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South Florida Coastal Sediment Ecological Risk Assessment

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Abstract This study evaluated the degree of sediment contamination in several South Florida estuaries. During the 2010 National Condition Assessment, Florida Fish and Wildlife Research Institute collected water column, sediment and biotic data from estuaries across the entire state of Florida. Sediments were analyzed for arsenic, cadmium, chromium, lead, mercury, zinc and total polychlorinated biphenyls and were compared relative to empirically derived sediment quality guidelines. As a result of this data collection and assessment effort, it was determined that the degree of contamination with respect to sediment was low for all southern Florida estuaries assessed, except the Miami River which was determined to be considerably contaminated. However only one monitoring location was used to assess the Miami River, and as such should be viewed with caution. A low degree of contamination was determined for Biscayne Bay sediments, possibly indicating a recovery from its previously reported higher contaminant level.

Contaminants enter estuarine ecosystems through riverine, atmospheric or anthropogenic inputs. Meanwhile coastal sediments have the potential to act as both sources and sinks of contaminants (Summers et al. 1996) depending upon the characteristics of the sediments (i.e. grain size,

percent clay, percent organic matter, mineral composition, etc.) and loading of a specific contaminant. Depending upon their structure and ionic charge, contaminants have varying capacities to sorb onto sediment particles. Therefore sediments that contain toxic contaminants have the potential to impact the ecological health of a region or site (Håkanson 1980; Förstner et al. 1990).

The uptake of contaminants, including metals and organic toxicants, may pose a threat to upper level trophic animals (i.e. piscivorous fauna) and humans that consume fish or shellfish. Metals of particular concern include chromium, cadmium, mercury, lead and arsenic due to their high levels of toxicity to biota and limited natural biochemical processes to mitigate their toxicological effects (Kennish 1991).The objectives of this study were to evaluate concentrations of specific contaminants in the estuarine and coastal sediments from several South Florida sites and to assess their relative ecological risks to aquatic life.

Materials and Methods

Benthic, water column and biotic parameters were collected by the Florida Fish and Wildlife Research Institute (FWRI) as part of the United States Environmental Protection Agency (USEPA) National Coastal Assessment (NCA) research program. Data were collected from sites selected through a stratified survey design during the index period between June and August of 2010 (USEPA 2010a). The USEPA NCA program is designed to provide statistically valid regional and national estimates of the condition of coastal water throughout the US.

Sediment chemical data were obtained from USEPA Office of Wetlands, Oceans and Watershed. All fatally

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qualified data were removed prior to analysis. Fatally qualified data included any data that did not meet quality control requirements or program data quality objectives. Sediment parameters including arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), zinc (Zn), total polychlorinated biphenyls (ΣPCB), total organic carbon (TOC), and percent sand, silt and clay were analyzed by a USEPA approved laboratory consistent with laboratory methods identified by USEPA (2010b). Analytical methods EPA6020 (USEPA 2007a) was utilized to analyze for As, Cd, Cr, Cu, Pb and Zn, method EPA245.1 (USEPA 2009) was used for Hg analysis and EPA8270C (USEPA 2007b) was used for PCB analysis. Concentrations less than the method detection limit (MDL) were assigned a value one-half of the MDL unless otherwise noted.

Sediment samples collected within South Florida's estuaries (Fig. 1) were assessed utilizing the contamination factor (C_f) and degree of contamination (C_D) approach (Eqs. 1 and 2, respectively) developed by Håkanson (1980).

$$C_f^i = \frac{C_{0-1}^i}{C_n^i} \tag{1}$$

where C_f^i = Contamination factor or C_f; C_{0-1}^i = Concentration of a particular contaminant (i = PCB, Hg, Cd, As, Cr, Cu or Zn); C_n^i = Threshold effect level for a particular contaminant (MacDonald 1994)

$$C_D = \sum_{i=1}^{8} C_f^i \tag{2}$$

C_D = Degree of contamination or C_D; C_f^i = Contamination factor or C_f. The C_f accounts for the contamination of a single element relative to an established baseline concentration. Håkanson (1980) used a pre-industrial baseline to determine the C_f for each chemical. For this study, the marine sediment threshold effect limit (TEL) identified by (MacDonald 1994; Table 1) was used for each contaminant of interest. The TEL is operationally defined as the concentration below which adverse biological effects rarely occur. The use of TELs versus pre-industrial reference points were deemed more appropriate for a sediment ecological risk assessment since a TEL is linked to the biology of indicator species rather than historic concentrations. Therefore if the sediment concentration exceeded a TEL for a particular parameter, adverse effects might be expected.

