Assessment of Sediment Contamination in the Lower Mobile-Tensaw Delta (*Rangia* Study)

Final Report

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ASSESSMENT OF SEDIMENT CONTAMINATION IN THE LOWER MOBILE-TENSAW DELTA

Introduction

The Alabama Department of Conservation and Natural Resources has been engaged in acquiring large tracts of land in the Mobile-Tensaw Delta through the Forever Wild Program and is planning a major interpretive center for the Mobile Causeway. This level of interest parallels local concerns regarding the impact of the causeway structure itself on the ecology of the lower delta and upper portions of Mobile Bay.

Within the Mobile-Tensaw Delta proper, a large dike-like causeway, built in the late 1920s, has reduced water exchange between a number of once open bays and the Gulf. This hydrological modification may have also altered the productivity of ecological communities within the lower Delta via reduced salt and fresh water exchange and altered circulation patterns, resulting in changes in sediment characteristics and depositional patterns. Alterations of sediment depositional patterns are of great significance throughout the Gulf of Mexico, since benthic habitats, and the organisms they support, play a key role in determining the ecological productivity of most estuarine food webs. They also play a vital role in nutrient recycling and sediment contaminant concentration (e.g., Aller 1978, 1982; Swartz and Lee 1980; Hartley 1982; Hargrave and Theil 1983; Philips and Segar 1986; Armstrong, 1987; Collie 1987; Weston 1990; Kemp et al. 1992). Spatial and temporal variations in sediment grain size are important indicators of depositional areas with fine-grained materials occurring in areas of high deposition. Grain size characteristics are also correlated with TOC and C:N, which in turn are also positively correlated with levels of trace metals and organic compounds (Gibson *et al.* 2000).

During 2004, benthic samples were taken from stations located above and below the causeway. Samples collected from Polecat Bay and Delvan Bay were largely devoid of life. Lower faunal densities were also found in Chocolatta Bay. There were greater concentrations of fined grained sediments in all embayments located north of the causeway. Since such fine-grained sediments bind many forms of contaminants to the benthos, we hypothesized that the embayments north of the causeway might be sites of elevated contaminant deposition (McConnell and Harrel 1995, Wicker and Gantt 1994). To test this hypothesis, we proposed to collect sediment samples and conduct a pilot reciprocal transplant experiment, using the ubiquitous coot clam, *Rangia cuneata* (hereafter referred to as *Rangia*), to provide an initial assessment of the distribution of selected metals, and their availability to organisms, in benthic habitats around the causeway. This study was funded by Alabama Department of Conservation and Natural Resources, State Lands Division (Grant #: DISL-CZM-306-04-4) in 2004. Here we report the findings of this pilot study

Materials and Methods

Rangia were collected initially from a pristine reference station located south of the causeway on June 3, 2005. Previously in 2004, concentrations of selected metals in *Rangia* tissues collected from this area were nearly undetectable. The clams were numbered and measured in the laboratory. Subsequently, three replicate "benthic cages" (Salazar and Salazar 1997, 2002), each containing 10 *Rangia*, were deployed in Delvan Bay, Chocolatta Bay and Justin's Bay on June 7, 2005 (Fig. 1). Bad weather delayed deployment of cages in Polecat Bay and south of the causeway by one week (the remaining cages were deployed on June 14, 2005) (Fig. 1). *Rangia* survival was recorded throughout the cage deployment. A large number of dead clams in cages placed at a station in Polecat Bay (PB-1) and one to the South (S-3) were recorded. As a result, surviving clams in Polecat Bay (PB-1, PB-2 and PB-3) and at South #3 (S-3) were collected on July 28, 2005. On August 8, 2005, the remaining clams were collected from all sites. Additionally, three collections of 10 *Rangia* were made in the reference station vicinity to assess the extent to which *Rangia* metals uptake varies from year to year. Sediment grabs were also collected adjacent to the clam cages and at the reference site for metals analyses.

Rangia and sediment samples were transferred to prelabeled containers and then placed on ice. Upon return to the laboratory, the samples were refrigerated until processing. Clam lengths, widths and heights were measured and clam tissues were extracted. The extracted tissues and sediment samples were delivered to Severn Trent Laboratory (STL) in Mobile, Alabama for metals analyses. Mercury concentration was determined using EPA method SW846 7471A. Determinations aluminum, arsenic, cadmium, chromium, copper, lead and zinc were conducted using EPA method SW846 6010B.

The passage of Hurricane Dennis (July 10, 2005) had minor impacts on this project. One cage was lost at station South #1 and four cages (South #2, South #3, Delvan #1, Delvan #3) were pushed over but the clams survived. Clams placed in Polecat Bay, Chocolatta Bay and Justin's Bay survived Hurricane Dennis.

