard indices (HI) and cancer risks associated with consumption of oysters from the Pensacola Bay region.

ID	HI				Cancer Risk 70 year				Cancer Risk 30 year				Cancer Risk 9 year			
	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.	Rec	Sub	FL	8 oz.
O1	1.1	8.7	2.8	2.0	1.7E-04	1.4E-03	4.5E-04	3.1E-04	7.3E-05	6.0E-04	1.9E-04	1.3E-04	2.2E-05	1.8E-04	5.8E-05	4.0E-05
O2	0.9	7.1	2.3	1.6	2.3E-04	1.9E-03	6.2E-04	4.3E-04	1.0E-04	8.2E-04	2.6E-04	1.8E-04	3.0E-05	2.5E-04	7.9E-05	5.5E-05
O3	0.3	2.8	0.9	0.6	7.8E-05	6.3E-04	2.0E-04	1.4E-04	3.3E-05	2.7E-04	8.8E-05	6.1E-05	1.0E-05	8.1E-05	2.6E-05	1.8E-05
O4	0.4	3.5	1.1	0.8	5.6E-05	4.6E-04	1.5E-04	1.0E-04	2.4E-05	2.0E-04	6.3E-05	4.4E-05	7.2E-06	5.9E-05	1.9E-05	1.3E-05
O5	0.2	1.8	0.6	0.4	6.7E-05	5.5E-04	1.8E-04	1.2E-04	2.9E-05	2.3E-04	7.6E-05	5.3E-05	8.6E-06	7.0E-05	2.3E-05	1.6E-05
O6	0.3	2.6	0.9	0.6	2.7E-05	2.2E-04	7.0E-05	4.9E-05	1.1E-05	9.3E-05	3.0E-05	2.1E-05	3.4E-06	2.8E-05	9.0E-06	6.3E-06
O7	0.2	1.6	0.5	0.4	3.7E-05	3.0E-04	9.8E-05	6.8E-05	1.6E-05	1.3E-04	4.2E-05	2.9E-05	4.8E-06	3.9E-05	1.3E-05	8.8E-06
O8	0.3	2.3	0.7	0.5	5.6E-05	4.5E-04	1.5E-04	1.0E-04	2.4E-05	1.9E-04	6.3E-05	4.4E-05	7.2E-06	5.8E-05	1.9E-05	1.3E-05
O9	0.3	2.7	0.9	0.6	7.7E-05	6.3E-04	2.0E-04	1.4E-04	3.3E-05	2.7E-04	8.7E-05	6.0E-05	9.9E-06	8.0E-05	2.6E-05	1.8E-05
O10	0.5	3.7	1.2	0.8	3.2E-05	2.6E-04	8.5E-05	5.9E-05	1.4E-05	1.1E-04	3.6E-05	2.5E-05	4.1E-06	3.4E-05	1.1E-05	7.6E-06
O11	0.3	2.7	0.9	0.6	2.6E-05	2.1E-04	6.8E-05	4.8E-05	1.1E-05	9.1E-05	2.9E-05	2.0E-05	3.3E-06	2.7E-05	8.8E-06	6.1E-06
O12	0.4	3.1	1.0	0.7	3.5E-05	2.8E-04	9.2E-05	6.4E-05	1.5E-05	1.2E-04	3.9E-05	2.7E-05	4.5E-06	3.6E-05	1.2E-05	8.2E-06
O13	0.6	4.8	1.5	1.1	3.1E-05	2.5E-04	8.2E-05	5.7E-05	1.3E-05	1.1E-04	3.5E-05	2.4E-05	4.0E-06	3.2E-05	1.0E-05	7.3E-06
O14	1.0	8.2	2.6	1.8	4.9E-05	4.0E-04	1.3E-04	8.9E-05	2.1E-05	1.7E-04	5.5E-05	3.8E-05	6.3E-06	5.1E-05	1.6E-05	1.1E-05
O15	1.2	10.0	3.2	2.2	4.2E-05	3.5E-04	1.1E-04	7.8E-05	1.8E-05	1.5E-04	4.8E-05	3.3E-05	5.5E-06	4.4E-05	1.4E-05	1.0E-05
O16	0.6	4.7	1.5	1.1	4.3E-05	3.5E-04	1.1E-04	7.9E-05	1.9E-05	1.5E-04	4.9E-05	3.4E-05	5.6E-06	4.5E-05	1.5E-05	1.0E-05
O17	0.3	2.5	0.8	0.6	5.5E-05	4.5E-04	1.4E-04	1.0E-04	2.4E-05	1.9E-04	6.2E-05	4.3E-05	7.1E-06	5.7E-05	1.9E-05	1.3E-05
O18	0.4	3.0	1.0	0.7	2.3E-05	1.8E-04	5.9E-05	4.1E-05	9.7E-06	7.9E-05	2.5E-05	1.8E-05	2.9E-06	2.4E-05	7.6E-06	5.3E-06
O19	0.4	3.3	1.1	0.7	2.3E-05	1.9E-04	6.0E-05	4.2E-05	9.8E-06	8.0E-05	2.6E-05	1.8E-05	3.0E-06	2.4E-05	7.8E-06	5.4E-06
O20	0.4	3.5	1.1	0.8	1.9E-05	1.6E-04	5.1E-05	3.5E-05	8.3E-06	6.8E-05	2.2E-05	1.5E-05	2.5E-06	2.0E-05	6.5E-06	4.6E-06
O21	0.4	3.3	1.1	0.7	2.1E-05	1.7E-04	5.5E-05	3.8E-05	9.0E-06	7.3E-05	2.4E-05	1.6E-05	2.7E-06	2.2E-05	7.1E-06	4.9E-06
O22	0.4	3.5	1.1	0.8	2.0E-05	1.6E-04	5.2E-05	3.6E-05	8.5E-06	6.9E-05	2.2E-05	1.5E-05	2.5E-06	2.1E-05	6.7E-06	4.6E-06
O23	0.4	3.5	1.1	0.8	5.4E-05	4.4E-04	1.4E-04	9.9E-05	2.3E-05	1.9E-04	6.1E-05	4.3E-05	7.0E-06	5.7E-05	1.8E-05	1.3E-05