Calculated C_D values were compared between waterbodies using the Wilcoxon multiple comparison test with waterbodies represented by greater than one station. An exception was the Miami River site, where only a single site was sampled. All statistical operations were performed with JMP® (Ver 10.0.0, SAS, Cary, NC, USA.) and R© (Ver 3.1.2, R Foundation for Statistical Computing, Vienna, AT). The critical level of significance was set at α = 0.05.

Results and Discussion

Sediment texture was generally dominated by sand, ranging from 27 to 92 percent sand and 1.0 to 33 percent silt and clay. Sediment total organic carbon ranged from 0.07 to 9.7 percent TOC. The observed range of percent TOC values in this study correspond to values reported for sediments within the continental margins (Emerson and Hedges 1988), and presumably are being amended by the high organic carbon content of the rivers and canals of South Florida, as well as the highly productive estuarine benthic habitats (Yarbro 2013). Organic carbon within estuarine ecosystems plays an import role in several ecosystem functions, such as the regulation of metal and contaminant bioavailability (Burgess et al. 2013).

No single contaminant dominated all waterbodies assessed in this sediment ecological risk assessment. While some watersheds experienced similarities amongst contaminants in terms of calculated C_f values, their concentrations were not consistent amongst all waterbodies (Table 2). For instance C_f for Cd (cadmium) varied largely between sites from all other contamination factors regardless of the inclusion of the Miami River evaluation (Table 3). These differences between waterbodies and C_f are presumably due to several factors including upstream (watershed) effects such as differences in historic and current land uses, ongoing restoration efforts, regulatory assistance (i.e. cooperative hazardous waste clean-up efforts), geology and sediment characteristics.