Data Analysis

Measures of *Rangia* morphology and metals accumulation along with sediment metals concentration levels were analyzed using a SPSS Linear Mixed Model Analysis of Variance (ANOVA) with site nested within causeway location (north or south of the causeway). The assumption of homogeneity of variance for ANOVA could not be met following transformation for sediment cadmium concentration (p=0.003), sediment mercury concentration (p=0.02) or *Rangia* final width (p=0.084) (Table 2). As a result, analyses were conducted on raw data. While such violations can nullify the findings from ANOVA in some cases, they can also provide important insights into variance in treatment responses. This was the case in this study. Put simply, concentrations of these metals were consistently very low at some sites, as was growth, and higher, but more variable, at others. *Rangia* survival was based on the numbers of surviving clams and shells recovered. Missing or lost clams were discarded from the analyses. When *Rangia* and sediment metal concentrations were less than the STL Reporting Levels, the value zero (mg/kg) was assigned to the sample. *Rangia* metal concentration analyses excluded reference collections and South #1 where the benthic cage was lost during Hurricane Dennis.

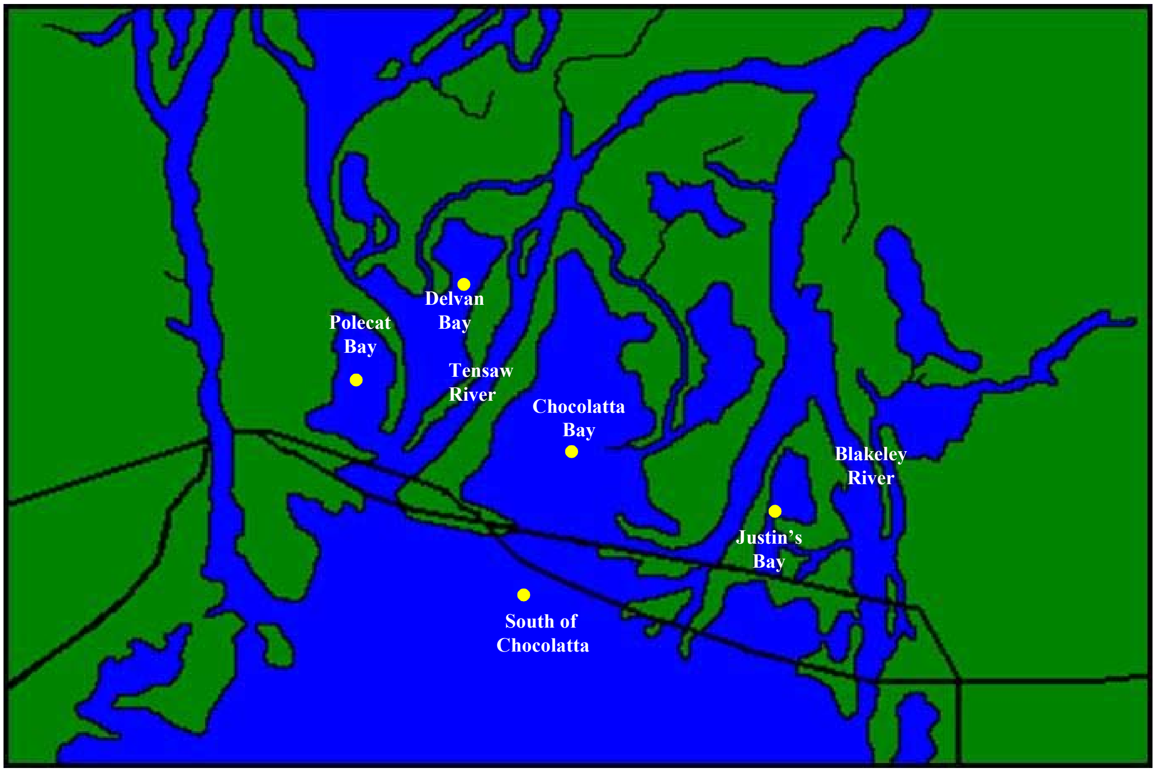

Figure 1. Mobile-Tensaw Delta study sites (yellow) used for the 2005 *Rangia* transplant study. Sampling stations include Polecat Bay, Delvan Bay, Chocolatta Bay, Justin's Bay, and South of Chocolatta (south of the causeway). Dots are not at the exact locations.

Table 1. Mobile-Tensaw Delta *Rangia* stations for 2005 listed by site, location with respect to the causeway (N = north, S = south) and *Rangia* cage number. The latitude and longitude and a brief sites descriptions are also provided for each site.