Rec = recreational fisher consumption rate (17.5 g·day⁻¹)
 Sub = subsistence fisher consumption rate (142.4 g·day⁻¹)
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 8 oz = one 8 oz. meal per week consumption rate (32 g·day⁻¹)

Risk Characterization

While the EPA-based SVs are intended to set a threshold above which fish consumption advisories may be required for a contaminant, the SVs do not characterize the specific health hazards for individuals exposed to contaminants in the fish or shellfish. We therefore utilized risk assessment guidance developed by the EPA to estimate the potential for adverse health effects (both cancer risk and non-cancer hazards) in various consumers of blue crabs and oysters from the Pensacola Bay region. We analyzed the tissue samples for two contaminant groups that are classified as carcinogens and for which a CSF is available - arsenic (inorganic) and dioxins/furans/dioxin-like PCBs. Crab hepatopancreas samples consistently exceeded a cancer risk of 1×10^{-4} regardless of consumption rate for the 30 and 70-year exposures, and all hepatopancreas samples exceeded a cancer risk of 1×10^{-5} (Table 10). Two hepatopancreas sampling locations in Bayou Chico and one in western Escambia Bay (Gaberonne) exceeded a cancer risk of 1×10^{-2} under a 70 year, subsistence fisher exposure scenario. Under the 30 and 70-year scenarios, all total edible crab tissue samples exceeded an excess cancer risk of 1×10^{-5} and the majority of samples exceeded a risk of 1×10^{-4} (Table 11). Excess cancer risk for crab muscle was substantially lower and exceeded 1×10^{-4} only at the highest consumption rate and/or the 70-year exposure regime (Table 12). Four locations exceeded this risk level under the Florida consumption scenario at 70 years exposure. Oyster samples exhibited a risk profile (Table 13) similar to crabs, although two samples from the urban bayous (Bayou Chico and Bayou Grande) exceeded an excess cancer risk of 1×10^{-4} even at the lowest consumption rate for the 70-year exposure. Dioxins/PCBs accounted for 85-99%, 60-90%, 27-94%, and 53-99% of the total excess cancer risk for crab hepatopancreas, total edible crab tissue, crab muscle, and oysters, respectively.

Non-carcinogenic health risks were evaluated for seven of the analyzed metals using the exposure assumptions described above. Three of the metals were not included in the HI calculations for any samples because either none of the samples exceeded the detection limits (lead) or RfDs were not available (copper, tin). Cadmium was omitted from the HI calculations for crab muscle because all concentrations were below the detection limits. The mercury HQ accounted for 64-87% of the total HI in crab muscle, and thus the primary potential non-carcinogenic health effects of concern under the consumption scenarios in which crab muscle samples exceed an HI of 1.0 would be neurological or reproductive. In crab hepatopancreas samples, mercury and cadmium accounted for the primary potential non-carcinogenic health effects of concern (neurological, reproductive and renal) in samples that exceeded a total HI of 1.0. In two hepatopancreas samples, Perdido Bay-Tarkiln and in Bayou Chico Mouth, cardiovascular effects may be of concern under the highest exposure scenario due to levels of inorganic arsenic. Potential non-carcinogenic health effects in oysters based on total HI that exceeded 1.0 included metabolic effects from zinc, renal effects from cadmium, and reproductive or neurological effects due to mercury.

Regional Contamination

Contaminant levels in all tissue types varied by study site. The highest TEQ_{DF} in crab muscle, crab hepatopancreas, and total edible crab tissue were observed in samples from western Escambia Bay and from the urbanized bayous, regardless of TEQ calculation method used (ND=DL/2 or ND=0) (Figure 2). Likewise, in oysters, the lowest TEQ_{DFPS} were observed for oyster samples from the commercial oyster beds in East Bay and Escambia Bay, and the highest TEQ_{DFPS} were found in samples taken from the urbanized bayous (Figure 3). Cancer risks were

highest for crabs and oysters collected from the urban bayous, reflecting the patterns observed for TEQ_{DFP} (Figures 4 and 5).