Contaminant concentrations varied largely between the different South Florida estuaries (Table 2). The degree of contamination (C_D) for all waterbodies, excluding the Miami River, was considered to be low (Table 4; Fig. 1). The Miami River monitoring location had relatively high concentrations of all contaminants with the exception of total PCBs and a C_D of 152.4. Contaminant concentrations above the TEL were observed for As, Cd, Cu, Pb, Hg and Zn, resulting in moderate to very high C_f values for these contaminants. These contaminants presumably originate from a variety of sources, including anti-fouling paints (Canning-Clode et al. 2011), wood treatments (Eisler 1988) and urban run-off (Davis et al. 2001). It is worth noting that due to access issues to the site, sediment was collected at a marina within the target location boundary. While this one site had elevated concentrations of key contaminants, it may not be representative of the entire waterbody. However, the increased concentrations of contaminants could pose a potential ecological risk to local biota.
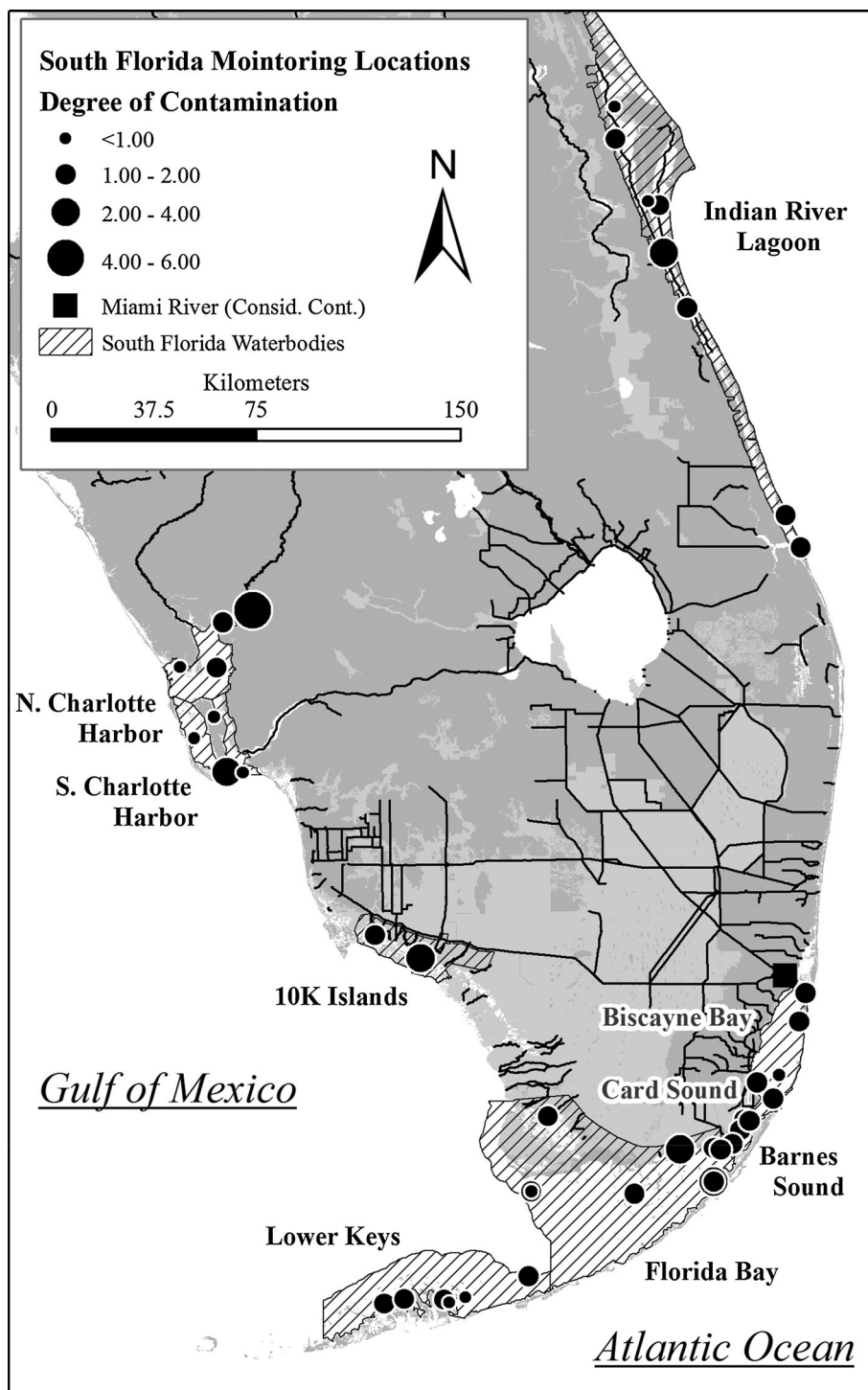
The C_D value accounts for the total sediment pollution within a given waterbody with respect to a particular suite of contaminants. Even with the low C_D values for all sites excluding the Miami River site, some differences were evident (Tables 2 and 4; Fig. 1). Most notably, the Ten Thousand Islands was significantly different from both the Lower Keys and Biscayne Bay but similar to all others

waterbodies. Furthermore the C_D within the Southern Charlotte Harbor waterbody was significantly different from that of Florida Bay and Indian River Lagoon but similar to all other waterbodies. These comparisons should be viewed with caution due to the number of stations used to represent each waterbody. Regardless of differences in contaminant concentrations, C_f and C_D values could be

Table 1 Marine sediment threshold effect limit (TEL) concentrations for each contaminant of interest used in this study (MacDonald 1994)

Parameter	Threshold effect limit (ng g^{-1})
Arsenic (As)	7240
Cadmium (Cd)	680
Chromium (Cr)	52,300
Copper (Cu)	18,700
Lead (Pb)	30,240
Mercury (Hg)	130
Zinc (Zn)	124,000
Total polychlorinated biphenyl (ΣPCB)	21.6

influenced by upstream watershed land uses and effects (point source vs. non-point source), regional geology and hydrodynamics, as well waterbody characteristics such as sediment type and distribution (Weis and Weis 2004; Simenstad et al. 2005).

