Strengthening Coastal Pollution Management in the Wider Caribbean Region

Reforzando la Gestión de Contaminación Costera en la Región Gran Caribe

Renforcerla Gestion de la Pollution Côtière dans la Région des Caraïbes

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ABSTRACT

Control of aquatic pollution is critical for improving coastal zone management and for the conservation of fisheries resources. Countries in the Wider Caribbean Region (WCR) generally lack monitoring capacity and do not have reliable information on the levels and distribution of pollutants, particularly chemical contaminants, and the ecological and/or human health risks. Given the substantial cultural and economic importance of coastal environments to WCR communities, this should be cause for serious concern. This paper describes two studies determining persistent organic pollutants (POPs) in 1) the white grunt fish (*Haemulon plumieri*) and 2) three oyster species. It highlights lessons learned on improving capacity for environmental monitoring of POPs and how to build an effective south-south network involving academic institutions, laboratories and management agencies. Data are reported for Jamaica, St. Lucia, Trinidad and Tobago, Belize, and the Caribbean coast of Mexico. Overall, PCB and organochlorine concentrations were low relative to consumption guidelines used to protect the health of humans consuming contaminated seafood. However, since both monitoring organisms occupy low to mid-trophic levels in the marine food web, there is a risk of higher contaminant concentrations accumulating in top trophic levels, such as piscivorous fish and birds. Identified sources of contaminants include domestic sewage, agriculture and industry, large continental rivers and atmospheric deposition. For example, data indicate that atmospheric deposition is a likely source of POPs in Belize, while there is evidence of point sources of POPs in St. Lucia. Currently, these are the only data available on POPs contamination in fish and oysters distributed across the WCR, but will hopefully lead to future studies, increased awareness and strengthening of coastal pollution management.

KEY WORDS: Chemical pollution, coastal management, environmental monitoring

INTRODUCTION

The coastal marine environment of the Wider Caribbean Region (WCR) consists of fragile ecosystems that are considered hotspots in marine biodiversity (Brooks and Smith 2001), and are integral to the economies of many WCR nations (WRI 2004). On average, coastal marine environments generate well in excess of 50% of GDP in Caribbean nations through the valuable resources and services they provide in the form of coastal tourism, fisheries, and shoreline protection (WRI 2011). The coastal tourism sector is an especially important economic driver and accounts for up to 70% of the GDP in the smaller islands such as Antigua and Barbuda (WTTC 2010). Hence, the integrity of the WCR marine and coastal environment is paramount to its sustainable future. These valuable ecosystems are under severe stress from a range of human activities (WRI 2004). Within the last 20 years, population growth, intensive tourism development, and industrialization, especially in the more developed WCR nations, have substantially increased the risk of contamination of coastal environments and associated coastal degradation in the Caribbean (GESAMP 1991, UNEP 1994, Chang 1997, UNEP 2002). In the past 15 years. the number of tourist accommodations more than doubled, with numbers still growing (CTO 2011), and it is estimated that 85% of the wastewater that is discharged into the Caribbean basin remains untreated (UNEP 2004a). The unique karst geology found in many WCR nations makes coastal areas especially susceptible to land-based pollution sources where contaminated groundwater resources are discharged into coastal zones (Metcalfe et al. 2010).

Of serious concern in the WCR region is pollution by persistent organic pollutants (POPs) (UNEP 1994, UNEP 2002, Fernandez 2007). POPs are highly toxic chemical substances that persist in the environment and often “biomagnify” in the food chain, causing adverse human health effects and impacts to the environment. These substances typically affect human health via consumption of fisheries products. Although POPs may not be a priority for the smaller Caribbean islands with limited industrial development, overall POPs ranked second in the WCR priority rankings of contaminant categories (GESAMP 2001). The potential negative effects of POPs in the marine and coastal environments include changes in reef community structure, such as decreases in live coral cover and increases in algae and sponges, and damage to seagrass beds and other aquatic vegetation from herbicides (Rawlins et al. 1998). Massive coral mortalities and cases of egg shell thinning in birds have been reported, and fish mass mortality has occurred in areas of agricultural runoff where pesticides have been illegally used (UNEP 2002). For example, in Jamaica an increase in fish mortality in coastal areas coincides with the period of the year when pesticides are applied on coffee plantations (Chin Sue 2002). Coral larvae show high susceptibility to the toxicity of pesticides at concentrations around their detection limit (Markey et al. 2007). These observations highlight the critical need to assess toxicity against all life-history stages of keystone organisms, as a focus on mature individuals may underestimate species sensitivity.

Most Caribbean nations are signatories to the Stockholm Convention, which aims to reduce and mitigate contamination from selected POPs. However, there is little capacity within the Caribbean to analyze and monitor POPs in humans, fish and wildlife, and the abiotic environment. Published data on POPs in coastal environments are scarce and an overall picture is difficult to make because of incomparability between surveys and lack of monitoring and surveillance programs. The available regional evidence of POPs in air, marine and freshwater ecosystems, biota, foods, and humans is scattered across time periods, locations, and analytical methods (UNEP 2002, Fernandez et al. 2007). Specific studies of POPs contamination in the Caribbean coastal environment have been limited to a few projects that have detected localized sources of contamination (Norena-Barroso et al. 2004, Coat et al. 2006). POPs sources identified in this region include sewage inputs, mineral extraction, pesticide usage in agriculture, hydrocarbon extraction, and waste from the industrial sector (UNEP 1999, UNEP 2002). In addition to contamination from localized point sources of POPs, the Caribbean basin may be influenced by inputs of contaminants at a regional scale from large continental rivers, such as the Orinoco River to the southeast and the three major rivers that enter the Gulf of Honduras to the southwest. It is predicted that 90% of the pesticides used in the WCR do not meet their intended target, and a high proportion enters the marine environment via runoff, erosion, misapplication, and atmospheric transport (Fernandez 2007). The steep topography of most of the islands and cultivation on precipitous slopes encourages soil erosion and the movement of pesticides to coastal areas. Finally, climate change may increase the planet's vulnerability to POPs and may result in changes in the atmospheric deposition of POPs to the Caribbean (Semeena et al. 2006, UNEP 2010). Considerable data gaps for POPs remain and necessitate reliable inventories of sources, as well as monitoring of emissions, transmission and deposition, and surveillance of environmental and health effects (UNEP 2002).

