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Preliminary Survey of Chemical Contaminants in Water, Sediment, and Aquatic Biota at Selected Sites in Northeastern Florida Bay and Canal C-111¹

LARRY R. GOODMAN, MICHAEL A. LEWIS, JOHN M. MACAULEY, RALPH SMITH, JR., AND JAMES C. MOORE

Several actions are under way to alter water management capabilities and practices in south Florida in order to restore a more natural hydroperiod for the Everglades. Because relatively little research has been conducted on contaminants entering Florida Bay, we undertook a preliminary study in June 1995 to determine contaminant concentrations in surface water, sediment, and biota prior to major changes in water management. The areas studied were the C-111 canal (five sites) beginning just above water control structure S-197 and extending to Manatee Bay (part of the Biscayne Bay system), Shell Creek (three sites), the mouth of Taylor River, Trout Creek (two sites), and a site near the Key Largo Ranger Station. Hydrographic observations were made at each site, and samples of water and sediment were collected at each of the five areas except the Key Largo site. Bio-residues were determined for indigenous oysters collected from the C-111 canal and Shell Creek and for transplanted oysters exposed at the Key Largo site, the C-111 canal, Shell Creek, Taylor River, and Trout Creek for 5-29 days. Water samples were analyzed for selected organochlorine pesticides and metals; sediments were analyzed for the same compounds and for polycyclic aromatic hydrocarbons (PAHs). Fish filets and shucked oysters were analyzed for selected organochlorine pesticides, polychlorinated biphenyl (PCB) congeners, and metals. Other than low dissolved oxygen at some C-111 canal sites, water quality was generally good. Most contaminants were below water and sediment quality guidelines designed to protect aquatic life, and contaminant concentrations in oysters were low. Threshold effect levels were exceeded for some organochlorine pesticides and PAHs in some sediment samples, but all values measured were below probable effect levels. Low concentrations of organochlorine pesticides were detected in sediments from the C-111 canal, Shell Creek, Taylor River, and Trout Creek; except for Taylor River, low concentrations of PCB congeners and PAHs were detected from the same areas. The only organochlorine pesticide detected in filets from seven fish was 3.2 µg DDE/kg (wet weight) in a sea catfish. Total mercury concentrations in filets of four species of fishes ranged from 0.53 to 1.3 µg/g, wet weight, which falls within a limited consumption advisory by the State of Florida.

Florida Bay is bordered by the Florida mainland to the north and the Florida Keys to the south and east and is open to the Gulf of Mexico on the west. It has a surface area of approximately 841 square miles with an average depth of 1.2-1.5 m over the central portion of the bay (Scholl, 1966). The shallow estuarine waters and bottom habitats of Florida Bay provide nursery areas for juvenile fish, shrimp, and crabs, and the bay supports fishery resources of commercial and recreational importance (Tilmant, 1989).

The environmental quality of Florida Bay has declined because of a number of problems, such as reduced freshwater inflow, algal blooms, and a decrease in seagrasses. Several federal and state environmental organizations have been conducting research in the Everglades and Florida Bay area, and such research activity is likely to increase. The focus of several of these ongoing studies has been on determining the effects of changing salinity and algal dynamics on the bay and determining the cause(s) of reduced water quality and loss of seagrass communities.

The environmental condition of Florida Bay waters and sediment is directly related to that of the freshwater Everglades to the north and its watershed. The extensive system of man-made canals in south Florida has enabled ag-

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riculture and urbanization to flourish but has seriously reduced overland flow of water to the Everglades and Florida Bay. In areas north and east of the Everglades, significant agricultural activity is present, and agricultural chemicals have been detected in the canals used to manage water levels (Matraw, 1975; Waller and Earle, 1975; Pfeuffer, 1985, 1991; Kucklick, et al., 1996; Miles and Pfeuffer, 1997). Various regulatory actions are under way to restore more overland flow of water through the Everglades by diverting water from the drainage canals. A concern, however, is that agricultural and perhaps other contaminants may enter Florida Bay by the increased freshwater input from the north. Information on potential impacts of toxic compounds on Florida Bay flora and fauna is scattered and limited. For this reason, a baseline study was initiated to identify and quantify contaminant levels in water, sediment, and biota collected at several sites in northeastern Florida Bay and in the C-111 canal.

MATERIALS AND METHODS

The areas sampled were the C-111 canal (five sites), Shell Creek (three sites), Taylor River (one site), Trout Creek (two sites), and a site in Florida Bay near the Key Largo Ranger Station (Fig. 1). At the C-111 canal, site A was at the mouth where the canal discharges into Manatee Bay, site D was just below water control structure S-197, and sites B and C were approximately $\frac{1}{3}$ and $\frac{2}{3}$ of the distance, respectively, between C-111 A and C-111 D. Site C-111 E was just above the water control structure. At Shell Creek, site A was in Florida Bay at the creek mouth, site C was where water from Long Sound flows into Shell Creek, and site B was approximately midway between sites A and C. The Taylor River site was in Little Madeira Bay at the mouth of the river. At Trout Creek, site A was in Florida Bay at the mouth of the creek and site B was in Joe Bay where water flows into the creek.

Samples of water, sediment, and biota were collected from the five study areas during June and July 1995. Samples were stored on ice or frozen until analyzed for selected pesticides, polychlorinated biphenyl (PCB) congeners, and heavy metals. Sediment samples were also analyzed for polycyclic aromatic hydrocarbons (PAHs). The organic carbon content of the sediments was not determined. The latitude and longitude of sample sites, types of media sampled, and dates sampled are presented in Table 1.

Water temperature, salinity, pH, and dissolved oxygen were measured with a Hydrolab H2O Water Column Profiler calibrated within 24 hr of usage. These measurements were determined just below the surface and just above the bottom at sites where the water depth was less than 2 m. At deeper sites, such as in Canal C-111, measurements were also taken at 1-m depth increments.

Water samples for chemical analyses were collected by with a hand-operated peristaltic pump and silicon tubing lowered to the desired depth. Samples were taken from 1 m below the surface and 1 m off the bottom at C-111 A (both the east and west sides of the canal), from 1 m below the surface at C-111 E, and from mid-water column at Shell Creek A, Trout Creek A, and Taylor River A. Except for C-111 E and Taylor River A, a second water sample was taken 2 hr after the initial sample. Samples for mercury and methyl mercury analyses were filtered on site through a 0.45- μ m membrane filter, with 250 ml saved for dissolved metals analyses and 100 ml saved for methyl mercury determination. Additional water samples (2.0 liters) were stored on ice and filtered through a GF/F filter to remove particulates. Approximately 1 liter of the filtered sample was drawn through a pipette packed with XAD4 resin for extraction of dissolved organics. The resin columns were stored at -20 C until extraction for chemical analyses.