Site	**North or South of Causeway**	**Rangia Cage**	**Latitude**	**Longitude**	**Description**
Polecat Bay	N	PB-1	N 30^{o} 41.606	W 088^{o} 00.553	Most southern cage; First duck blind at point; East side of bay; at sign "PITT"
		PB-2	N 30^{o} 41.796	W 088^{o} 00.552	Second duck blind on east side of bay; north side of blind at post
		PB-3	N 30^{o} 41.908	W 088^{o} 00.558	Third duck blind on east side of bay; Northeast side of blind; reeds "down"
Delvan Bay	N	DB-1	N 30^{o} 43.034	W 087^{o} 59.358	Most northern cage; Channel marker NE; Duck blind to NE; In line with 3 poles to SE and water towers
		DB-2	N 30^{o} 43.120	W 087^{o} 59.510	Duck blind to northeast of 1
		DB-3	N 30^{o} 42.959	W 087^{o} 59.606	Piling near west side; north of small cypress tree
Chocolatta Bay	N	CB-1	N 30^{o} 41.113	W 087^{o} 58.877	YSI location
		CB-2	N 30^{o} 41.067	W 087^{o} 58.672	Duck blind to east of YSI
		CB-3	N 30^{o} 41.057	W 087^{o} 58.490	Duck blind to east of 2
Justin’s Bay	N	JB-1	N 30^{o} 41.091	W 087^{o} 56.380	Most northern channel marker; Previous YSI location
		JB-2	N 30^{o} 41.073	W 087^{o} 56.390	2nd channel marker south of 1; Tree stump marker
		JB-3	N 30^{o} 41.028	W 087^{o} 56.415	4th channel marker from northern marker
South	S	South-1	N 30^{o} 40.567	W 087^{o} 59.371	Duck blind; furthest east; east of pink hotel
		South-2	N 30^{o} 40.531	W 087^{o} 59.436	Bamboo marker southwest of South-1
		South-3	N 30^{o} 40.517	W 088^{o} 00.055	Channel marker directly below Argiro's; south side of channel; furthest west cage
Reference	S	R-1	N 30^{o} 40.544	W 087^{o} 59.507	
		R-2	N 30^{o} 40.530	W 087^{o} 59.512	
		R-3	N 30^{o} 40.509	W 087^{o} 59.453	
2004 Reference	S		N 30^{o} 40.499	W 087^{o} 59.460	

Table 2. Results of the statistical comparisons of selected metals uptake by *Rangia* and sediment concentrations at the Mobile-Tensaw study sites. *Rangia* size (length (L), width (W) and height (H)) and survival at the end of the experiment are also provided. Treatment effects (causeway location) were considered highly significant when $p<0.05$ and marginally significant when $p<0.1$.

	2004 - 2005 Paired T-Test (2-tailed)	**Homogeneity of Variances (North/South)**	**Normality (North/South)**	**Mixed Model - Site nested in Location (North/South)**
Rangia Metals				
Arsenic	**0.028**	0.567	0.710	0.715
Cadmium	0.122	0.208	**0.003**	0.443
Chromium	**0.062**	0.577	0.611	**0.047**
Copper	**0.037**	0.563	0.401	0.372
Lead	**0.064**	0.581	**0.002**	**0.124**
Zinc	**0.058**	0.218	0.974	0.198
Aluminum	**0.095**	0.118	0.685	0.511
Mercury	**0.044**	0.713	**0.000**	0.778
Sediment Metals				
Arsenic		0.173	**S = 0.000**	**0.012**
Cadmium		**0.003**	**N = 0.000** **S = 0.000**	0.433
Chromium		0.282	**S = 0.000**	**0.000**
Copper		0.167	**S = 0.000**	**0.000**
Lead		0.435	**N = 0.069** **S = 0.007**	**0.001**
Zinc		0.289	**S = 0.000**	**0.001**
Aluminum		0.166	**S = 0.000**	**0.000**
Mercury		**0.020**	ns	**0.032**
Rangia LWH				
Initial Length		0.218	ns	0.473
Initial Width		0.156	ns	0.305
Initial Height		0.318	ns	0.344
Final Length		0.255	ns	**0.000**
Final Width		**0.084**	ns	**0.000**
Final Height		0.320	ns	**0.023**
Growth Length (cm/day)		0.417	ns	**0.065**
Growth Width (cm/day)		0.220	**0.048**	**0.093**
Growth Height (cm/day)		0.507	ns	0.400
Survival (trans)		0.447	**0.070**	**0.086**

Results

Rangia Size, Growth and Survival

Measures of Rangia growth (reported in cm), for initial and final length, width, height, are reported by location in Table 3 and by site in Table 4. Tables 3 and 4 also report *Rangia* survival and growth means standardized by day (cm/day) for length, width, height by location and site. Sites again included stations located south of the causeway, Polecat Bay, Delvan Bay, Chocolatta Bay, Justin's Bay and the Reference area. South #1 was lost during Hurricane Dennis and Reference site clams were collected only for metals analyses.