Poor water quality in coastal areas can lead to rapid degradation of coastal habitats, fishery resources, and biodiversity and impact economic activities and livelihoods of coastal communities. Given the substantial cultural and economic importance of the coastal environment to the people of the Caribbean, the lack of information concerning the occurrence, concentration, and impacts on biota of chemical pollutants should be cause for serious concern. There is a need to improve land management practices and to monitor the effectiveness of management on improving water quality on adjacent inshore reefs. This paper will describe two studies that were performed as part of the Caribbean Coastal Pollution Project (CCPP), initiated to develop capacity within the Caribbean for monitoring POPs in the coastal environment of eight WCR countries and to determine the distribution of POPs in marine resources throughout the WCR. The first study focuses on monitoring the levels of POPs in fish tissues using data from the white grunt fish (*Haemulon plumieri*). The second study involves a qualitative biomonitoring survey using oysters collected at selected study locations from Jamaica, Trinidad and Mexico. The contaminants monitored included the 12 POPs originally identified under the Stockholm Convention ("dirty dozen"), plus some of the POPs most recently listed under Stockholm in May, 2009 ("nasty nine").

METHODS AND MATERIALS

White Grunt Study

White grunt were collected by the 8 partner countries (Figure 1) at a total of 61 coastal sites in the WCR (Table 1). The rationale for selecting the white grunt for the monitoring study was that this species:

i) Is widely distributed across the Caribbean,
ii) Is a reef fish that is relatively philopatric, and so reflects contamination in discrete locations and,
iii) Has been monitored previously for POPs in the western Caribbean through the Meso American Barrier Reef (MBRS) program.

White grunt from Jamaica, Trinidad and Tobago, and St. Lucia were shipped to the regional laboratory at UWI Mona in Jamaica, and white grunt collected from Belize, the Dominican Republic, Honduras, and the Caribbean coast of Mexico were sent to the regional laboratory at CINVESTAV in Merida, Mexico. Note that no data were generated for samples collected along the Caribbean coasts of Dominican Republic, Honduras, Guatemala because the samples were deemed unusable. Each country collected three fish (where available) at an average of six sites per country. Ideally at each site, the fish sampled would be 300 – 500 g in weight. If no white grunt were present, another benthic-feeding, non-pelagic fish were collected.

Muscle tissue was analyzed because it can be related to risk for the consumption of POPs in edible tissues of fish. There are drawbacks to using white grunt for a monitoring study of POPs. This species of fish is not high in trophic position, and therefore, is expected to show little effect of food web biomagnification. It also has low lipid content in its tissues, and therefore, is not likely to accumulate lipophilic contaminants (i.e., POPs) to high concentrations. Dorsal muscle tissues of white grunt (4 - 5

g) were spiked with an internal standard (PCB 30) and extracted using cold column extraction at UWI Mona, and by another solvent extraction method at CINVESTAV. Because of the low lipid content of the white grunt tissues (i.e., < 0.5%), it was not necessary to remove lipid using gel permeation chromatography (GPC), so tissues were cleaned up directly using either florisil (Lazar et al. 1992) or silica gel column chromatography. Three fractions were generated by florisil chromatography:

i) Fraction 1 containing primarily PCBs, and
ii) Fractions II and III containing organochlorine compounds. For silica gel chromatorgraphy, Fraction I contained primarily PCBs and Fraction II contained organochlorine compounds

These fractions were analyzed for the PCB congeners and organochlorine compounds listed in Table 2 by gas chromatography with an electron capture detector (i.e., GC -ECD), using either an Agilent 7890 or a Varian Saturn gas chromatograph. Laboratory blanks and a certified reference material (CRM) of Lake Michigan fish were extracted with each batch of 3 - 6 white grunt samples. Only the POPs data for samples collected in Mexico, Jamaica, St. Lucia, and in Trinidad and Tobago are presented in this report, for reasons that are discussed below.

In addition, a limited number of samples of white grunt collected from Belize (n = 5) were analyzed for concentrations of selected congeners of polybrominated diphenyl ethers (PBDEs). For PBDE analysis, Fraction II from the florisil cleanup step was analyzed by gas chromatography with mass spectrometry using an Agilent 7890 gas chromatograph with a mass selective detector (i.e., GC-MSD). Analysis of the PBDE congeners listed in Table 2 was conducted at the Great Lakes Institute for Environmental Research (GLIER) at the University of Windsor.

Figure 1. Sites in the wider Caribbean region where white grunt were sampled for analysis by the regional laboratories at UWI Mona (Jamaica) and CINVESTAV (Mexico).

Oyster Study

Mangrove oysters, *Crassostrea rhizophorae* were collected from three locations along the Caribbean coast of Mexico, four sites in Trinidad and one site in Jamaica. The oysters species, *Isognomon alatus* and *Perna viridis* were also collected from three sites in Jamaica. Table 3 lists the sampling locations and their GPS coordinates, where available. Several individual oysters of the smaller mangrove species, *Crassostrea rhizophorae*, were pooled into 1 g samples (approximately five shucked individuals

Table 1. List of target compounds analyzed in samples of white grunt dorsal muscle.

Organochlorine compounds

Hexachlorobenzene (HCB)
∑chlordane: *cis*-chlordane, *trans*-chlordane, *oxy*-chlordane
∑DDT: o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, o,p'-DDT, p,p'-DDT
∑BHC : α-BHC, ß-BHC, γ-BHC, δ-BHC
∑'drins: aldrin, dieldrin, endrin
∑heptachlor: heptachlor, *cis*-heptachlor epoxide, *trans*-heptachlor epoxide
∑endosulfan: endosulfan I, endosulfan II
Mirex
Methoxychlor

PCBs:

∑PCB: Congener numbers 18, 31/28, 33, 44, 49, 52, 66/95, 70/76, 74, 82/151, 87, 99, 101, 105/132, 110, 118, 128, 138, 149, 153, 156/171, 158, 170/190, 177, 180, 183, 187, 191, 194, 195/208, 201, 205, 206, 209

PBDEs:

∑PBDE : Congener numbers 3, 7, 15, 17, 28, 47, 49, 66, 71, 77, 85, 99, 100, 123, 138, 153, 154, 183, 184, 196, 197

Table 2. Sampling sites, site codes and numbers of white grunt analyzed from each site (in brackets).