Fish were collected for chemical analysis with traps and hook and line. One hardhead catfish (*Arius felis*) was collected at Trout Creek A. Two great barracuda (*Sphyrna barracuda*) were collected, one from the Key Largo Ranger Station dock and one at Taylor A. Three crevalle jacks (*Caranx hippos*) were collected, two at Taylor River A and one at Trout Creek A. One largemouth bass, *Micropterus salmoides*, was collected at C-111 E. Except for the catfish, which wasn't measured, fish lengths and dates of capture are presented in Table 1. Tissue samples analyzed were skinless filets except for the hardhead catfish, which was not skinned. Filets were either wrapped in aluminum foil or placed in prewashed polycarbonate containers and frozen until chemically analyzed.

The oyster samples analyzed included both indigenous oysters and transplanted (caged *Crassostrea virginica*) ones that were deployed and sampled at a later date. Indigenous oysters were collected from red mangrove (*Rhizophora mangle*) prop roots at sites C-111 D and Shell Creek A and C. Oysters used in cage studies were obtained from Santa Rosa Sound in northwest Florida and cleaned of fouling or-

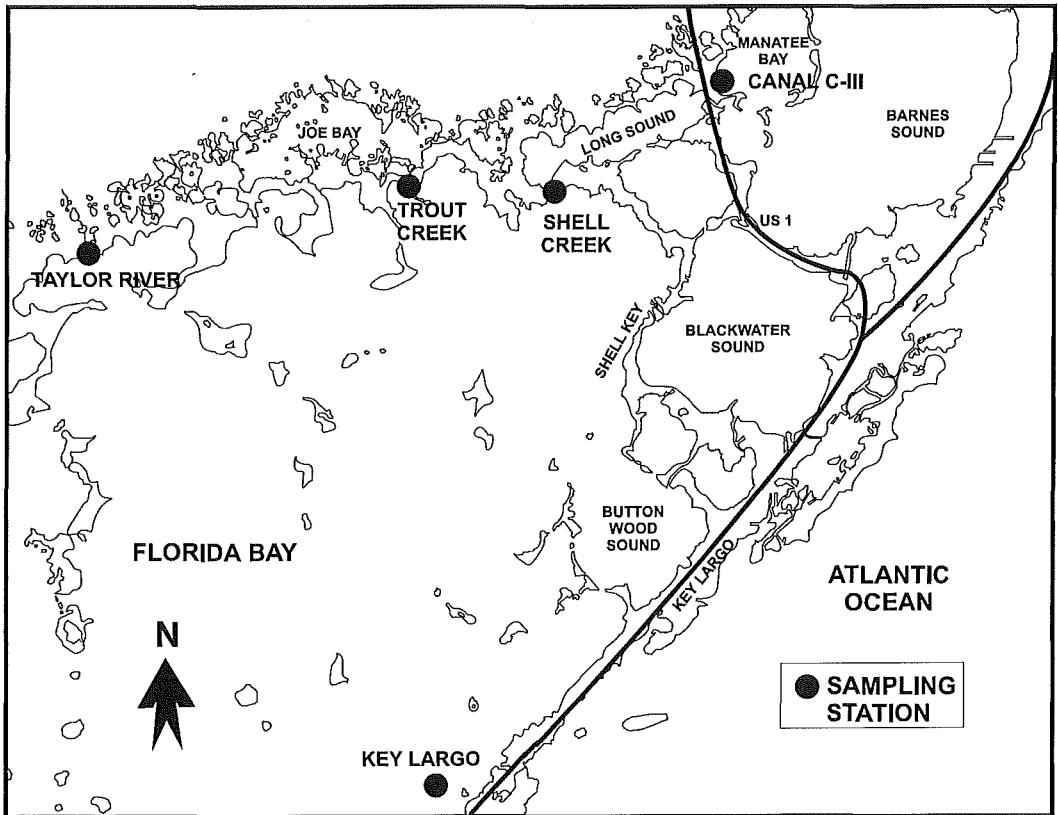


Fig. 1. Map of northeastern Florida Bay indicating sites sampled.

ganisms prior to transporting them to south Florida. These oysters were sampled for pre-deployment analyses after being held in ambient seawater overnight at the Key Largo Ranger Station. Oysters were maintained in ambient seawater at the Ranger Station for up to approximately 36 hr until deployed at study sites in cages constructed of plastic mesh and polyvinyl chloride (PVC) pipe. Cages containing approximately 24 oysters were deployed at the Key Largo site, Shell Creek B, Taylor River, and Trout Creek A on 14 June and at C-111 B on 15 June 1995.

Caged oysters were sampled on 20 June and 13 July 1995 for chemical analyses of metals and organochlorine pesticide content. Oyster samples (≈ 50 g) were placed in polycarbonate containers and frozen until chemically analyzed. The cages and all oysters remaining in them were removed from the sites on 13 July.

Sediment samples were obtained with a stainless steel ponar grab sampler. Except at C-111 E, where we were unable to obtain a sediment sample, the entire contents of the grab sampler were placed in a stainless steel con-

tainer and mixed thoroughly. A 500-ml sample was placed in a glass container for analysis of organic contaminants, and a 125-ml sample was placed in an acid-rinsed polypropylene container for metals analyses. Sediment samples were stored at -20 C until analyzed.

Chemical analyses were performed at two laboratories. Personnel at Skidaway Institute of Oceanography (Savannah, GA) analyzed water samples for selected metals and organochlorine pesticides and sediment samples for selected metals, organochlorine pesticides, PAHs, and PCB congeners. Tissue samples were analyzed for selected metals, organochlorine pesticides, and PCB congeners by Avanti Corp. (Annandale, VA).

The analyses of trace metals in water samples were accomplished by inductively-coupled plasma emission mass spectroscopy (ICP/MS) after preconcentration with silica-immobilized 8-hydroxyquinoline as described by McLaren et al. (1985). A five-point calibration curve was prepared by spiking quartz-distilled water and concentrating the spiked water in the same manner as the samples. An internal standard was

TABLE 1. Location of Florida Bay sampling sites, media sampled, and dates that samples were collected. Latitude and longitude were determined by Global Positioning System. Fish lengths are total length.

Site	Latitude (N)	Longitude (W)	Medium and date sampled
Key Largo, NPS ^a Ranger Station	25°05.20'	80°27.32'	Barracuda, 39 cm (6/20/95); caged oysters (6/14/95)
Key Largo	25°05.60'	80°27.38'	Sediment (6/19/95); caged oysters (7/13/95)
Canal C-111			
A	25°15.43'	80°25.40'	Sediment and water (6/15/95)
B	25°15.71'	80°25.68'	Sediment (6/15/95); caged oysters (6/20 and 7/13/95)
C	25°16.06'	80°26.28'	Sediment (6/15/95)
D	25°17.10'	80°26.44'	Sediment and indigenous oysters (6/15/95)
E	ND ^b	ND	Water and largemouth bass, 28 cm (6/18/95)
Shell Creek			
A	25°12.44'	80°29.22'	Sediment, water, and indigenous oysters (6/16/95)
B	25°12.50'	80°29.32'	Sediment (6/16/95); caged oysters (6/20 and 7/13/95)
C	25°12.77'	80°29.16'	Sediment and indigenous oysters (6/16/95)
Taylor River	25°11.41'	80°38.34'	Sediment (6/17/95); water (6/18/95); caged oysters (6/20 and 7/13/95); barracuda, 43 cm (6/19/95); crevalle jacks, 36.5 and 37 cm (6/18/95)
Trout Creek			
A	25°12.82'	80°31.99'	Sediment and water (6/16/95); caged oysters (6/20 and 7/13/95); hardhead catfish (6/17/95); crevalle jack, 37 cm (6/19/95)
B	25°12.94'	80°32.08'	Sediment 6/17/95

^a NPS = National Park Service.