This study presents an ecological risk assessment utilizing empirically derived TEL sediment quality guidelines (SQG). Empirically derived SQGs provide a prediction of whether or not sediments may be toxic to benthic organisms based on known adverse effects. Meanwhile, mechanistically derived SQGs have also been developed for risk assessments which are rooted in equilibrium partitioning theory and are becoming more prevalent in ecological assessments and peer-reviewed literature (Wenning 2005; Burgess et al. 2013). Mechanistic SQGs use properties of both the contaminant and the sediment system to predict the bioavailability and toxicity of the contaminant. Characteristics of the sediment system such as TOC or acid-volatile sulfide (AVS) are used in these predictions (Burgess et al. 2013). Since AVS data was not determined, the empirical approach alone was used in this study.

Even though this analysis is somewhat limited due to the coverage in monitoring locations within each waterbody and the limited sample collection time frame (one season), this assessment suggests that ecological risk for benthic organisms is relatively low for most estuaries within southern Florida. Furthermore, based on information presented by Schropp et al. (1990), it seems that Biscayne Bay has recovered from an area considered to be contaminated ("suspected contaminated sediment") to an area with a low degree of contamination. Additional data including water column contaminant concentration, other water quality, benthic macroinvertebrate presence/absence and other characteristics were measured as part of the NCA.

Table 2 South Florida estuary sediment contaminant concentration summary statistics for samples collected between June and August of 2010

Analyte (ng g^{-1})	Northern Charlotte Harbor	Southern Charlotte Harbor	Ten thousand Islands	Florida Bay	Lower Keys
West coast					
Arsenic	950 ± 409 (4)	688 ± 300 (6)	2033 ± 406 (3)	2548 ± 455 (9)	3349 ± 423 (8)
Cadmium	400 ± 268 (4)	108 ± 80 (6)	233 ± 88 (3)	76 ± 26 (9)	51 ± 14 (8)
Chromium	13,450 ± 7890 (4)	4700 ± 1518 (6)	27,200 ± 3530 (3)	12,822 ± 2700 (9)	4666 ± 842 (8)
Copper	2050 ± 1239 (4)	1233 ± 600 (6)	2833 ± 578 (3)	1444 ± 314 (9)	854 ± 117 (8)
Lead	606 ± 594 (2)	1167 ± 502 (6)	4233 ± 884 (3)	1644 ± 501 (9)	419 ± 91 (8)
Mercury	36 ± 25 (4)	7 ± 1 (6)	27 ± 9 (3)	18 ± 5 (9)	5 ± 0 (8)
Zinc	10,750 ± 8197 (4)	1488 ± 990 (6)	7267 ± 1139 (3)	2895 ± 435 (9)	1306 ± 360 (8)
ΣPCB	11 ± 0 (4)	11 ± 0.1 (6)	11 ± 0.2 (3)	11 ± 0.1 (9)	11 ± 0.1 (8)

Analyte (ng g^{-1})	Barnes Sound	Card Sound	Biscayne Bay	Indian River Lagoon	Miami River[a]
East coast					
Arsenic	2726 ± 308 (3)	2250 ± 50 (2)	2750 ± 824 (5)	779 ± 226 (9)	10,600
Cadmium	56 ± 23 (3)	13 ± 0 (2)	18 ± 5 (5)	125 ± 22 (9)	1400
Chromium	6263 ± 2317 (3)	5850 ± 1150 (2)	3926 ± 893 (5)	6436 ± 1816 (9)	37,000
Copper	1431 ± 645 (3)	1200 ± 0 (2)	1820 ± 479 (5)	2737 ± 1152 (9)	2,285,000
Lead	1347 ± 759 (3)	13 ± 0 (2)	1026 ± 367 (5)	5098 ± 1256 (9)	199,300
Mercury	23 ± 3 (3)	35 ± 15 (2)	7 ± 1 (5)	16 ± 6 (9)	1430
Zinc	2617 ± 893 (3)	2000 ± 300 (2)	2513 ± 871 (5)	7500 ± 3150 (9)	974,300
ΣPCB	11 ± 0.2 (3)	11 ± 0 (2)	11 ± 0 (5)	11 ± 0.1 (9)	11