Mexico	Pt Pajaros **MX010** (3)	Villablanca **MX012** (2)	Tulum **MX013** (3)	Chitales **MX014** (3)				
Jamaica	Cow River **JM001** (2)	Cow Bay **JM002** (3)	Discovery Bay **JM003** (2)	Kingston Harbour **JM004** (0[1])	Negril **JM005**(3)	Ocho Rios **JM006** (3)	Portland Bight **JM007** (1)	St. Marg Bay **JM008**(4)
St. Lucia	Anse Le Raya Bay **LC001** (0[1])	Castries Harbour[2] **LC002** (0[1])	Ciceron Bay **LC003** (0[1])	Fond d"Or **LC004** (3)	Roseau **LC005** (3)	Vieux Fort BB **LC006** (3)	Castries Harbour[2] **LC007**(3)	Vieux Fort Airport **LC008**(3)
Trinidad & Tobago	Charlotteville **TT001** (2)	Matura **TT002** (3)	Ortoire **TT003** (3)	Mt. Irvine **TT004** (3)	Moruga **TT005** (3)	Chagaramus **TT006** (3)		

1) No white grunt were collected at these sites
2)Two sites at Castries Bay were sampled. No fish were collected at the first site.

per sample). Both the number of oysters and relative weight of individual oysters contributed to each pool were recorded. *Isognomon* and *Perna* spp. were analysed as individuals, owing to the larger size of these organisms.

Chemical analysis — Oysters collected from Trinidad and Jamaica were extracted for selected POPs compounds using a micro-extraction method (Daley et al. 2009) followed by florisil cleanup (Lazar et al. 1992). Oysters collected from Mexico were extracted by a solvent/sample sonication procedure, followed by florisil clean-up. Each sample was spiked with 7 ng PCB 30 for use as an internal recovery standard prior to extraction. For each batch of six samples, a blank and reference tissue homogenate was extracted. For Jamaica and Trinidad oysters, an in-house (Aroclor spiked goat liver homogenate) reference tissue was used. Extractions of Trinidad and Jamaica oysters were performed at the University of Windsor. Extractions and chemical analysis of Mexico oysters were performed by the CINVESTAV laboratory, Mexico. Instrumental analysis was performed by gas chromatography with electron capture detection (GC-ECD), as described in Lazar et al. (1992). Both laboratories used the same certified standards, Quebec Ministry of Environment PCB Congener Mix (Chromatographic Specialties, Brockville, ON, Canada, Cat # C-QME-01) and Pesticide/Congener Mix 1 (Chromatographic Specialties, Brockville, ON, Canada, Cat # AE-00010) for quantitation purposes.

Organochlorine pesticide analytes included the following compounds: cis-chlordane, trans-chlordane, oxy-chlordane, o,p'-DDD, p,p'-DDD, o,p'-DDE, p,p'-DDE, o,p'-DDT, p,p'-DDT, dieldrin, α-endosulfan, β-endosulfan, α-HCH, β-HCH, У-HCH, heptachlor, cis-heptachlor epoxide, trans-heptachlor epoxide, hexachloro-benzene and mirex. Polychlorinated biphenyls were analysed as the sum of 41 individual and co-eluting congeners present in the certified standard mixture. All analytes were identified by retention time and according to expected elution profiles in florisil fractions.

RESULTS AND DISCUSSION

Despite the limited number of samples available, the two studies were able to identify some major classes of POPs in white grunt and three oyster species, establish a very preliminary geographic pattern of POPs in coastal areas, as well as indentify potential sources, with indications for transboundary and atmospheric transport. Furthermore, through these studies the regional capacity for monitoring and management of POPs in coastal biota was assessed and enhanced.

White Grunt Study

Quality control — checks of the laboratory blanks generated for the samples from Belize and Guatemala indicated that there was considerable background contamination, which interfered with the analysis of extracts prepared from white grunt. Samples from the Dominican Republic were not suitable for analysis because of delays in delivery of the samples to the regional lab in Mexico. Therefore, POPs data generated from white grunt collected off the coast of Belize, Guatemala, and the Dominican Republic are not included in this report. Tissue samples from white grunt (n = 11) collected off the Caribbean coast of Mexico were extracted at Trent University using the cold column extraction method and analyzed by GC-ECD.

The laboratory blanks generated from white grunt from Jamaica, St. Lucia, and Trinidad and Tobago extracts

Table 3. Sample locations and species of oysters collected per country.

	Site	Coordinates	Species
Mexico	Isla de Contoy		
	Station 1	N21o28' 04.5" W86o47'23.70"	*Crassostrea rhizophorae*
	Station 2	N21o29' 34.5" W86o47'59.50"	*Crassostrea rhizophorae*
	Station 3	N21o21' 28.2" W86o47'22.53"	*Crassostrea rhizophorae*
	Sian Ka'an		
	Station 1	N19o47' 12. 2" W87o28'52.4"	*Crassostrea rhizophorae*
	Station 2	N19o48' 11. 4" W87o33'08.9"	*Crassostrea rhizophorae*
	Station 3	N19o46' 19. 0" W87o35.10.1"	*Crassostrea rhizophorae*
	Xcalak		
	Station 1	N18o16' 37.0" W87o50'15.0"	*Crassostrea rhizophorae*
	Station 2	N18o16' 42.7" W87o50'12.4"	*Crassostrea rhizophorae*
	Station 3	N18o16' 40.8" W86o47'23.7"	*Crassostrea rhizophorae*
Trinidad	Blue River	N10o36"21.8" W61o28'25.86"	*Crassostrea rhizophorae*
	Entrance Canal	N10o36"18.7" W61o26'31.50"	*Crassostrea rhizophorae*
	L. Lagoon	N10o35"49.6" W61o27'5.10"	*Crassostrea rhizophorae*
	Espagnol River	N10 o32"35.0" W61o27'41.40"	*Crassostrea rhizophorae*
Jamaica	Port Royal		*Crassostrea rhizophorae*
	Old Harbour		*Isognomon alatus*
	Bowden, St.		*Perna viridis*
	Thomas		*Isognomon alatus*
			Perna viridis
			Isognomon alatus
			Perna viridis

had acceptable levels of background contamination, so the results of the analyses of these extracts are presented in this report. Typically, three white grunt were analyzed from each site, although in a few cases, 1, 2 or 4 white grunt were analyzed (Table 1). At some locations, no white grunt were collected, and so there are no contaminant data (Table 1).