^b ND = not determined.

added to the samples and standards prior to analysis by ICP/MS. Methyl mercury concentrations in water were determined by methods described by Kannan et al. (1998).

Sediment sample digestions for metals analyses were performed in a Class-100 clean room to prevent contamination during preparation. Samples consisted of 250 mg of oven-dried (60 C) and powdered sediment. Total digestion was accomplished in clean teflon beakers with either Baker "Instra-Analyzed" or GFS redistilled nitric, perchloric, and hydrofluoric acids. All metals except Al and Fe were analyzed by ICP/MS. Flame atomic absorption was used for Al and Fe determination. After digestion, samples were diluted or aliquoted without dilution and spiked with an internal standard or internal standard mixture and placed in an auto-sampler behind the calibration standards. A continuing calibration standard was used to verify instrument calibration throughout the sample run. Methods described by Smith (1993) were used to determine total mercury concentrations, and methods described by

Kannan et al. (1998) were used for methyl mercury analyses.

Sample preparation procedures for the analyses of water for organochlorine pesticides and for analyses of sediment for organochlorine pesticides, PCB congeners, and PAHs are described in the Environmental Monitoring Assessment Program Laboratory Methods Manual (U.S. Environmental Protection Agency 1993). PCBs and chlorinated pesticides were analyzed by high-resolution capillary gas chromatography with electron capture detection. A five-point calibration curve was generated for each pesticide and PCB congener. PAHs were analyzed by capillary gas chromatography-mass spectrometry in the full scan mode. A 30-m DB-5MS or XLB column was used. Samples were analyzed in batches with a decafluorotriphenylphosphine (DFTPP) standard, and a continuing calibration standard analyzed between batches to check for consistency of tuning.

Fish and oyster tissues intended for metals analyses were digested by a Model 2100 pro-

TABLE 2. Hydrological observations at Florida Bay sampling sites at time of sampling (June and July 1995). Values not in parentheses are surface measurements; those in parentheses are bottom measurements.

Site	Date	Temperature (C)	pH (Units)	Dissolved oxygen (mg/liter)	Salinity (‰)
Key Largo	6/19/95	30.0 (29.6)	8.1 (8.1)	6.8 (6.5)	28.8 (29.0)
	7/13/95	31.5 (31.6)	8.4 (8.3)	6.3 (6.3)	29.1 (29.2)
Canal C-111					
A	6/15/95	31.7 (31.3)	7.8 (8.0)	5.8 (6.6)	21.1 (23.4)
B	6/15/95	29.2 (27.7)	7.5 (6.6)	3.0 (0.2)	16.0 (36.3)
	7/13/95	30.0 (27.8)	8.0 (6.7)	6.4 (0.3)	15.0 (37.5)
C	6/15/95	29.7 (27.8)	7.4 (6.7)	2.8 (0.3)	16.0 (35.2)
D	6/15/95	31.8 (28.6)	7.2 (7.1)	2.0 (0.6)	16.2 (22.7)
E	6/20/95	26.9 (26.6)	7.1 (7.3)	3.8 (3.3)	0.3 (0.3)
Shell Creek					
A	6/16/95	29.1 (29.3)	8.0 (8.1)	5.8 (6.2)	23.2 (25.4)
B	6/16/95	29.4 (29.2)	8.0 (7.9)	5.4 (4.9)	18.0 (24.6)
	7/13/95	29.5 (29.5)	8.3 (8.3)	7.0 (6.9)	10.5 (10.5)
C	6/16/95	28.8 (29.1)	8.1 (8.1)	6.4 (6.4)	17.4 (17.8)
Taylor River	6/17/95	27.0 (27.2)	7.5 (7.5)	3.6 (3.7)	9.8 (10.5)
	7/13/95	29.5 (30.4)	7.5 (8.1)	4.8 (6.7)	3.6 (10.5)
Trout Creek					
A	6/16/95	29.6 (29.6)	8.1 (8.1)	6.8 (6.6)	12.1 (12.0)
	7/13/95	29.8 (29.7)	8.5 (8.5)	7.1 (6.9)	2.5 (2.6)
B	6/17/95	27.7 (27.7)	8.1 (8.1)	6.4 (6.6)	11.1 (11.2)

grammable microwave digestion system. Fish filets were digested with 10 ml of 1:1 nitric acid and deionized water, and oyster digestion was accomplished with either 7 ml of a 5:2 nitric acid and deionized water solution added to the sample followed by addition of 1.5 ml of 30% H₂O₂ or with 5 ml of nitric acid and 2 ml of HCl. After digestion, samples were transferred into 50-ml polypropylene tubes with deionized water and diluted to 25 ml. Except for mercury analyses, a Jarrel-Ash Atomcomp Series 800 ICP was used to determine heavy metal concentrations in fish and oysters. Instrument calibration standards were prepared in nitric acid solutions from certified standards. An instrument calibration verification solution, a quality control standard, a digestion blank, and a laboratory fortified blank solution were analyzed to verify system performance.

Concentrations of mercury in tissues were determined with a PS200 Automated Mercury Analyzer (Leeman Laboratories) with mercury cold vapor atomic absorption analysis and tin (IV) as the reductant. Standard solutions were prepared by using certified mercury standards and nitric acid. A digestion blank was also analyzed to verify system performance. When ad-

equate sample was available, matrix spikes were prepared and analyzed.

Fish and oyster tissue samples were analyzed for selected organochlorine pesticides and PCB congeners by electron-capture gas chromatography. After tissues were thawed, approximately 5 g was weighed, spiked with 1.0 ml of acetone containing 100 ng of mirex, and homogenized. Samples were analyzed with a Hewlett Packard (HP) 5890 Series II gas chromatograph and dual capillary columns coupled to electron-capture detectors. Multiple standards were used for peak identification and quantification; compounds were identified by retention time and confirmed by detection on both columns.

RESULTS

The results of hydrological observations are presented in Table 2. Salinity varied both temporally and spatially. Site C-111 E was essentially freshwater (salinity, 0.3 ‰).

The water temperatures at all sites were within the range of 26.6–31.8 C, and pH values ranged from 6.6 to 8.5, with the lower values generally associated with low dissolved oxygen

(DO) concentrations. DO concentrations in surface water ranged from 2.0 mg/liter at Canal C-111 D to 7.1 mg/liter at Trout Creek A. DO concentrations in bottom waters were generally 5 mg/liter or greater except at Canal C-111 B-E and at Taylor River in June. At C-111 B-D, DO concentrations were less than 1.0 mg/liter in bottom waters. At Canal C-111 E, which was above the water control structure, the bottom DO concentration was 3.3 mg/liter.