Values are denoted as mean ± standard error (sample size)

[a] Only one sample was collected for this waterbody

Table 3 Mean and standard error (SE) for contamination factor (C_f) for each analyte and waterbody

Waterbody	Statistics	Contamination factor (C_f)							
		Arsenic	Cadmium	Chromium	Copper	Mercury	Lead	Zinc	ΣPCB
N. Charlotte Harbor	Mean	0.17	0.74	0.33	0.14	0.36	0.04	0.11	0.51
	SE	0.06	0.52	0.18	0.08	0.24	0.00	0.08	0.00
S. Charlotte Harbor	Mean	0.09	0.16	0.08	0.06	0.05	0.03	0.01	0.50
	SE	0.04	0.1	0.03	0.03	0.01	0.02	0.01	0.005
10 K Islands	Mean	0.28	0.34	0.52	0.15	0.21	0.14	0.06	0.50
	SE	0.06	0.13	0.07	0.03	0.07	0.03	0.01	0.008
Florida Bay	Mean	0.35	0.11	0.25	0.08	0.14	0.05	0.02	0.50
	SE	0.06	0.04	0.05	0.02	0.04	0.02	0.004	0.004
Lower Keys	Mean	0.46	0.07	0.09	0.05	0.04	0.01	0.01	0.50
	SE	0.06	0.02	0.02	0.01	0.00	0.003	0.003	0.004
Barnes Sound	Mean	0.38	0.08	0.12	0.08	0.18	0.04	0.02	0.50
	SE	0.04	0.03	0.04	0.03	0.03	0.03	0.01	0.008
Card Sound	Mean	0.31	0.02	0.11	0.06	0.27	0.0004	0.02	0.51
	SE	0.01	0.00	0.02	0.00	0.12	0.00	0.002	0.00
Biscayne Bay	Mean	0.38	0.03	0.08	0.1	0.05	0.03	0.02	0.49
	SE	0.11	0.01	0.02	0.03	0.01	0.01	0.01	0.00
Indian River Lagoon	Mean	0.11	0.18	0.12	0.15	0.12	0.17	0.06	0.51
	SE	0.03	0.03	0.03	0.06	0.04	0.04	0.03	0.003
Miami River	Mean	1.46	2.06	0.71	122.19	11.00	6.59	7.86	0.49
	SE	–	–	–	–	–	–	–	–

Table 4 Summary statistics for the degree of contamination factor (C_D) for each estuary

Waterbody[a]	Degree of contamination (C_D)						
	Arithmetic mean	Standard error	Number of sites	Minimum	Maximum	Category[b]	Similarity[c]
Northern Charlotte Harbor	2.0	0.9	4	0.8	4.7	Low	ABC
Southern Charlotte Harbor	1.0	0.2	6	0.6	2.2	Low	ABC
Ten Thousand Islands	2.2	0.3	3	1.7	2.6	Low	AB
Florida Bay	1.5	0.2	9	1.0	2.3	Low	AC
Lower Keys	1.2	0.1	8	0.9	1.5	Low	BC
Barnes Sound	1.4	0.1	3	1.2	1.7	Low	ABC
Card Sound	1.3	0.1	2	1.2	1.4	Low	ABC
Biscayne Bay	1.2	0.2	5	0.7	1.6	Low	BC
Indian River Lagoon	1.4	0.2	9	0.9	2.8	Low	AC
Miami River	152.4	–	1	–	–	High	–

[a] Miami River was excluded from statistical analysis due to limited data and extremely high C_D value relative to other estuaries in the region

[b] Category delineations consistent with Håkanson (1980). Categories delineated as Low: $C_D < 8$; Moderate: $8 \leq C_D < 16$; and High: $16 \leq C_D < 32$

[c] Waterbodies not connected by same letter are significantly different (i.e. $\rho < 0.05$) based on the Wilcoxon multiple comparison test

However this assessment focused solely on sediment contaminant concentrations, one piece of the overall ecosystem puzzle. Additional factors should be considered in an integrated ecological health assessment (i.e. the whole puzzle) of a particular waterbody or region.

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