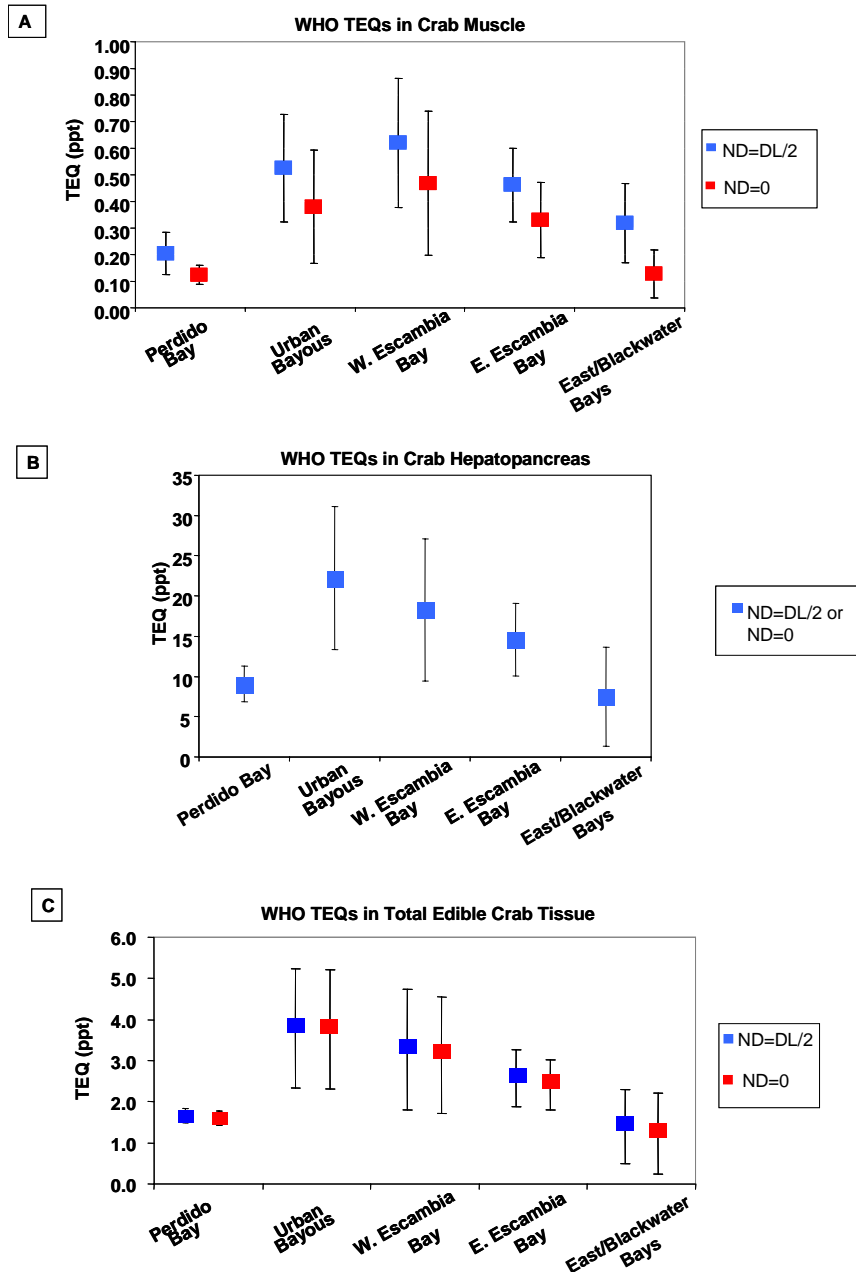


Figure 2. Mean TEQs ($pg\ g^{-1}$) in crab muscle (A), hepatopancreas (B,) and total edible crab tissues (C) from the five sampling regions in the Pensacola Bay system. TEQ_{DFPS} were calculated using TEF values derived by the WHO and by substituting either one-half the detection limit ($ND=DL/2$) or zero ($ND=0$) for congeners that were below the detection limit. Samples from the urban bayous and from western Escambia Bay consistently exhibited the highest TEQs. Data points and error bars represent mean \pm standard deviation.

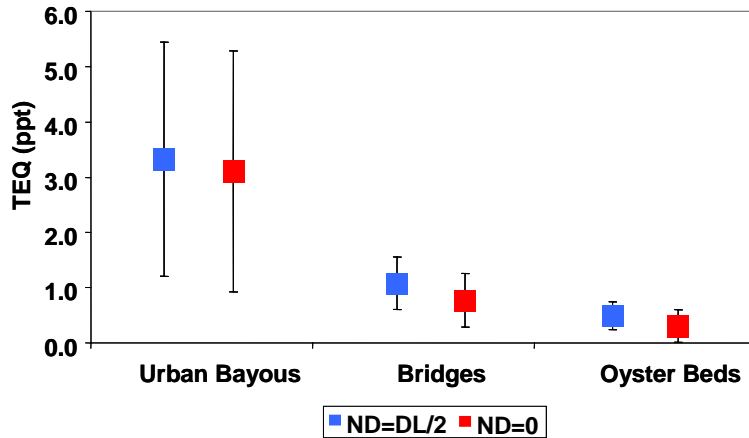


Figure 3. Mean TEQ_{DFP} (pg.g⁻¹) in oysters collected from urban bayous, bay-spanning bridges, and commercial oyster beds in the Pensacola Bay system. TEQ_{DFP}s were calculated from dioxin/furan and dioxin-like PCB concentrations using TEF values derived by the WHO and by substituting either one-half the detection limit (ND=DL/2) or zero (ND=0) for congeners that were below the detection limit. Samples from the urban bayous consistently exhibited the highest TEQ_{DFP}s. Data points and error bars represent mean± standard deviation.