No organochlorine pesticides or PCB congeners were measured in water at concentrations above 50 ng/liter.

The concentrations of metals measured above the method detection limit (MDL) in filtered surface waters of the C-111 canal, Shell Creek, Taylor River, and Trout Creek are presented in Tables 3-4. Concentrations of both total Hg and MeHg in water samples from this study also have been reported by Kannan et al. (1998).

Low concentrations of 14 organochlorine compounds were measured in sediments from one or more of the sampling sites (Table 5). Because of the low values, some of which were only slightly above the MDL (0.35 ng/g), the concentrations reported should be considered as estimates. Pesticides were not detected (<MDL) in sediments from C-111 C, Shell Creek B, and Shell Creek C.

Twelve PCB congeners were measured above the MDL (0.35 ng/g) in sediments from one or more sites (Table 6). One or more congeners were detected at each site except Taylor River.

Polycyclic aromatic hydrocarbons were detected above the MDLs in all sediment samples except those from Shell Creek B and C and Taylor River (Table 7). A number of the concentrations reported in Table 7 are low relative to the MDL; those less than 10 times the MDL should be considered estimates because of the lack of duplicates or repetitive sampling.

Concentrations of the 15 metals detected (>MDL) in sediment samples are presented in Table 8. Silver was detected at only two sites, and antimony was detected at only one site. Each of the remaining metals was detected at seven or more sites.

Only one of the seven fish tissue samples contained concentrations of organochlorine pesticides or PCBs above the method detection limit (2.0 µg/kg). Filets from a hardhead catfish collected at Trout Creek contained 3.2 µg pp-DDE/kg, wet weight. Filets of the following fishes, which are high in the food chain, did not contain detectable (≥ 2.0 µg/kg) concentrations of organochlorine pesticides or PCBs:

a barracuda from Taylor River and one from the National Park Service (NPS) Ranger Station boat basin, two crevalle jacks from Taylor River, and one largemouth bass from C-111 E.

Metal bioresidue data for fish are presented in Table 9. Of the 12 metals analyzed for, only arsenic, iron, mercury, and zinc were detected at concentrations above MDLs. The only sample containing detectable arsenic (≥ 2.2 µg/g) was the barracuda from the Key Largo Ranger Station (2.4 µg/g). Concentrations of iron in fish tissue ranged from 2.1 µg/g in a barracuda from Taylor River to 41 µg/g in a crevalle jack from the same area. Mercury concentrations ranged from 0.53 to 1.3 µg/g in the fish filets analyzed. Zinc concentrations ranged from 2.4 µg/g in a barracuda from the Taylor River area to 22.0 µg/g in a hardhead catfish collected from the Trout Creek area.

The only oysters containing concentrations of organochlorine pesticides greater than the MDL (2.0 µg/kg) were those caged at the Key Largo site. Indigenous oysters from Canal C-111 D and Shell Creek A and C did not contain concentrations of organochlorine pesticides or PCB congeners ≥ 2.0 µg/kg. Transplanted oysters held overnight (baseline sample) in ambient seawater at the Key Largo Ranger Station and those caged for 5-6 days at C-111 B, Shell Creek B, Taylor River, and Trout Creek B contained no detectable concentrations of PCB congeners or organochlorine pesticides. When oysters were removed from the above sites and from the Key Largo site after 28-29 days and analyzed, the only concentrations of organochlorine pesticides or PCB congeners greater than the MDL were 2.1 µg pp-DDE/kg and 2.4 µg pp-DDD/kg in oysters from the Key Largo site.

Metal residues in oysters are presented in Tables 10-11. Only 6 of 13 metals were measured at concentrations above the MDL. For indigenous oysters collected from the C-111 canal and Shell Creek, the ranges in concentrations (µg/g, wet weight) were 9.0-24.0 for aluminum, <0.70-1.1 for chromium, 1.6-10.0 for copper, 36.0-40.0 for iron, 0.034-0.065 for mercury, and 26.0-54.0 for zinc (Table 10). Data for oysters transplanted to, and caged in, selected areas of northeastern Florida Bay and Canal C-111 for 28-29 days are presented in Table 11. Prior to caging, the concentrations (µg/g, wet weight) of Al, Cr, Cu, Fe, Hg, and Zn in the oysters were 16, <0.7, 4.1, 20, 0.013, and 64, respectively. After being caged for 5 (C-111 B) or 6 days (Shell Creek, Taylor River, Trout Creek), the ranges in concentrations of Al, Cr, Cu, Fe, Hg, and Zn in the oysters sam-

TABLE 3. Concentrations ($\mu\text{g}/\text{liter}$) of selected metals in filtered surface waters of Canal C-111 during June 1995.

Sampling site	Time (hr)	Depth	Al	Cd	Co	Cu	Fe	MeHg	Mn	Ni	Pb	Zn
C-111 A, east	0	S	4.5	0.004	0.15	0.18	6.8	—	7.6	0.38	0.013	0.28
	0	B	7.0	0.004	0.19	0.19	18.6	ND ^a	3.3	0.45	0.025	0.092
	2	S	5.2	0.004	0.15	0.18	5.7	0.00024	4.4	0.38	0.018	0.23
	2	B	6.4	0.004	0.17	0.18	12.6	0.000015	3.3	0.44	0.021	0.16
C-111 A, west	0	S	4.6	0.003	0.14	0.18	6.7	0.000003	7.3	0.38	0.012	0.22
	0	B	5.9	0.006	0.13	0.17	10.6	0.000064	2.7	0.39	0.022	0.14
	2	S	5.1	0.004	0.12	0.17	7.3	0.000066	2.3	0.33	0.017	0.21
	2	B	6.0	0.008	0.098	0.17	6.9	0.000020	2.8	0.32	0.022	0.097
C-111 A, \bar{x}			5.6 ^b	0.0046 ^b	0.14 ^b	0.18 ^b	9.4 ^b	0.000068 ^c	4.2 ^b	0.38 ^b	0.019 ^b	0.18 ^b
Florida WQC ^d			$\leq 1,500$	≤ 9.3	— ^e	≤ 2.9	≤ 300	≤ 0.025 ^f	— ^e	≤ 8.3	≤ 5.6	≤ 86
C-111 E			0.77	0.0060	0.058	0.16	4.7	0.0015	0.37	0.53	0.017	3.2
MDL ^g			0.47	0.0020	0.0020	0.020	0.64	0.0000010	0.013	0.014	0.0030	0.010

^aND = less than MDL.

^bMean of the eight samples analyzed.

^cMean of the six detectable values.

^dState of Florida water quality criteria ($\mu\text{g}/\text{liter}$) for Class III marine waters (Florida Administrative Code, 1996).

^eNo Florida criteria value.

^fValue is for total mercury.

^gMDL = method detection limit.

TABLE 4. Concentrations ($\mu\text{g}/\text{liter}$) of selected metals in filtered waters of Shell Creek, Taylor River, and Trout Creek at their confluence with Florida Bay during June 1995.