At UWI Mona, the recoveries of the internal standard (i.e., PCB 30) varied between 72 - 113%, indicating that the analytes were extracted from muscle tissue with acceptable recoveries. Table 4 shows the mean concentrations of PCBs and organochlorine (OC) compounds in the 8 samples of the Certified Reference Material (CRM) that were analyzed at UWI Mona in comparison to the certified values. These data indicate that the UWI Mona was reasonably accurate in analyzing the CRM samples, although, this regional laboratory tended to overestimate the concentrations of o,p-DDE and PCB congener 87, while underestimating the concentration of p,p-DDE, dieldrin and PCB congeners 52, 99, 153, and 180. Note that p.p-DDT was not detected in the CRM (Table 4), indicating that the UWI Mona laboratory experienced a problem with this compound. The concentrations of PCBs and OCs were generally 2-3 orders of magnitude greater in the CRM (i.e., Lake Michigan fish) relative to the concentrations detected in white grunt. Therefore, the analysis of white grunt from the Caribbean presented a considerable technical challenge to the two regional laboratories.

PCBs and organochlorines in white grunt — The data generated from the analysis of white grunt showed that PCB congeners and OC compounds were generally present in the muscle tissues at concentrations < 10 µg/kg wet weight (i.e., ppb). These low concentrations were expected, due to the low lipid content of the tissues and the low trophic position of white grunt within the marine food web. Marine fish with higher lipid contents, such as tuna or mackerel would likely accumulate higher concentrations of these lipophilic compounds (Uemo et al. 2004). However, these pelagic fish species are highly mobile and are not likely to provide an indication of regional or local patterns of POPs contamination.

The pesticide, p,p-DDT were not detected in any of the tissues analyzed by the UWI Mona lab, but it must be noted that the latter compound was also not detected in the CRM. This compound was detected at low concentrations (< 0.1 µg/kg) in samples from Mexico that were analyzed at Trent University. Mirex was not detected in any of the white grunt tissues. Figure 2 shows the trends for mean levels of ∑PCB, ∑DDT, ∑BHC, ∑chlordane, ∑heptachlor, ∑endosulfan, HCB and methoxychlor in the white grunt collected from Mexico, Jamaica, St. Lucia, and Trinidad and Tobago. These data indicate that the mean concentrations of these classes of compounds were relatively homogeneous across the sampling sites. However, the mean concentrations of methoxychlor, ∑PCB and ∑BHC were significantly higher in white grunt collected from St. Lucia. The concentrations of ∑chlordane were marginally higher in white grunt from the Caribbean coast of Mexico, but this difference was not statistically significant.

Table 4. Mean concentrations of (n = 8) of reference compounds in the Lake Michigan CRM compared to the certified values (µg/kg wet weight).

PCB congener	Concentration measured	Certified concentration	OC compound	Concentration measured	Certified concentration
31/28	16.2	10.4/14.1	HCB	5.2	7.5
44	9.6	20.4	"BHC	1.1	1.3
49	12.8	27.3	*trans*-chlordane	15.8	12.8
52	7.5	36.4	oxychlordane*	14.2	23.6/13.4
74	27.5	33.7	dieldrin	25.4	80.8
66/95	51.3	69.4	mirex	12.6	5.1
87	41.6	27.9	o,p-DDE	28.7	3.4
99	38.8	78	p,p-DDE	218.5	720
101	75.7	90.8	o,p-DDD	0.9	3.3
110	54.2	94.6	p,p-DDD	21.2	45.9
118	81.3	112	o,p-DDT	43.9	15.7
105/132	43.1	50.3/20.8	p,p-DDT	ND	59.5
128	26.1	31.6			
138	128.4	162			
149	40.1	67.1			
153	110.2	201			
156/171	15.4	13.3			
158	10.1	11.3			
180	50.9	80.8			
183	15.5	23.3			
187	36.2	54.8			
170/190	23.0	29.2			
194	13.9	13.2			
195/208	4.9	4.9			
206	5.1	6.2			

For BHCs detected in white grunt from locations other than St. Lucia, ß-BHC was either the dominant congener, or the only one detected. This indicates that the BHCs originate from pesticide applications of "technical BHC"; a mixture of BHC isomers in which ßBHC is the dominant compound. ∑DDT was not present at high concentrations in any of the white grunt samples (Figure 3), and p,p'-DDE was the predominant compound detected from this class in white grunt samples. The presence of the DDE metabolite reflects transformation from DDT that was used at some time in the past, and shows that there has been no recent use of this insecticide. The structurally related compound, methoxychlor has been used as a substitute pesticide for DDT because it is less persistent in the environment. Methoxychlor was observed in white grunt from St. Lucia at concentrations that were significantly elevated relative to levels in fish from the other two locations (Table 1).

Because of their recent or ongoing use for the control of insect pests, BHC and chlordane compounds have been detected in marine biota from tropical and subtropical countries in both the western and eastern hemispheres (Norena-Barroso et al. 2004, Bayen et al. 2005, Minh et al. 2006, Imo et al. 2008). Dieldrin has been detected in marine biota from other developing countries in the western hemisphere, such as Argentina (Menone et al. 2001), but the origin of this compound could be from the widespread use of the related insecticide, aldrin, which is rapidly transformed in the environment to dieldrin. Rainwater et al. (2007) detected dieldrin, as well as DDE, DDT, endrin and methoxychlor in the caudal scutes of crocodiles sampled off the coast of Belize. However, these contaminants tend to occur at concentrations below the levels observed in fish from industrialized areas of the northern hemisphere. Table 4 shows the very high concentrations of OCs in the Lake Michigan fish CRM, including the very high concentrations of p,p-DDE in fish from this Great Lakes region.