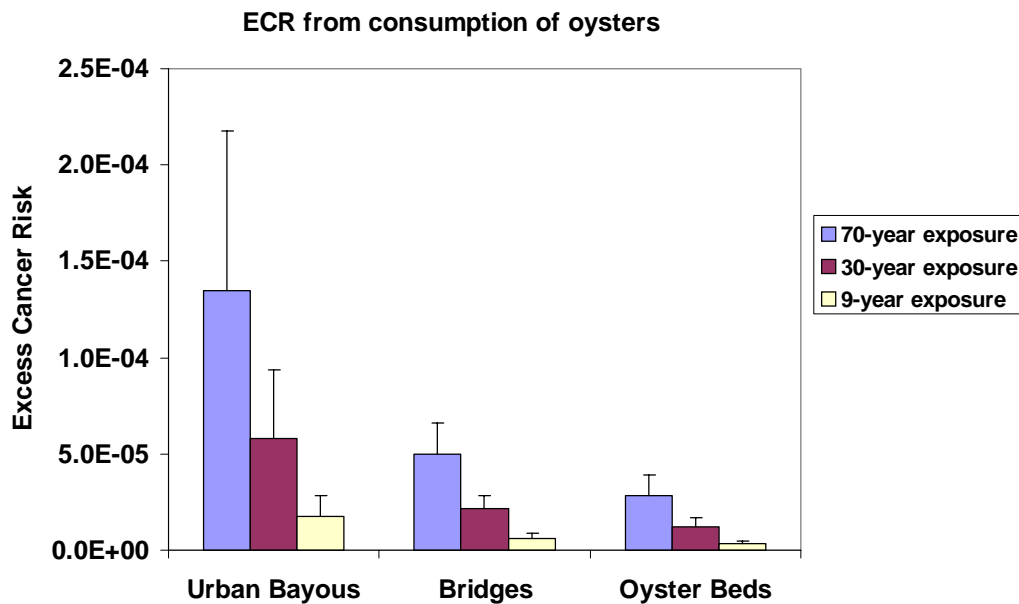


Figure 4. Excess cancer risk (ECR) from consumption of oysters collected in the Pensacola Bay system. The ECR was calculated using the recreational fisher consumption rate (17.5 g day⁻¹). Oyster samples collected from the urban bayous exhibited the highest ECRs due to contamination by dioxins/furans and dioxin-like PCBs. Data and error bars represent mean± standard deviation.

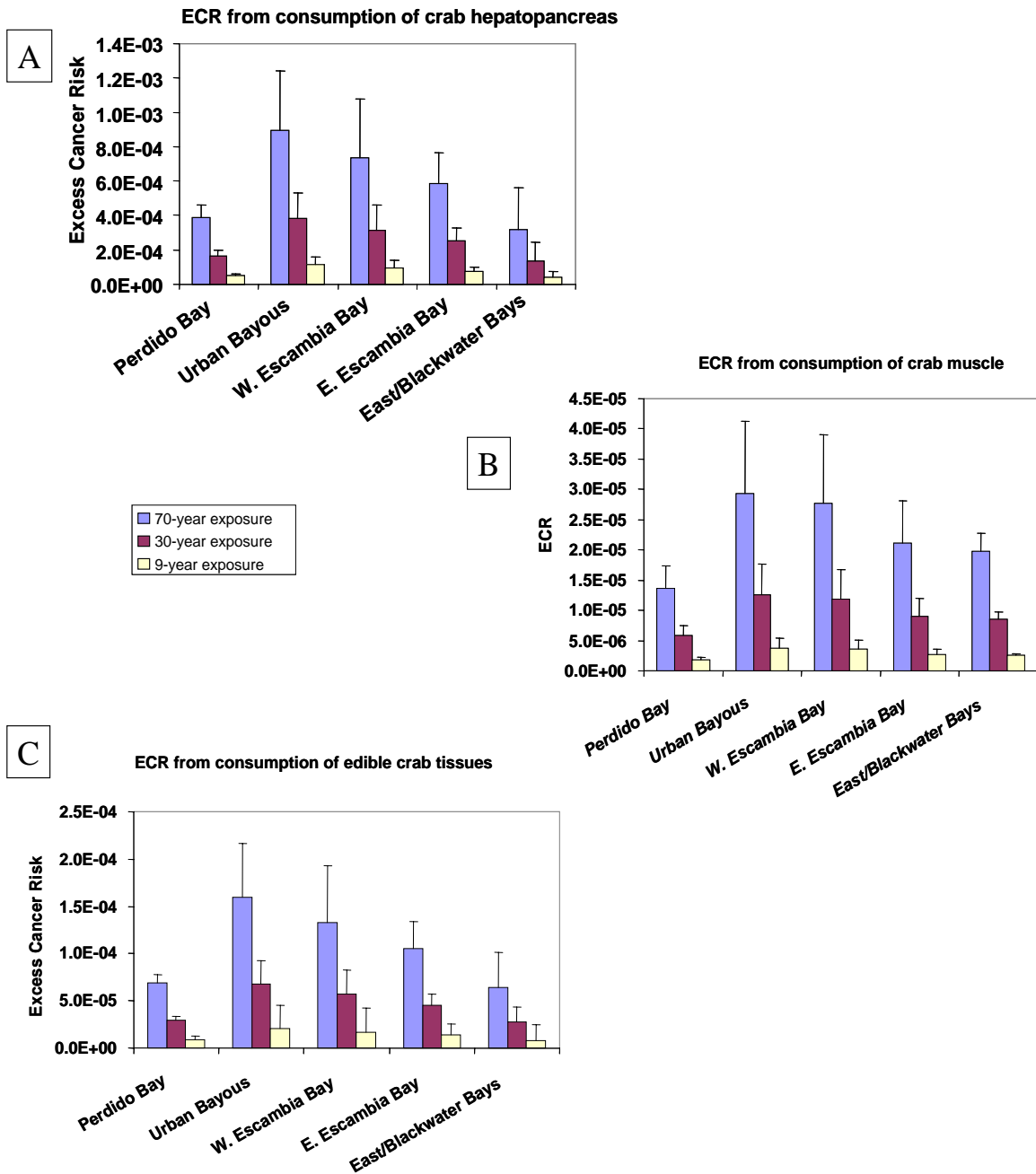


Figure 5. Excess cancer risk (ECR) from consumption of blue crabs collected in the Pensacola Bay system. ECR represented in these graphs were calculated using the recreational fisher consumption rate ($17.5 \text{ g}\cdot\text{day}^{-1}$). Crab hepatopancreas (A), crab muscle (B), and total edible crab tissues (C) from the urban bayous and western Escambia Bay exhibited the highest ECRs. Data and error bars represent mean \pm standard deviation.

Metal concentrations were more ubiquitous in their geographic patterns of contamination than dioxins/PCBs, and although no consistent patterns were evident in the distribution of all

metals, crabs and oysters from the urbanized bayous exhibited the highest levels of several metals including copper and cadmium. In oysters, mercury and zinc concentrations were highest in samples collected from the urban bayous and bridge pilings, and lowest in commercial oyster beds, whereas copper levels were highest in samples from the urban waters.