Sampling site	Time (hr)	Al	Cd	Co	Cu	Fe	MeHg	Mn	Ni	Pb	Zn
Shell Creek A	0	4.6	0.0040	0.15	0.15	5.4	0.0019	1.5	0.38	0.034	0.31
	2	4.2	0.0040	0.12	0.14	5.8	0.000017	1.7	0.36	0.022	0.14
\bar{x}^a		4.4	0.0040	0.14	0.14	5.6	0.000096	1.6	0.37	0.028	0.22
Taylor River	0	3.6	0.0030	0.13	0.089	16.0	0.00011	4.7	0.31	0.040	0.18
Trout Creek	0	5.8	0.0040	0.084	0.099	5.6	0.00038	0.89	0.26	0.020	0.19
	2	6.2	0.0030	0.10	0.11	6.5	0.0023	1.1	0.29	0.025	0.11
\bar{x}^a		6.0	0.0035	0.092	0.10	6.0	0.0013	1.0	0.28	0.022	0.15
Florida WQC ^b		$\leq 1,500$	≤ 9.3	— ^c	≤ 2.9	≤ 300	$\leq 0.025^d$	— ^e	≤ 8.3	≤ 5.6	≤ 86
MDL ^e		0.47	0.0020	0.0020	0.020	0.64	0.0000010	0.013	0.014	0.0030	0.010

^a Mean of the two samples.^b State of Florida water quality criteria values ($\mu\text{g}/\text{liter}$) for Class III marine waters (Florida Administrative Code, 1996).^c No Florida criteria value.^d Value is for total mercury.^e MDL = method detection limit.

pled were 12–21, <0.7–0.65, 7.2–9.7, 15–27, 0.016–0.035, and 89–130, respectively. When the oysters were removed and sampled after 28–29 days, the ranges in concentrations of the same elements were 4.5–20, <0.5–1.2, 8.2–22, 26–48, 0.026–0.066, and 130–160 $\mu\text{g}/\text{g}$, respectively.

DISCUSSION

Water quality was generally good at the sites studied except for DO concentrations at C-111 B–E. The Florida standard for DO in Class III freshwater is 5.0 mg/liter (Florida Administrative Code, 1996). In June, the instantaneous DO measurements at C-111 E (freshwater) were 3.8 mg/liter at the surface and 3.3 mg/liter on the bottom. Similarly, the Florida standard for Class III marine waters is at least 4.0 mg/liter at all times. At C-111 B–D, the bottom DO concentrations were <1.0 mg/liter during our study, and, except for the sample at C-111 B on 13 July, DO concentrations in surface waters at the same sites were <4.0 mg/liter (Table 2). The metal concentrations measured in filtered saltwater from the study sites were less than maximum concentrations specified in Florida standards (Florida Administrative Code, 1996). However, metal concentrations measured at Canal C-111 E (freshwater) could not be compared with Florida standards because the hardness was not determined. The mean concentrations of Mn, Co, Cu, Cd, and Pb measured in water from northeastern Florida Bay were less than or similar to those reported by Horvath et al. (1972) for Lostman's Bay, a small bay in Collier County, FL, with no obvious anthropogenic source of heavy metals.

Sediment contaminant data were compared with sediment quality guidelines developed for use in evaluating data for Florida coastal sediments (MacDonald et al., 1996). The threshold effects level (TEL) is an estimate of a concentration below which adverse effects are rarely observed, and the probable effects level (PEL) is an estimate of the concentration above which adverse effects are frequently observed (MacDonald et al., 1996). Although 14 organochlorine compounds were detected in sediments at low ng/g concentrations, five were DDT and its derivatives (Table 5). At least one DDT derivative was detected at all sites except C-111 C and Shell Creek B and C. Total DDT measured at C-111 A (4.2 ng/g) was slightly above the TEL reported by MacDonald et al. (1996). Similarly, the concentrations of total chlordane (2.9 ng/g), 4,4 DDT (1.8 ng/g), and lindane (0.62 ng/g) measured in sedi-

TABLE 5. Concentrations of organochlorine pesticides (ng/g, dry wt.) in sediments from selected sites in northeastern Florida Bay and Canal C-111. Concentrations only slightly above the method detection limit (MDL; 0.35 ng/g, dry wt.) should be considered as estimates. Concentrations in bold are \geq the threshold effects level of sediment quality guidelines for Florida coastal sediments (MacDonald et al., 1996).

Compound	Site							SQG ^b (ng/g)	
	Canal C-111 ^a			Shell Cr. ^a A	Taylor River	Trout Creek A	TEL	PEL	
	A	B	D						
Cis-chlordane	1.2	— ^c	0.44	1.1	—	—	—	—	
Trans nonachlor	0.81	0.40	0.40	1.8	—	—	—	—	
Chlordane (total)	2.0	0.40	0.84	2.9	—	—	2.3	4.8	
2,4'DDD	—	—	—	—	—	0.76	—	—	
2,4'DDE	—	—	—	—	0.37	—	—	—	
4,4'DDE	2.0	1.7	0.40	—	—	—	2.1	374	
2,4'DDT	1.4	—	—	—	—	—	—	—	
4,4'DDT	0.79	—	—	1.8	—	—	1.2	4.8	
DDT (total)	4.2	1.7	0.40	1.8	0.37	—	3.9	52	
Dicofol	1.4	—	—	—	—	0.54	—	—	
Dieldrin	0.39	—	—	—	—	—	0.72	4.3	
Endosulfan 1	1.1	—	—	0.35	—	—	—	—	
Endosulfan sulfate	1.4	—	—	—	—	0.42	—	—	
Endrin	—	—	—	1.3	—	0.87	—	—	
Heptachlor	0.46	—	—	0.65	—	—	—	—	
Lindane	—	—	—	0.62	—	—	0.32	0.99	

^a Pesticide concentrations were less than the MDL at C-111 C and at Shell Creek B and C.

^b SQG = sediment quality guidelines, TEL = threshold effects level, PEL = probable effects level (MacDonald et al., 1996).

^c Dashes indicate less than MDL or not reported by MacDonald et al. (TEL and PEL).

ments from Shell Creek A were greater than their respective TEL values. The compounds detected in this study have previously been reported from sediments from south Florida canals (Pfeuffer, 1985, 1991; Miles and Pfeuffer, 1997). Both endosulfan (1.1 ng/g) and endo-

sulfan sulfate (1.4 ng/g) were detected in sediments at C-111 A; endosulfan was also detected at Shell Creek A (0.35 ng/g), and endosulfan sulfate was detected at Trout Creek A (0.42 ng/g). Endosulfan has been detected in water from canals in the Homestead area (up to 290

TABLE 6. Concentrations of polychlorinated biphenyl (PCB) congeners (ng/g, dry wt.) in sediments from selected sites in Canal C-111 and in northeastern Florida Bay.^a Concentrations only slightly above the method detection limit (MDL; 0.35 ng/g) should be considered as estimates.