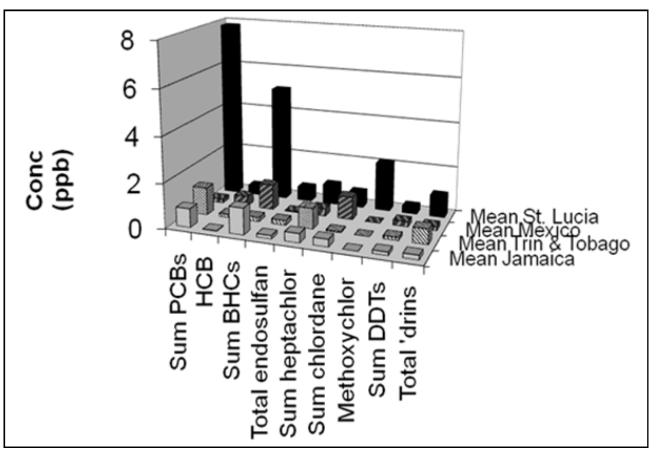

Figure 2. Mean concentrations (μg/kg wet weight) of classes of compounds analyzed in white grunt collected from all sites in Jamaica (n = 19), St. Lucia (n = 15), Trinidad and Tobago (n = 17), and the Caribbean coast of Mexico (n = 11), respectively.

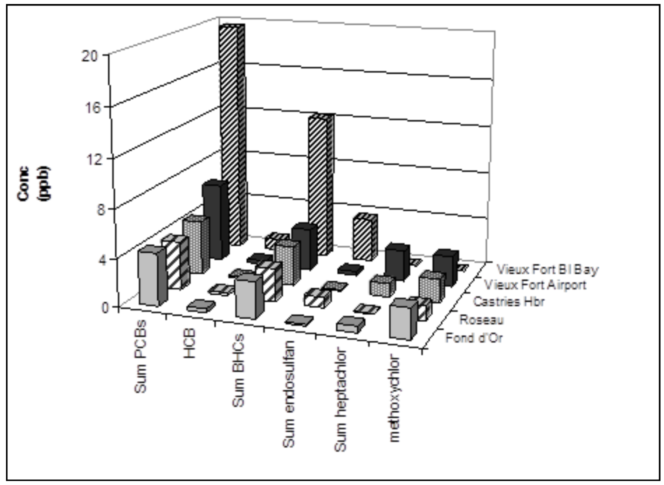

Figure 3. Mean concentrations (μg/kg wet weight) of classes of compounds analyzed in white grunt (n = 3) collected from each of the five sites in St. Lucia.

The differences in OC contamination observed in white grunt from the four countries located in the Caribbean basin to the north (Jamaica), west (Mexico) and east (St. Lucia, Trinidad and Tobago) may reflect:

i) Geographical differences in the use of pesticides,
ii) Differences in overland or subsurface transport pathways from the source to the coastal zone,
iii) Marine circulation patterns and currents, and/or
iv) Patterns of atmospheric deposition of POPs in the Caribbean.

However, a more complete data set is required to evaluate the factors that influence OC contamination in the Caribbean. Data are also required to evaluate pesticide use in these countries to determine whether white grunt contamination reflects local use of OC compounds.

To further investigate the trend of higher concentrations of PCBs and BHCs in white grunt from St. Lucia, the mean concentrations of several classes of compounds were determined in the white grunt (n = 3 per site) collected from the five different sampling sites in St. Lucia (Figure 3). These data indicate that the levels of methoxychlor, HCB and ∑heptachlor were relatively homogeneous across all stations. However, the mean concentrations of ∑PCB and ∑BHC were significantly elevated in fish collected at Vieux Fort Black Bay (LC006). Although ∑endosulfan appeared to also be present at a higher mean concentration in white grunt collected at Vieux Fort Black Bay (Figure 3), this difference was not statistically significant. The significantly higher mean concentration of BHC in the samples from Vieux Fort Black Bay was primarily due to the very high ∑BHC concentration of 34.3 µg/kg wet weight observed in one of the 3 fish collected from this site (i.e., 26.2 µg/kg ßBHC, 6.9 µg/kg γBHC, 1.2 µg/kg δBHC). The ∑BHC concentrations in the other two fish from this location were 1.84 and 1.67 µg/kg, respectively. These data on BHC levels should be interpreted with caution until more fish are analyzed from this site.

Several PCB congeners were detected in extracts prepared from white grunt muscle tissue. Figure 4 shows the PCB congener pattern for three white grunt collected at the Vieux Fort Airport (LC008) site in St. Lucia, where the congener patterns were dominated by PCBs with a low degree of chlorination (i.e., tri-, tetra-, and penta-chlorobiphenyls). This pattern is typical of the PCBs detected in white grunt at other locations in the Greater Caribbean region, except for the three fish collected from Vieux Fort Black Bay in St. Lucia where more highly chlorinated PCB congeners were detected (Figure 4). The pattern of PCB congeners generally seen in white grunt from the greater Caribbean region (except for Vieux Fort Black Bay) indicates that the source of contamination is atmospheric deposition, since the less chlorinated PCB compounds are subject to transport in the atmosphere. However, the congener pattern observed in white grunt collected from Vieux Fort Black Bay in St. Lucia indicates that there is a point source of PCBs at this single site. A more extensive monitoring program may have identified other point sources of PCBs, but it was often difficult to collect white grunt at industrialized locations, such as Kingston Harbour (JM004) in Jamaica.

PCBs have been used extensively in the WCR since the 1930s, reaching the marine environment via dry and wet deposition, sewage sludge used as fertilizer, and leaching from landfills (Mansingh and Wilson (1995), Sbriz et al. (1998) and Jaffé et al. (2002). POPs data from Barbados Trinidad and Tobago, and Jamaica have indicated that POPs may be transported by the Northeast Trade Winds (UNEP 2002). This is supported by Fernandez et al. (2007) who suggest that POPs can be found in most parts of the region, including locations that are far from the pollution sources which indicates long-range transport of these contaminants. The countries of North Africa in the Sahel region apply large amounts of pesticides, including those banned in the WCR and the United States. These pesticides are present in dust reaching the WCR and southern United States from North Africa (USGS 2000).