DISCUSSION

Dioxins/furans, dioxin-like PCBs, arsenic, mercury, cadmium, and zinc were identified as potential chemicals of concern in crabs and/or oysters collected from the Pensacola Bay region. The levels of these contaminants exceeded at least one of the screening values calculated based upon four consumption scenarios that estimated fish ingestion rates for various population segments of the Pensacola Bay region. However, the spatial distribution of the SV exceedences was not homogeneous. Several hotspot areas were identified, and these areas were characterized by SV exceedences for multiple chemicals.

Organic Contaminants

Analysis of crabs and oysters obtained from many locations in the Pensacola Bay region suggests that elevated levels of dioxins/furans and dioxin-like PCBs exist in localized areas. The elevated levels are particularly evident in crab and crab hepatopancreas samples taken in the urbanized bayous in the city of Pensacola and along the western edge of Escambia Bay, which abuts the city of Pensacola. However, crab samples from several locations exhibited consistently lower levels of contamination. These areas included Perdido Bay and East/Blackwater Bays. Similar patterns were observed in oyster tissues - those samples collected in urbanized areas exhibited the highest TEQ_{DFF}. Of the three tissues sampled, crab muscle exhibited the lowest

levels of contamination, which reflects its lower lipid content relative to hepatopancreas and oyster tissue. In general, because of their direct contact with sediment and diet of mostly benthic organisms, crabs are expected to contain higher levels of dioxins and PCBs than filter-feeders such as oysters (Ylitalo et al., 1999), and based on the significant accumulation of these contaminants in the crab hepatopancreas samples in the present study, our data support this observation.

Direct comparisons of our data with those from other studies were complicated by differences in TEQ calculation method (International-TEQ vs. WHO-TEQ), use of various substitution methods for concentrations that are below detection limit, higher detection limits in previous studies, and exclusion of either dioxins/furans or dioxin-like PCBs from the analyses. Comparison studies that reported TEQ_{DFP} for oysters or blue crabs could not be identified. Likewise, few studies of blue crabs and oysters reported congener-specific data, which could have allowed for recalculation of TEQs using the WHO method, and most studies reported PCB concentrations as total PCBs. In studies where detailed data were provided, we recalculated TEQs in order to enable more accurate comparisons to our data.

Ylitalo et al. (1999) studied only dioxin-like PCBs in blue crabs collected from several locations along the east coast of the United States, the majority of which were located either within or just downstream of urban areas. Although mean TEQ_P in crab hepatopancreas samples (Table 5b) from the urbanized bayous and western Escambia Bay were lower than mean TEQ_P reported by Ylitalo et al. (1999) for samples from Baltimore Harbor, MD (24 pg g^{-1}) and the St. John's River, FL (83 pg g^{-1}), the maximum concentrations from the most contaminated locations in the present study fell within the range observed in Baltimore Harbor. Likewise, the hepatopancreas samples from the urban bayous, western Escambia Bay, and eastern Escambia

Bay exceeded the mean concentrations reported by Ylitalo et al. (1999) for three other locations along the lower east coast of the United States that are considered urban-impacted areas (Charleston Harbor, SC, Cape Fear River, NC, and Savannah River, GA). Hepatopancreas samples from the areas in the present study with lower levels of industrial or urban development (Perdido Bay and East/Blackwater Bay) also exceeded TEQ_P from comparable locations reported by Ylitalo et al (Sapelo Sound, GA and Chester River, MD). However, because none of their samples exceeded the detection limit for PCB 126, Ylitalo et al. did not include PCB126 in their TEQ_P calculations. Due to its high TEF value (0.1), PCB126 accounted for 44-87% of our TEQs in crab hepatopancreas and muscle samples. Therefore, the TEQ_P calculated by Ylitalo et al. likely underestimated the actual TEQ_P in their study.

TEQ_P for crab muscle samples collected from the urbanized bayous and western and eastern Escambia Bay also exceeded all mean crab muscle TEQ_P reported by Ylitalo et al. (1999) for samples collected in urbanized areas. However, the crab muscle samples we collected from the less developed areas (Blackwater/East Bays and Perdido Bay) exhibited similar TEQ_P to those reported by Ylitalo et al. (1999) at comparable locations.

The highest TEQ_{DF} for crab hepatopancreas samples from the most contaminated locations within the Pensacola Bay region (urban bayous) were between five and ten fold lower than TEQ_{DF} for data reported for an urbanized river in the New York/New Jersey Harbor Estuary (Lower Raritan River) by Ashley and Horwitz (2002) (106.9-210.9 pg·g⁻¹; ND=0) and by Iannuzzi et al. (2004) for the lower Passaic River (210-410 pg·g⁻¹; ND=DL/2). Maximum TEQ_{DF} for crab muscle samples from the urban bayous in the Pensacola Bay region were also lower than nearly all samples from the Lower Raritan River (0.0 - 7.9 pg·g⁻¹; ND=0) and lower Passaic River (30 - 150 pg·g⁻¹; ND=DL/2). The range of TEQ_{DF} (0.002-1.00 pg·g⁻¹ ND=0 and 0.043-

1.002 $\text{pg}\cdot\text{g}^{-1}$ ND=DL/2) reported by Jensen and Bolger (2001) for blue crab muscle tissue collected from 500 retailers across the United States also exhibited higher maxima and mean levels than we observed in any of our sample groups.