PCB congener	Site							
	Canal C-111				Shell Creek			Trout Creek A
	A	B	C	D	A	B	C	
PCB 018	— ^b	—	—	—	—	—	0.54	—
PCB 028	0.72	—	—	—	0.44	—	—	—
PCB 044	1.6	—	—	—	0.72	—	0.40	—
PCB 052	1.8	0.36	—	—	1.3	—	—	—
PCB 066/095	1.4	—	—	—	—	—	—	—
PCB 101/090	1.0	—	—	0.70	2.3	0.43	—	—
PCB 087	0.53	—	—	—	0.72	0.37	0.59	—
PCB 118	0.72	—	—	—	0.71	0.36	—	—
PCB 153	1.3	—	—	0.35	0.70	0.37	—	0.44
PCB 138/163/164	—	—	—	0.40	0.38	—	0.58	—
PCB 187/182/159	—	—	—	0.40	—	0.36	1.0	—
PCB 180	—	—	0.38	0.67	—	—	0.45	—
Sum PCBs	9.1	0.36	0.38	2.5	7.3	1.9	3.6	0.44

^a No congeners detected above MDL in Taylor River sample.

^b Dashes indicate less than MDL.

TABLE 7. Concentrations ($\mu\text{g/g}$, dry weight) of polycyclic aromatic hydrocarbons (PAHs) in sediments from selected sites in Canal C-111 and in northeastern Florida Bay.^a Concentrations only slightly above the method detection limit (MDL) should be considered as estimates. Concentrations in bold are \geq the threshold effects level of sediment quality guidelines for Florida coastal sediments (MacDonald et al., 1996).

Compound	Site						MDL ($\mu\text{g/g}$)	SQG ^b ($\mu\text{g/g}$)	
	Canal C-111				Shell Creek A	Trout Creek A		TEL ^b	PEL ^b
	A	B	C	D					
Fluorene	— ^c	—	—	0.0074	—	—	0.0050	0.021	0.14
Phenanthrene	0.030	—	—	0.082	0.0071	—	0.0050	0.087	0.54
Anthracene	0.019	—	—	0.040	—	—	0.0038	0.047	0.24
1-Methylphenanthrene	0.020	—	—	0.015	0.0080	—	0.0049	—	—
Fluoranthene	0.42	0.029	0.0085	0.50	—	0.0088	0.0050	0.11	1.5
Pyrene	0.44	0.025	0.0068	0.39	0.023	0.014	0.0050	0.15	1.4
Benz[a]anthracene	0.21	—	—	0.23	—	—	0.0044	0.075	0.69
Chrysene	0.24	—	—	0.21	0.0061	—	0.0051	0.11	0.85
Benzo[b]fluoranthene	0.13	—	0.0057	0.19	—	—	0.0050	—	—
Benzo[k]fluoranthene	0.054	—	—	0.074	—	—	0.0050	—	—
Benzo[e]pyrene	0.073	—	—	0.087	—	—	0.0050	—	—
Benzo[a]pyrene	0.071	—	—	0.12	—	—	0.0045	0.089	0.76
Perylene	0.012	—	—	0.040	—	—	0.0038	—	—
Indeno[1,2,3-cd]pyrene	—	—	—	0.057	—	—	0.0088	—	—
Dibenz[a,h]anthracene	—	—	—	0.012	—	—	0.0074	0.0062	0.14
Benzo[g,h,i]perylene	—	—	—	0.051	—	—	0.0088	—	—
Sum PAHs	1.7	0.054	0.021	2.1	0.044	0.023	—	1.7	16.8

^a No PAHs detected above the MDL in samples from Shell Creek B and C or from Taylor River.

^b SQG = sediment quality guidelines, TEL = threshold effects level, PEL = probable effects level (MacDonald et al., 1996).

^c Dashes indicate less than MDL (chemical analyses) or not reported by MacDonald et al. (TEL and PEL).

ng/liter) and from Florida Bay (up to 28 $\mu\text{g/liter}$) by Kucklick et al. (1996). In their summary of agricultural pesticide usage in coastal areas, Pait et al. (1992) classified endosulfan as a major pesticide of concern because of its acute toxicity, high bioconcentration factor, and fairly long half-life in soil. Although our data cannot be properly compared between sites without normalization for organic carbon content, the data suggest that more organochlorine contaminants occur at C-111 A, Shell Creek A, and Trout Creek A than at the other sites sampled. Pesticide concentrations may have been higher at C-111 A than at C-111 B–D because site A is at the mouth of the canal where sediment deposition would likely be greater than at the other canal sites. The same spatial relationship existed for sites at Shell Creek and may account for the higher pesticide concentrations at site A than at sites B and C.

The low concentrations of PCB congeners detected in sediment samples suggest that Canal C-111 A (sum = 9.1 ng/g) has the greatest PCB contamination followed by Shell Creek A (sum = 7.3 ng/g). However, the data are not normalized for organic carbon content.

The concentrations of PAHs in sediments

were generally low (Table 7). Although PAH concentrations at Canal C-111 A and D were higher than for other sites, the concentrations measured are within the range of concentrations reported for Penobscot Bay, ME, which was largely undeveloped at the time of a study by Johnson et al. (1985). However, fluoranthene, pyrene, benz [a] anthracene, chrysene, and the sum of PAH concentrations at Canal C-111 A and D, as well as benzo [a] pyrene and dibenz [a,h] anthracene concentrations at C-111 D, were above the TEL values reported by MacDonald et al. (1996). Somewhat surprising was that PAH concentrations were much lower at C-111 B and C than at C-111 D. Possible reasons for these concentration differences may be differences in organic carbon content of the sediments (not measured) or differences in particulate material distribution due to factors such as turbulence and currents, which could affect distribution of PAHs associated with particulates (McElroy et al., 1989). PAHs are almost ubiquitous compounds resulting from incomplete combustion of organic matter and originate from both natural and anthropogenic sources (U.S. Environmental Protection Agency, 1980). ZoBell (1971) reported that PAHs in marine sediments are believed to

TABLE 8. Concentrations ($\mu\text{g/g}$, dry weight except aluminum and iron, which are in %) of metals measured in sediments from selected areas in Canal C-111 nd in northeastern Florida Bay during June 1995 and sediment quality guidelines for Florida coastal waters (MacDonald et al., 1996). Values in bold print are greater than the threshold effects level.