PBDEs in white grunt — Analysis of samples prepared from five white grunt that were collected off the coast of Belize for PBDEs revealed that several congeners were present at detectable concentrations in the muscle tissue, including congeners 47, 77, 99, 85, 126, 153 and 184 (Figure 5). The mean and maximum total PBDE concentrations were 0.84 and 1.4 µg/kg wet weight, respectively, or 284 and 452 µg/g lipid weight, respectively. The concentrations on a lipid normalized basis are similar to fish from other regions of the world, and the congener pattern is the same as has been reported for marine fish from regions in the Pacific, North America and Europe (Boon et al. 2002, Dodder et al. 2002, Ueno et al. 2004, Minh et al. 2006, Brown et al. 2006).

Fish consumption advisories — The ∑PCB concentrations in the muscle of the three white grunt collected from Vieux Fort Black Bay were 12.8, 17.5 and 25.2 µg/kg wet weight,

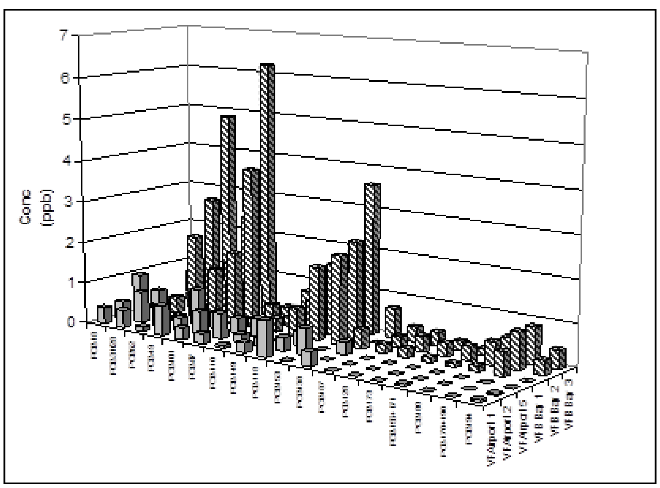

Figure 4. Concentrations (µg/kg wet weight) of major PCB congeners detected in the three white grunt collected from each of the Vieux Fort Airport (grey bars) and Vieux Fort Black Bay (black bars) sites in St. Lucia.

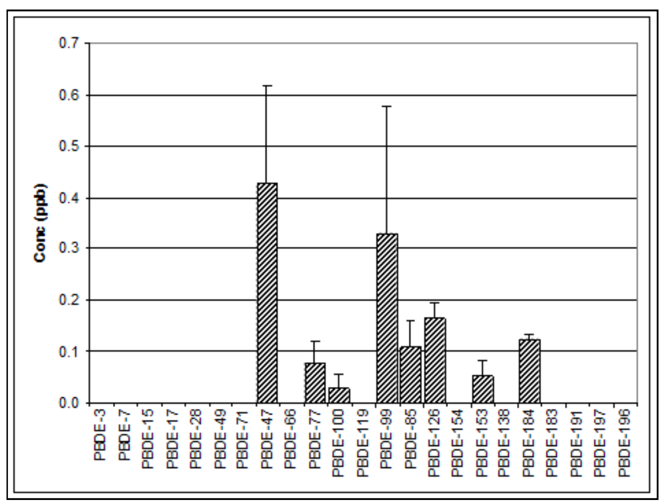

Figure 5. Mean concentrations (µg/kg wet weight) of PBDE congeners in white grunt (n = 5) collected off the coast of Belize.

and ∑PCB concentrations in all other samples were less than 10 µg/kg wet weight. For comparison, the average measured ∑PCB concentration in the CRM of a fish from Lake Michigan fish was 1,079.5 µg/kg wet weight. Note that the concentrations of PCBs in the white grunt from Vieux Fort Black Bay are below the most restrictive fish consumption advisory for PCBs reported in the USA of 50 µg/kg wet weight (Table 5). The Health Canada fish consumption advisory for PCBs is 2,000 µg/kg wet weight. The summary data shown in Table 5 shows that none of the concentrations of compounds detected in white grunt approached even the most stringent of fish consumption advisory levels from the USA, or the higher advisories recommended by Health Canada. Therefore, there are not likely to be any health impacts from the consumption of white grunt from these three regions of the Caribbean. The very low lipid content of the muscle tissues for this fish species contributed to the low concentrations of these lipophilic compounds.

Oyster Study

Large-scale biomonitoring programs such as Mussel Watch (O'Connor 1999) have been the model for biomonitoring methods that involve collecting native mussels at study sites to compare spatial patterns of chemical contamination in biological tissues. Oysters and various species of filter feeding mussels are widely used as biomonitors of hydrophobic organic chemical and heavy metal contamination (O'Connor 1999, Sures et al. 1999, Gewurz et al. 2003). Sessile filter feeders possess a number of desirable qualities as biomonitors, including that they are common in different types of environments, tolerate wide variations in habitat types, are sedentary, exhibit slow growth, and exhibit poor capabilities to biotransform many types of organic contaminants (Gewurtz et al. 2002). Bioaccumulated residues in filter feeding oysters and mussels provide a time-integrated measure of bioavailable chemical contamination that is likely to be more representative of the time scales over which exposures and bioaccumulation is experienced by other large invertebrates and small fish occupying the same system.

PCBs and organochlorines in oysters — At the time of writing, data from Mexico were not yet available, owing to delays in instrument installation on site. Partial data sets were available from Jamaica and Trinidad. For Jamaica, the sampling design allowed a comparison of bioaccumulation of POPs among three different oyster species at the same site. However, this analysis was not yet completed in time for this report. A total of 30 oysters or oyster pools were extracted and analyzed, including 19 from Port Royal, Jamaica, six from Old Harbour, Jamaica, one from St. Thomas, Jamaica and four pools of oysters from Trinidad (one pool per site). Figure 6 summarizes the mean OC pesticide concentrations (ng/g wet weight) in oysters analysed to date. Figure 7 presents total PCBs across sites, as well as congener profiles observed in oyster tissues. For organochlorine pesticides, lindane (У-HCH) was the highest contaminant measured, followed by low concentrations of p,p'-DDE at the different sites of study. Relative rankings of contaminants followed the trend: lindane > total PCBs > p,p-DDE at most sites.