Sericano et al. (1994) reported TEQ_P for oysters collected from Galveston Bay, TX and Tampa Bay, FL, two highly urbanized watersheds. The majority of samples from these locations exhibited higher TEQ_P (2.7-55.5 $\text{pg}\cdot\text{g}^{-1}$ and 0.3-14.5 $\text{pg}\cdot\text{g}^{-1}$, respectively) than those reported here for urban sampling locations. Jensen and Bolger (2001) sampled oysters from retailers across the United States and reported TEQ_{DF} (0.11-0.898 $\text{pg}\cdot\text{g}^{-1}$, mean 0.442 $\text{pg}\cdot\text{g}^{-1}$ ND=0 and 0.14-0.901 $\text{pg}\cdot\text{g}^{-1}$, mean 0.448 $\text{pg}\cdot\text{g}^{-1}$ ND=DL/2) that were higher than the maxima and mean TEQ_{DF} in oysters collected from commercial oyster beds and bridges in the Pensacola Bay region. Likewise, our commercial oyster bed and bridge samples had lower TEQ_{DF} than oysters collected by Fiedler et al. (1997) from seafood markets in southern Mississippi (0.65-0.79 $\text{pg}\cdot\text{g}^{-1}$, mean 0.69 $\text{pg}\cdot\text{g}^{-1}$, ND=DL/2). However, both mean and maximum TEQ_{DF} of samples collected from the urban waterways in the Pensacola region exceeded those reported by Jensen and Bolger (2001) and Fiedler et al. (1997) by two to five fold.

Inorganic Contaminants of Concern

Of the contaminants identified as potential chemicals of concern in the present study, four were metals (inorganic arsenic, mercury, cadmium, and zinc). Although all four are released naturally into the environment through weathering and leaching processes, human activities have modified the budgets of these elements in estuaries and coastal waters such that their levels in fish and shellfish pose a threat to human consumers.

Both organic and inorganic arsenic species are present in marine tissues. Inorganic arsenic is substantially more toxic to humans than organic species, but it typically represents from <1 to 20% of total arsenic in seafood and is not transferred efficiently through marine food webs (U.S. EPA, 2000). Although nearly all of the samples in the present study exceeded at least one of the SVs, consumption of crab hepatopancreas would present the highest health risk due to inorganic arsenic, even at the lowest consumption rates analyzed. However, crab muscle and oysters from select locations may also be a significant source of inorganic arsenic to consumers. To date, most studies of contamination in marine species have focused on total arsenic concentrations and therefore few data are available on inorganic arsenic levels in blue crabs and eastern oysters. Higher than national average arsenic levels have been previously reported at many locations in the southeastern U.S. and Gulf Coast in sediments and oysters as a result of elevated natural and anthropogenic inputs (Valette-Silver et al., 1999). According to the National Status and Trends (NST) Mussel Watch Project, the national NST mean concentration for total arsenic is $11.1 \pm 3.4 \text{ mg} \cdot \text{kg}^{-1}$ dry weight (ca. $1.65 \pm 0.5 \text{ mg} \cdot \text{kg}^{-1}$ wet weight) and contamination in oysters is considered “high” when arsenic levels are above $14.5 \text{ mg} \cdot \text{kg}^{-1}$ dry weight (ca. $2.15 \text{ mg} \cdot \text{kg}^{-1}$ wet weight) (Valette-Silver et al., 1999). Although a number of sampling locations in the present study exceeded these national levels, especially in the commercial oyster beds, arsenic levels in all of our samples were below the NST mean concentration for the southeast coast of the U.S. ($25.4 \pm 10.4 \text{ mg} \cdot \text{kg}^{-1}$ dry weight, ca. $3.77 \pm 1.5 \text{ mg} \cdot \text{kg}^{-1}$ wet weight). The higher oyster and sediment levels in the Pensacola region also appear to be reflected in crab tissue concentrations. Mean total arsenic concentrations in all crab muscle and hepatopancreas sample groups in the present study exceeded those reported by Jop et al. (1997) for two urbanized estuaries in Connecticut and also exceeded those reported by Ju and Harvey (2002) for a reference site in

Maryland. Crab muscle and hepatopancreas samples from Perdido Bay, the urban bayous and East/Blackwater Bay also exhibited higher mean total arsenic levels than two urbanized sites near Baltimore, MD (Ju and Harvey, 2002).

Mercury is among the most widely dispersed contaminants in the aquatic environment, and nearly 75% of fish consumption advisories in the United States have been issued due to mercury contamination (U.S. EPA, 2003). Although both organic and inorganic forms of mercury are considered neurotoxins, mercury is assimilated by fish and shellfish primarily as methylmercury (U.S. EPA, 2000). With few exceptions, crab muscle samples collected in the present study exhibited the highest levels of mercury of the three tissue types analyzed. Because of their trophic status, crabs are expected to bioaccumulate higher levels of mercury than oysters. Mercury was unique among the monitored contaminants in that higher concentrations were found in muscle relative to hepatopancreas. In general, the mercury concentrations found in crab muscle and hepatopancreas in the present study exceeded those observed in several locations in the northeastern U.S. (Eisenberg and Topping, 1984; Jop et al., 1997; Ju and Harvey, 2002; Iannuzzi et al., 2004). However, other locations in the Gulf of Mexico with comparable land use features and similar annual rainfall amounts exhibited similar levels of mercury in crab muscle to those observed in the Pensacola Bay region (Ache et al., 2000).

The levels of mercury in oysters from the present study fell within the range (0.01-0.14 $\text{mg}\cdot\text{kg}^{-1}$) of concentrations reported previously for the Pensacola Bay system and other locations along the Florida Panhandle (0.008-0.37 $\text{mg}\cdot\text{kg}^{-1}$) (Ache et al., 2000; Oliver et al., 2001; Lewis et al., 2004). However, they generally exceeded the NST national median concentration (0.015 $\text{mg}\cdot\text{kg}^{-1}$ wet weight), and mean levels in samples from the urban waterways and bridges exceeded the NST 85th percentile (0.034 $\text{mg}\cdot\text{kg}^{-1}$ wet weight) (O'Connor, 2002). Despite these

exceedences, mercury levels in oysters in the present study, especially those from commercial oyster beds, were generally low and are unlikely to cause adverse health effects. In contrast, the higher mercury levels in crabs may be of concern for consumers whose diet frequently includes large portions of crabs. Long-term ingestion of mercury-contaminated seafood is associated with a wide range of neurological effects, and the increased risk of adverse neurological effects from exposure to methylmercury is of particular concern for fetuses and young children (U.S. EPA, 2000).