Sampling site	Ag	Al (%)	As	Cd	Cr	Cu	Fe (%)	Hg	Mn	Ni	Pb	Sb	Se	Sn	Zn
C-111 canal															
A	— ^a	0.67	10.4	0.12	13	6.4	1.0	0.042	78	6.8	6.6	0.19	— ^a	0.65	20
B	— ^a	0.75	7.2	0.12	15	8.4	1.3	0.035	78	6.9	6.8	— ^a	0.26	0.56	21
C	— ^a	0.82	— ^a	0.08	15	3.3	0.53	0.022	53	8.3	3.4	— ^a	2.5	0.45	7.5
D	— ^a	0.62	4.4	0.08	14	3.3	0.54	0.020	47	7.6	4.1	— ^a	— ^a	0.40	90
Shell Creek															
A	— ^a	0.56	1.5	0.060	11	2.0	0.44	0.024	64	6.4	2.7	— ^a	0.31	0.34	49
B	0.040	1.1	4.6	0.060	19	1.8	0.68	0.019	135	7.4	3.1	— ^a	2.3	0.40	3.1
C	— ^a	1.0	2.8	0.050	20	2.3	0.84	0.031	98	7.8	5.0	— ^a	2.0	0.40	4.2
Taylor River	— ^a	0.52	— ^a	0.15	11	2.6	0.65	0.086	62	6.2	2.7	— ^a	— ^a	0.46	6.6
Trout Creek															
A	— ^a	0.88	5.9	0.040	17	1.4	0.80	0.021	83	7.6	3.4	— ^a	0.27	0.41	2.7
B	0.040	1.4	3.6	0.050	27	2.0	1.1	0.027	120	9.2	5.1	— ^a	1.0	0.60	4.6
MDL ^b	0.040	0.0065	1.4	0.030	4.0	1.1	0.0026	0.0070	1.0	1.0	0.90	0.17	0.10	0.15	1.1
TEL ^b ($\mu\text{g/g}$)	0.73	— ^c	7.2	0.68	52	19	— ^c	0.13	— ^c	16	30	— ^c	— ^c	— ^c	124
PEL ^b ($\mu\text{g/g}$)	1.8	— ^c	42	4.2	160	108	— ^c	0.70	— ^c	43	112	— ^c	— ^c	— ^c	271

^a Less than MDL.

^b MDL = method detection limit; TEL = threshold effects level; PEL = probable effects level (MacDonald et al., 1996).

^c Not determined.

TABLE 9. Metal concentrations^a ($\mu\text{g/g}$, wet weight) in filets of fish collected in the Florida Bay area during June 1995.

Site and species	As	Fe	Hg	Zn
Key Largo Ranger Station				
Barracuda	2.4	3.1	0.54	4.3
C-111 canal E				
Largemouth bass	— ^b	2.8	0.53	3.6
Taylor River				
Crevalle jack no. 1	—	15	1.3	7.8
Crevalle jack no. 2	—	41	0.84	5.4
Barracuda	—	2.1	0.61	2.4
Trout Creek				
Hardhead catfish	—	9.7	0.53	22
Crevalle jack	—	12 ^c	1.3 ^c	6.9 ^c
MDL ^d	2.2	0.80	0.0050	1.3

^a Antimony, barium, cadmium, chromium, copper, nickel, lead, and selenium concentrations were below the MDL in all samples.

^b Dashes indicate less than MDL.

^c Mean of two analyses.

^d MDL = method detection limit.

be derived largely from terrestrial pollution and partly from biosynthesis by bacteria and algae in the sea.

The majority of sediment metals data appear to be within the natural range. Concentrations of As, Cd, Cr, Cu, Ni, Pb, and Zn were evaluated with the graphs of Schropp et al. (1990), in which the concentration of specific metals is normalized to the aluminum concentration. The only samples within the "metal-enriched" category were those from C-111 D and Shell Creek A, where zinc concentrations were elevated. However, the "enriched" zinc concentrations were below the TEL reported by MacDonald et al. (1996). Schropp et al. (1990) reported that zinc concentrations at almost all the sediment sites sampled in the Miami River and Biscayne Bay exceeded the expected natural range. In their studies of Cd, Cr, Cu, Hg, Ni, Mn, and Zn concentrations in Florida Bay sediments, Ryan et al. (1989) determined that metals concentrations in Florida Bay sediments were very low.

Our data for Fe and Mn were compared with aluminum-normalized data reported by Windom et al. (1989) for Florida estuarine sediments. On the basis of this comparison, iron concentrations at C-111 A and B appear to be somewhat enriched, as do those at Taylor River and Trout Creek A and B, whereas all the manganese data appear to be within the normal range. When concentrations of Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn were compared with sediment quality guidelines reported by MacDonald et al. (1996), only the As concentration at C-111 A (10.4 $\mu\text{g/g}$) was greater than the TEL (7.2 $\mu\text{g/g}$).

All metal concentrations measured in sediments, except manganese, were compared with concentrations considered "high" in the National Oceanic and Atmospheric Administration Status and Trends Program (Daskalakis and O'Connor, 1995), and only the selenium concentrations at C-111 C (2.5 $\mu\text{g/g}$) and at Shell Creek B (2.3 $\mu\text{g/g}$) and C (2.0 $\mu\text{g/g}$) were within that range. The sediments collect-

TABLE 10. Metal concentrations^a ($\mu\text{g/g}$, wet weight) in indigenous oysters collected from Canal C-111 and Shell Creek during June 1995.

Sampling site	Al	Cr	Cu	Fe	Hg	Zn
C-111 Canal D	9.0	1.1	10	40	0.034	540
Shell Creek A	24	— ^b	1.6	38	0.045	26
Shell Creek C	18	0.76	2.9	36	0.065	32
MDL ^c	1.9	0.70	1.4	0.80	0.005	1.3

^a Antimony, arsenic, barium, cadmium, nickel, lead, and selenium concentrations were less than MDL in all samples.

^b Less than MDL.

^c MDL = method detection limit.

TABLE 11. Metal concentrations^a (µg/g, wet weight) in transplanted oysters (from Santa Rosa Sound, Santa Rosa County, FL) that were held in cages in the C-111 canal and at selected sites in northeastern Florida Bay. Samples were collected during June and July 1995.

Sampling site	Al	Cr	Cu	Fe	Hg	Zn
Prior to caging ^b	16	— ^c	4.1	20	0.013	64
Key Largo						
Caged for 29 days	4.5	1.2	22	30	0.026	160
C-111 Canal B						
Caged for 5 days	12	—	7.2	15	0.016	89
Caged for 28 days	10	—	12	48	0.026	160
Shell Creek B						
Caged for 6 days ^d	20	—	7.5	21	0.020	110
Caged for 29 days	15	0.56	10	31	0.029	140
Taylor River						
Caged for 6 days	20	—	9.7	27	0.035	130
Caged for 29 days ^d	20	0.93	9.7	39	0.066	130
Trout Creek A						
Caged for 6 days ^d	21	0.65	8.5	25	0.022	100
Caged for 29 days	6.0	—	8.2	26	0.029	140
MDL ^e						
Predeployment and caged						
for 5–6 days	1.9	0.70	1.4	0.80	0.0050	1.3
28- and 29-day samples	1.9	0.50	0.90	0.80	0.0020	1.6

^a Antimony, arsenic, barium, cadmium, nickel, lead, and selenium concentrations were less than the MDL in all samples.

^b Sampled after being held overnight in ambient seawater at the Key Largo Ranger Station.

^c Dashes indicate less than MDL.

^d Mean of duplicate analyses.

^e MDL = method detection limit.

ed from the same sites used in this study have been evaluated for toxicity with both aquatic animals and plants (Lewis et al., unpublished). Significant toxicity was not observed with either animals or plants, which reinforces the findings of this study that toxicant levels are low. However, sediments collected from the Taylor River area were stimulatory to macrophyte seedlings.