Oyster consumption advisories — In all cases, absolute POPs concentrations measured in oysters were low relative to human health concerns associated with POP exposures due to consumption of contaminated food items. For PCBs, the highest concentration observed was 4 ng/g wet weight. The values found for PCBs were an order of magnitude lower than the most stringent action level in the United States (50 ng/g wet weight restricted fish consumption threshold). The pesticide metabolite p,p'-DDE was less than 1 ng/g at all locations and 5,000 times lower than the action level (5,000 ng/g wet weight) used in the United States to assess the requirement of fish consumption restrictions. For lindane, the maximum concentrations observed was 3 ng/g wet weight, which was two orders of magnitude lower than the most stringent action levels used in the United States (300 ng/g wet weight fish consumption advisory).

Table 5. Mean and maximum concentrations and fish consumption advisory limits (µg/kg wet weight) for classes of organochlorine compounds and ∑PCB detected in white grunt muscle. The advisory levels reported are for the most stringent values from the USA, and where applicable, for higher values from Health Canada.

Chemical	Mexico	Jamaica	St. Lucia	Trinidad & Tobago	Advisory Limit
Aldrin	ND	0.07, 0.09	0.93, 0.84	0.45, 0.49	300
Endrin	ND	0.21, 0.48	0.13, 0.14	0.42, 1.28	300
Dieldrin	0.09, 0.13	0.14, 0.19	0.76, 1.28	0.05, 0.09	300
∑BHC	1.12, 3.11	1.17, 4.91	5.07, 34.32	0.19, 0.84	100, 300
∑DDT	0.24, 0.33	0.15, 0.51	0.32, 1.25	0.14, 0.32	5000
∑chlordane*	0.92, 1.55	0.33, 0.98	0.67, 1.27	0.05, 0.15	300, 5620
HCB	0.16, 0.23	0.02, 0.11	0.41, 1.25	0.15, 0.21	10, 100
∑PCB	0.15, 0.26	0.83, 2.01	7.83, 25.24	1.22, 3.20	50, 2000

* plus heptachlor

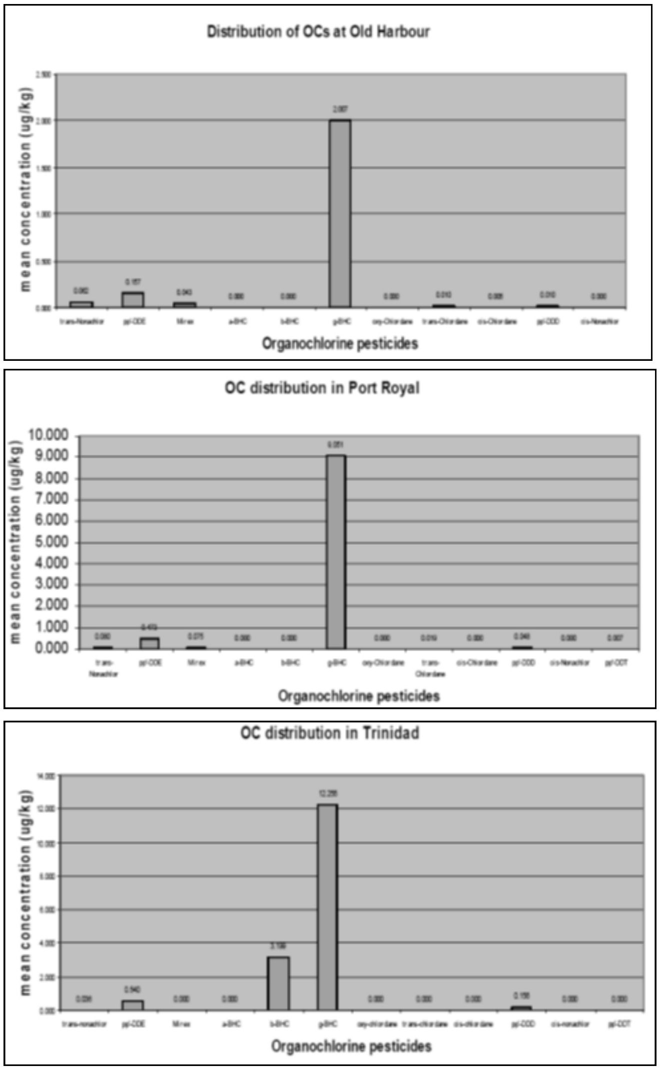

Figure 6. Organochlorine pesticide concentrations in oyster samples from Jamaica and Trinidad.

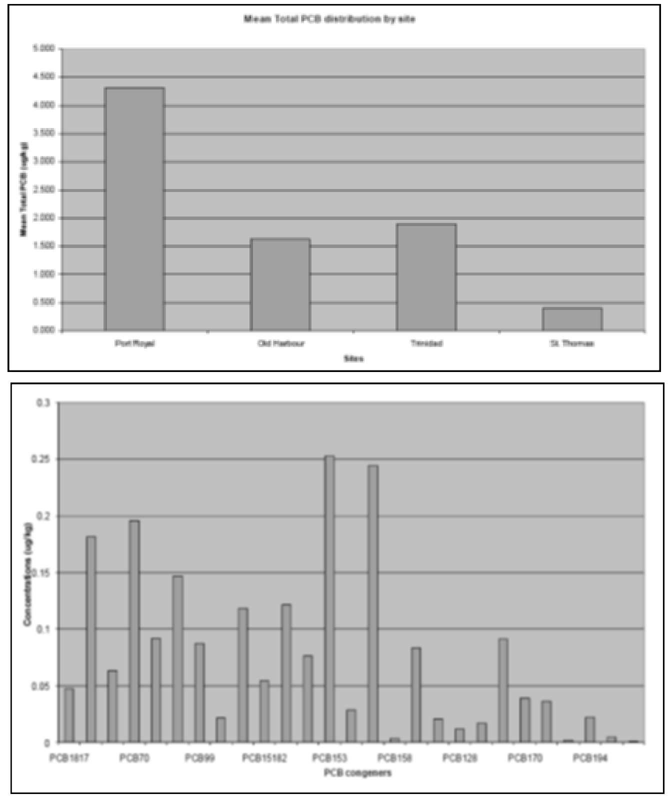

Figure 7. Total PCB concentrations (*top graphic)* across sites and representative PCB congener composition in Jamaica and Trinidad oyster sample*s (bottom graphic).*