As has been observed for mercury, increasing coal combustion in the U.S. has resulted in rising cadmium levels in the aquatic environment. Cadmium is bioconcentrated in marine animals to levels hundreds to thousands of times higher than those in water, and data indicate that cadmium bioaccumulates in all levels of the food chain, although biomagnification may not be significant (ATSDR, 2002). In the present study, the primary concern for cadmium exposure above screening values was from crab hepatopancreas samples. The hepatopancreas preferentially accumulates cadmium when blue crabs are exposed to cadmium in their diet (Brouwer et al., 1995), and cadmium is known to accumulate in blue crabs in proportion to environmental exposure (Ju and Harvey, 2002). Mean cadmium levels in our hepatopancreas samples from the urbanized bayous were higher than those reported by Jop et al. (1997) for blue crab hepatopancreas collected from two urban estuaries in Connecticut (mean \pm SD = 1.18 ± 0.10 and 0.93 ± 0.02 , respectively) and by Iannuzzi et al. (2004) for the Passaic River in New Jersey (0.67 ± 0.23). Likewise, Ju and Harvey (2002) reported lower cadmium levels in samples from one reference and two urban locations in the Chesapeake Bay (mean range 0.19 - 0.28 $\text{mg} \cdot \text{kg}^{-1}$ wet weight). Although cadmium was detected in many oyster samples, the levels were generally below all screening values and were similar to levels reported by an FDA survey of Eastern

oysters collected from U.S. coastal areas used for shellfish production (0.51 ± 0.31 mg/kg wet weight) (ATSDR, 2002).

Zinc, also identified as a potential contaminant of concern in the present study based on the subsistence fisher SVs, is an essential nutrient, which is required by humans at low levels. However, excess dietary zinc can also be harmful to human health. Among the potential effects of excess dietary zinc are copper deficiency anemia, reduced HDL-cholesterol and increased LDL-cholesterol, and acute health effects include dehydration, electrolyte imbalance, gastrointestinal distress (pain, nausea, vomiting), lethargy, dizziness, and lack of muscular coordination (U.S. EPA, 2004). The highest zinc concentrations in the present study were observed in Pensacola Bay area oysters - 1200 mg kg^{-1} , a concentration that would result in consumption of about 272 mg of zinc in an eight-ounce meal of oysters. Available data suggest that 500 to 1,000 milligrams or more of zinc may be ingested daily without acute adverse effects (Texas Department of Health, 2003). Therefore, the levels of zinc reported here are unlikely to cause acute health effects in consumers. Chronic effects from zinc due to oyster consumption would only be likely at the highest consumption rate (subsistence fishers) and few, if any, adverse health effects would be expected from zinc at the lower consumption rates.

Risk Analyses

Although the screening values used in the present study identified contaminants that are of potential concern to human consumers of shellfish caught in the Pensacola Bay region, the SVs focus only on individual chemicals and do not take into account the total potential for adverse health effects from all analyzed contaminants in a sample or tissue type. Therefore, we also evaluated the cancer or non-cancer risks posed by consumption of shellfish from the various

sampling locations. Based on the risk analyses, consumption of hepatopancreas would pose the highest cancer and non-carcinogenic health effects risks. In general, blue crab hepatopancreas contained the highest levels of lipid-soluble contaminants (dioxins and PCBs) and metals such as arsenic, copper and cadmium. Consumers who do not deliberately eat the hepatopancreas can still be exposed to its contaminants if crabs are cooked whole because contaminants in the hepatopancreas are transferred to cooking liquid and muscle tissue. Zabik et al. (1992) reported that PCB concentrations in cooked crab muscle was 14% higher when the organisms were cooked whole. Our estimates of contaminant levels in total edible tissue demonstrated the effects of including hepatopancreas in a crab meal. Both cancer risks and SV exceedences increased over those observed for crab muscle samples alone. Many states have issued consumption advisories specifically for crab hepatopancreas including Maryland, New York, New Jersey and Washington (U.S. EPA, 2003), and based on the results from the present study, consumption of hepatopancreas, whether directly or indirectly, from crabs collected in the Pensacola Bay region should be discouraged.

In contrast to crab hepatopancreas, analysis of crab muscle and oyster tissue revealed elevated risks only at specific locations and under the longest exposure and highest consumption scenarios. For example, none of the oyster samples from commercial beds exceeded an excess cancer risk of 1×10^{-4} , except under the subsistence fisher consumption scenario (142.6 g/d or 35 oz per week). Likewise, in crab muscle, an excess cancer risk of 1×10^{-4} was exceeded primarily under the subsistence fisher consumption scenario. A notable trend revealed by the data indicated that regardless of tissue type, samples from one of the urbanized and most industrialized bayous (Bayou Chico) consistently had the highest cancer risks under all evaluated scenarios. Similarly, another of the urbanized bayous, Bayou Grande, also showed consistently elevated risks.

Coincidentally, samples from these two waterbodies also had among the highest copper and cadmium levels in oysters and crab hepatopancreas. Previous studies of these two bayous have demonstrated significant contamination of sediments and water samples, including metals and various organics (Lewis et al., 2001), and our data indicate that many of these contaminants are being accumulated by shellfish to levels that are of potential human health concern.