The filets of seven fish from Florida Bay contained no detectable (≥ 2.0 µg/kg) pesticides or PCBs except for a sea catfish that contained 3.2 µg pp-DDE/kg. Ogden et al. (1974) reported 3.6 µg DDE/kg, 5.0 µg DDT/kg, and 5.0 µg dieldrin/kg (whole body, wet weight) in a sample of three sea catfish collected from Florida Bay during 1971–1973. They also reported similar concentrations in crevalle jacks; those analyzed in this study contained no detectable organochlorine pesticides.

Of the metal concentrations measured in fish filets (Table 9), mercury appears to be the only one of concern. The arsenic and zinc concentrations for barracuda, hardhead catfish, and crevalle jacks were within the ranges of val-

ues reported for those species (Hall et al., 1978). The concentrations of mercury measured in filets of barracuda, largemouth bass, crevalle jacks, and hardhead catfish ranged from 0.53 to 1.3 µg/g, wet weight. This range includes values above the U.S. Food and Drug Administration's "Action Level" of 1 µg methyl mercury/g in edible portions of fish and shellfish (U.S. Food and Drug Administration, 1994). The State of Florida published a health advisory (Florida Health and Rehabilitative Services, 1995) urging limited consumption of selected species of fishes from coastal Florida, including Florida Bay. The advisory recommended limited consumption of fish containing 0.5–1.5 µg mercury/g and no consumption of fish containing >1.5 µg mercury/g. Kannan et al. (1998) determined total and methyl mercury concentrations in nine species of estuarine fishes from Florida waters; some of the samples were from this study. Mean total mercury concentrations reported for the nine species ranged from 0.03 to 2.2 µg/g, wet weight. In their report on mercury concentrations in tissues of largemouth bass from Flori-

da, Hand and Friedemann (1990) found that the highest median concentrations and the greatest variation in mercury concentrations were in fish from stations in the Everglades region. Mercury in the south Florida ecosystem is a known problem (Stober et al., 1992, 1995, 1996) and the subject of several investigations.

The concentrations of some metals detected in oysters collected from the C-111 canal and Shell Creek differed from the data of Heil (1986) for oysters from 25 locations in or near Florida shellfish harvesting beds. However, none of the 25 locations was along the southern tip of Florida. When our data for indigenous oysters from Florida Bay are compared with his summer mean ± 1 SD, the aluminum, copper, and iron values fall within that range. However, our chromium concentrations of 1.1 (C-111 D) and 0.76 $\mu\text{g/g}$ (Shell Creek C) are greater than the maximum value of 0.64 $\mu\text{g/g}$ that he derived during winter and summer sampling. Our mercury values for Shell Creek A and C (0.045 and 0.065 $\mu\text{g/g}$, respectively) are greater than Heil's summer mean + 1 SD; however, only the value for Shell Creek C is greater than his maximum mercury concentration (0.049 $\mu\text{g/g}$). The zinc concentration in indigenous oysters (540 $\mu\text{g/g}$) from C-111 D is close to the maximum summer value reported by Heil (546 $\mu\text{g/g}$). However, zinc concentrations for Shell Creek A and C (26 and 32 $\mu\text{g/g}$, respectively) are considerably lower than Heil's mean concentration of 215.9 ± 149.6 $\mu\text{g/g}$.

The maximum change in metals concentration in oysters obtained from Santa Rosa Sound, FL, and caged at the study sites for 28–29 days was five times the predeployment value (Table 11). Aluminum values varied within a factor of 5, and chromium was nondetectable in oysters prior to deployment and ranged from nondetectable at C-111 B to 1.2 $\mu\text{g/g}$ at the Key Largo site. Although chromium appears to have increased in caged oysters, this may be at least partially, if not primarily, attributable to the detection limits differing because the sample weights digested were not the same. For samples taken prior to deployment and after 5–6 days in the cages, the detection limit was 0.70 $\mu\text{g/g}$, whereas that for oysters sampled after 28–29 days in the cages was 0.5 $\mu\text{g/g}$. Copper concentrations after caging ranged from two to five times the predeployment value, with the highest residue measured in oysters caged at the Key Largo site (22 $\mu\text{g/g}$); iron concentrations in oysters after 28–29 days were within a factor of 2 of the predeployment concentration. After 28–29 days of deployment,

mercury concentrations in oysters in the C-111 canal, Shell Creek, and Trout Creek were twice the predeployment value of 0.013 $\mu\text{g/g}$, and in those caged at Taylor River were five times the initial concentration. However, only the Hg concentration measured in oysters caged at Taylor River (0.066 $\mu\text{g/g}$) was greater than the maximum Hg concentration of 0.049 $\mu\text{g/g}$ reported by Heil (1986) for oysters sampled in summer. Zinc concentrations increased from 64 $\mu\text{g/g}$ prior to caging to 130–160 $\mu\text{g/g}$ after 28–29 days at the five study sites. However, zinc concentrations measured in these samples were considerably less than the mean concentration of 1,428 $\mu\text{g/g}$ that Pringle et al. (1968) reported for approximately 100 oyster samples taken on the Atlantic coast from Maine through North Carolina.

Copper concentrations in oysters, before and after caging, were within the summer mean ± 1 SD reported by Heil (1986) at all sites except the Key Largo site. The copper concentration in oysters caged for 29 days at this site (22 $\mu\text{g/g}$) was five times greater than in the predeployment sample but less than Heil's maximum summer concentration of 28.4 $\mu\text{g/g}$.

These data on metal concentrations in caged oysters must be interpreted with caution because changes in metal concentrations can sometimes be attributed to changes in biomass rather than actual movement of metals into or out of the animal (Roesijadi, 1996). Natural factors such as food availability, reproduction, salinity, and the presence of organic substances can contribute to variability in metal concentrations in these organisms (Roesijadi, 1996). Considerable rainfall occurred in the watershed draining into Florida Bay during the oyster deployment, and lowered salinity could have affected the physiological condition of the oysters and the speciation of metals.

CONCLUSIONS

Our preliminary survey identified a number of contaminants at concentrations above detection limits in sediments of northeastern Florida Bay and Canal C-111. However, the concentrations were generally low. At one site each, concentrations of total chlordane, 4,4' DDT, total DDT, and lindane in sediment exceeded TEL values. PAH compounds in excess of TEL values were measured at C-111 A (four PAHs and total PAHs) and D (six PAHs and sum PAHs). Although not normalized for organic carbon content, Canal C-111 appears to have the greatest organic contamination followed by

Shell Creek and Trout Creek. Only one organic contaminant was detected from Taylor River sediments. In general, the highest concentrations of organic contaminants were found at sites at the mouth of waterways, where one might expect that deposition would be relatively high. The only metal concentration measured in sediments that was above TEL values (MacDonald et al. 1996) was arsenic at C-111 A. Sediment PEL values for organics and metals were not exceeded in any samples.

Concentrations of mercury in fish filets (0.53–1.3 µg/g, wet weight) were within the range covered by the limited consumption advisory by the State of Florida. Dissolved oxygen concentrations in the lower portion of C-111 were below Florida standards but were generally acceptable in other areas.

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