CONCLUSIONS AND RECOMMENDATIONS

Overall, our studies show that there are low concentrations of a variety of chemical pollutants present in marine resources in the WCR. A more complete data set is required with the use of comparable and standardized methods, sampling schemes and parameters to evaluate the factors that influence POPs contamination in the Caribbean. Achieving sound and effective coastal resource management will require environmental policies that support a comprehensive long-term coordinated data collection program, encompassing the entire geographic area of the WCR. Single sampling events conducted in localized regions provide only a snapshot view of pollution in that area. In contrast, long-term monitoring studies that consist of multiple sampling events collected from a wide geographic area are a more effective means of assessing marine pollution. Furthermore, sampling over a wide geographic area can allow for distinguishing between localized 'hotspots' situated near point sources and more widespread anthropogenic contamination, as well as providing important information on the transport and dispersal of pollutants from both point and non-point sources. Long-term studies that are conducted over several years are also helpful in determining temporal trends, as well as rates of input of contaminants, and may better indicate which areas are susceptible to significant environmental stressors.

The white grunt study indicates that contamination by POPs in white grunt is not likely to be a health risk to consumers of this fish species in the four Caribbean countries from which the samples were collected. However, it must be emphasized that these are only preliminary data from a relatively small number of a single species of fish collected from four of the eight partner countries. These preliminary data do indicate that atmospheric sources of contamination may be responsible for contamination by some compounds, but point sources may contribute to contamination at selected sites. More data are required to determine whether there are geographic and regional trends in the distribution of POPs in this region. In order to evaluate local trends in the distribution of POPs at some locations (e.g., Vieux Fort Black Bay) it may be appropriate to use other monitoring methods, such as passive sampling (O'Toole et al. 2006) or deployment of bivalves (Gewurtz et al. 2002).

The oyster biomonitoring survey confirmed the presence of POPs in waters of Jamaica and Trinidad and Tobago. The concentrations of POPs measured in oyster tissues were generally low relative to threshold levels used to address human health concerns associated with contaminated seafood. Concentrations of PCBs measured in oyster tissues were consistent with the magnitude of concentrations determined in white grunt skinless fillet samples collected from the same countries. However, lindane (γ-HCH) was a major contaminant in the oysters, but was not observed at high concentrations in white grunt. This may reflect monitoring at near shore sites using oysters versus more offshore sites for white grunt. PCBs are most likely to undergo food web biomagnification. Since both oysters and white grunt occupy low to mid-trophic levels in the marine food web, there may be a risk of higher PCB concentrations in top trophic level piscivorous fish and fish eating sea birds.

It would be useful to determine the distribution of POPs in biota from the entire food web in the Caribbean, including fish species that have a higher trophic status and/or have a high lipid content in their tissues (Ueno et al. 2004). Other food web studies have shown that marine crustaceans can accumulate relatively high concentrations of POPs, including crabs (Menone et al. 2001, Bayen et al. 2005) and spiny lobster (Coat et al. 2006). Future work could also focus on determining whether subsets of the white grunt and oysters samples are contaminated by POPs of emerging interest (e.g., new pesticides, mercury, PFOS, "new" brominated flame retardants). However, it must be pointed out that this report contains the only data that are currently available on POPs contamination in fish distributed across the WCR region, and therefore, are a valuable contribution to the literature on contamination of marine biota.

A critical and much needed improvement to coastal zone management is to focus on protecting overall environmental quality, rather than relying on crisis-mode efforts to mitigate specific instances of serious pollution. However, there are some major obstacles to overcome in order to implement effective coastal pollution management in the WCR. A lack of capital investment in appropriate infrastructure to deal with domestic and industrial wastewater, as well as runoff from the agricultural and tourism sector is a major stumbling block to solving the problem. Other factors include political will and administrative and legal structures to regulate human development activities. Our project showed that there is some but limited existing laboratory expertise, limited equipment for monitoring pollution, and lack of administrative links between those responsible for water and coastal management. The problem lies not with lack of regulations that govern pollution, but with lack of awareness of the economic and other long-term costs of pollution, and the lack of resources and administrative capacity to achieve better management practices. At present, WCR nations lack information on contaminant loads, and the risks that toxic chemicals and other pollutants pose to the environment and/or to human health. Therefore, these nations are not able to plan mitigation or remediation actions before crises erupt. Early intervention is less expensive and more effective than restoration of ecosystems that have already tipped into a seriously polluted state.

Specific management recommendations include:

i) Systematic monitoring of POPs in atmospheric and aquatic environments, establishment of inventories of sources and surveillance of biological and environmental effects of POPs, and hot spot studies;
ii) Enhancement of human capacity through training of scientists, technicians, policy makers, administrators and managers at universities, in the public and private sectors in environmental management, POPs monitoring and analysis, and waste management;
iii) Enhancement of laboratory capacity for monitoing and analyzing for POPs in atmospheric and aquatic environments;
iv) Enhancement of clean technologies, including application, appropriate modification and development of clean technologies and effluent and emission treatment for agriculture, industry, the tourism sector and waste management;
v) Improved dissemination of information at all levels of society in the form of training, dissemination of information, information transfer; and
vi) Regulatory development, enforcement and compliance.

Growing coastal populations and tourism development will increase the risk of contamination of WCR coasts. Prevention and mitigation measures are needed to ensure that expanding development does not impact the marine environment and human health. Integrated approaches to water management are required that are built upon participation by all stakeholders, including the private sector, government and the communities. Without integrated approaches, the predominantly tourism and fisheries based economies in many of the WCR nations will not be sustainable in the long run.

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