All of the cancer risks discussed in this report should be considered upper bound estimates of the increased risk resulting from exposure to the analyzed chemicals. However, because the shellfish analyzed in this study may also contain other carcinogenic contaminants that were not analyzed here, the reported risk levels may in actuality underestimate the true risk. The hazard indices and estimates of cancer risks presented here are based on the consumption of an individual shellfish species and tissue type, and do not take into account multiple species diets, which could significantly change the exposure rate to the various contaminants. Generally, people who regularly eat contaminated seafood are exposed to low concentrations of contaminants over an extended time. This pattern of exposure seldom results in acute toxicity but may increase the risk of subtle, delayed or chronic adverse health effects (Texas Department of Health, 2003).

Effects of below detection limit values

For several chemicals and samples, concentrations were found to be below the detection limits. This scenario increases the uncertainty associated with any calculations because the actual concentrations of chemicals that are present at or below detection limits could lay anywhere between the detection limit and zero. Therefore, an assumption must be made as to which value to use in calculating the various indices. The most common methods used in previous studies

substituted either zero or one-half the detection limit for those values (Ylitalo et al., 1999; Jensen and Bolger, 2001; U.S. EPA, 2002), and we compared both substitution methods in our calculations. Due to the high levels of dioxins and PCBs in crab hepatopancreas, using the alternate ND=0 method for calculating TEQs had no effect on the values. In contrast, in crab muscle samples, use of the ND=0 method substantially lowered the TEQs and consequently the cancer risks (data not shown) for several locations, such as Blackwater Bay and Yellow River. A similar response was observed for oyster samples from the commercial oyster beds. This exposes an inherent bias in this approach, which artificially increases the TEQ proportionally with an increasing number of non-detects. Few differences were observed in the HI calculations between the two substitution methods.

Spatial Distributions of Contaminants

The results of the crab and oyster tissue analyses in the present study appear to reflect the spatial distribution of contaminants in the sediment of the Pensacola Bay system. Samples from East and Blackwater Bays, which have low to moderate levels of sediment contamination (Debusk et al., 2002) generally exhibited the lowest levels of the measured contaminants. Likewise, although several discrete areas of Perdido Bay are contaminated and it is considered an area of potential concern due to sediment contamination (U.S. EPA, 1997), several reports have shown that Perdido Bay generally has low levels of toxic compounds (Brim, 1993). These observations were supported by the generally low levels of contamination in crab tissue in Perdido Bay relative to other locations.

A sediment data review conducted by DeBusk et al. (2002) found that the highest sediment concentrations of PCBs occurred in Escambia Bay, particularly along the western edge,

and in the urban bayous of Pensacola, which was reflected in the PCB and dioxin contamination patterns in crabs and oysters from the present study. Potential sources of PCBs in Escambia Bay include residual contamination from a 1969 PCB spill from a local chemical company and several industrial facilities located in the upper part of the Bay and on the Escambia River (Hemming et al., 2003). Likewise, industrial facilities and Superfund areas are the primary potential sources of PCBs in the bayous.

Few data are available on sediment dioxin levels in the Pensacola region. Although extremely elevated sediment levels of dioxins have been reported for a freshwater tributary to Perdido Bay, Hemming et al. (2003) and Brim (1993) found that within the bay itself, sediment dioxin levels are similar to those observed in Pensacola Bay. This observation was supported by the levels of dioxins in crab tissues, which showed similar concentrations in samples from all sampling regions except the urban bayous. Oyster and crab tissue samples from the bayous consistently exhibited among the highest dioxin concentrations. Sediment profiles of dioxin levels in the urban bayous of Pensacola have not been previously reported. However, dioxins are often found as impurities of PCB formulations (Hemming et al., 2003), and thus, in addition to areas impacted by known dioxin point sources, elevated sediment dioxin levels are commonly observed in locations with elevated PCBs.

Levels of certain metals in tissue samples also reflected regional patterns of sediment contamination. For example, copper concentrations in both crab hepatopancreas and oysters were highest in the urban bayous, which have also been reported to contain the highest sediment levels of copper (Debusk et al., 2002). Similarly, sediment copper concentrations are generally higher on the western side of Escambia Bay than on the eastern side (Debusk et al., 2002), which again was reflected in levels of copper in crab hepatopancreas. Cadmium concentrations in blue crab

hepatopancreas also reflected the higher sediment levels in the urbanized bayous than in the other sampling regions.

Conclusions

We found that oysters and blue crabs from several locations in the Pensacola Bay region contain levels of contaminants that may pose a risk to human health, based on exceedence of calculated screening values and elevated cancer or non-cancer risk indices. In general, risks to human health were greatest from consumption of shellfish collected from urbanized waterbodies including the bayous within the city of Pensacola and from locations in Escambia Bay. However, several inherent uncertainties exist when calculating human health risks. As was demonstrated by the risk analyses, factors such as exposure duration and consumption rate can have a profound effect on the level of carcinogenic and non-carcinogenic risk that is associated with ingestion of contaminated tissues. For that reason, we chose three periods of exposure and four consumption rates to provide a range of risk estimates. These estimates will allow individuals to gauge their own risk relative to harvest locations and consumption rates. The risk estimates were also based on the assumption that only one species or tissue type would be consumed. Because most people eat a diet that is composed of multiple fish and shellfish species, these estimates may not adequately represent actual risk for consumers. Despite these uncertainties, our data demonstrate that certain contaminants, particularly dioxins/furans and dioxin-like PCBs, are accumulating in regional shellfish samples, which suggests that further investigation is warranted to determine whether consumption advisories should be issued for shellfish from specific locations in the Pensacola Bay region. In general, direct or indirect consumption of hepatopancreas from crabs collected anywhere in the Pensacola Bay region is not recommended.

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