Initial lengths (F=0.954, df =4, 10, p=0.473), widths (F=1.393, df =4, 10, p=0.305) and heights (F=1.269, df=4, 10, p=0.344) were similar north and south of the causeway and by site (Tables 2 through 4). Since the initial deployment dates varied, *Rangia* growth was standardized to a daily basis. Increases in *Rangia* length (F=3.264, df=4, 9, p=0.065) and width (F=2.778, df=4, 9, p=0.093) were marginally greater north of the causeway than south of the causeway. Increases in height (F=1.134, df=4, 9, p=0.400) varied little among locations (Table 3). Over all sites, clams placed in Justin's Bay and Delvan Bay had the highest growth rates for length and width (Figs. 2 and 3).

Percent *Rangia* survival (F=2.880, df=4, 9, p=0.086) was marginally different among locations. Clams placed north of the causeway (n = 12 cages) survived better than clams placed south of the causeway (n = 2 cages) (Tables 2 and 3). During the study, five clams were lost in Delvan #3, and larger numbers of *Rangia* died at one of the sites south of the causeway (South #3) and at Polecat #1 (Table 4). It is of note that South #3 and Polecat #1 were located furthest west of all cages.

Table 3. *Rangia* means and standard deviations for initial and final length, width, height, growth (cm/day) and survival are reported by location north or south of the causeway for the Mobile-Tensaw 2005 *Rangia* study.

Location	**Mean Initial Length (cm)**	**STD Mean Initial Length (cm)**	**Mean Initial Width (cm)**	**STD Mean Initial Width (cm)**	**Mean Initial Height (cm)**	**STD Mean Initial Height (cm)**	**Mean Final Length (cm)**	**STD Mean Final Length (cm)**	**Mean Final Width (cm)**	**STD Mean Final Width (cm)**	**Mean Final Height (cm)**	**STD Mean Final Height (cm)**
North	3.29	0.07	3.18	0.09	2.20	0.08	3.56	0.08	3.44	0.10	2.38	0.11
South	3.27	0.05	3.13	0.03	2.21	0.05	3.23	0.09	3.07	0.18	2.24	0.20

Location	**Growth Length (cm / day)**	**STD Growth Length (cm / day)**	**Mean Growth Width (cm / day)**	**Std Mean Growth Width (cm / day)**	**Mean Growth Height (cm / day)**	**Std Mean Growth Height (cm) / day**	**Survival (%)**	**Std Survival (%)**
North	0.0040	0.0015	0.0039	0.0012	0.0027	0.0009	82.50	24.54
South	0.0017	0.0009	0.0021	0.0007	0.0031	0.0014	54.44	48.71

Table 4. *Rangia* means and standard deviations for initial and final length, width, height, growth (cm/day) and survival are reported by site for the Mobile-Tensaw 2005 *Rangia* study.

Site	**Mean Initial Length (cm)**	**STD Mean Initial Length (cm)**	**Mean Initial Width (cm)**	**STD Mean Initial Width (cm)**	**Mean Initial Height (cm)**	**STD Mean Initial Height (cm)**	**Mean Final Length (cm)**	**STD Mean Final Length (cm)**	**Mean Final Width (cm)**	**STD Mean Final Width (cm)**	**Mean Final Height (cm)**	**STD Mean Final Height (cm)**
South	3.27	0.11	3.13	0.11	2.21	0.09	3.28	0.14	3.17	0.10	2.31	0.24
Polecat	3.27	0.16	3.15	0.18	2.20	0.12	3.51	0.17	3.36	0.18	2.36	0.14
Delvan	3.35	0.14	3.27	0.10	2.27	0.08	3.63	0.12	3.52	0.10	2.49	0.21
Chocolatta	3.25	0.24	3.13	0.29	2.15	0.17	3.48	0.20	3.36	0.21	2.31	0.14
Justin's	3.28	0.17	3.20	0.17	2.17	0.13	3.61	0.14	3.51	0.13	2.35	0.10
Reference	na	na	na	na	na	na	3.08	0.17	2.96	0.17	2.07	0.15

Site	**Growth Length (cm / day)**	**STD Growth Length (cm / day)**	**Growth Width (cm / day)**	**Std Mean Growth Width (cm / day)**	**Growth Height (cm / day)**	**Std Mean Growth Height (cm / day)**	**Mean Survival (%)**	**Std Mean Survival (%)**
South	0.0017	0.0014	0.0021	0.0016	0.0031	0.0035	54.44	48.71
Polecat	0.0028	0.0010	0.0029	0.0013	0.0021	0.0010	56.67	40.41
Delvan	0.0045	0.0014	0.0042	0.0010	0.0036	0.0028	100.00	0.00
Chocolatta	0.0034	0.0010	0.0036	0.0014	0.0023	0.0007	90.00	10.00
Justin's	0.0052	0.0011	0.0050	0.0011	0.0028	0.0007	83.33	5.77
Reference	na	na	na	na	na	na	na	na

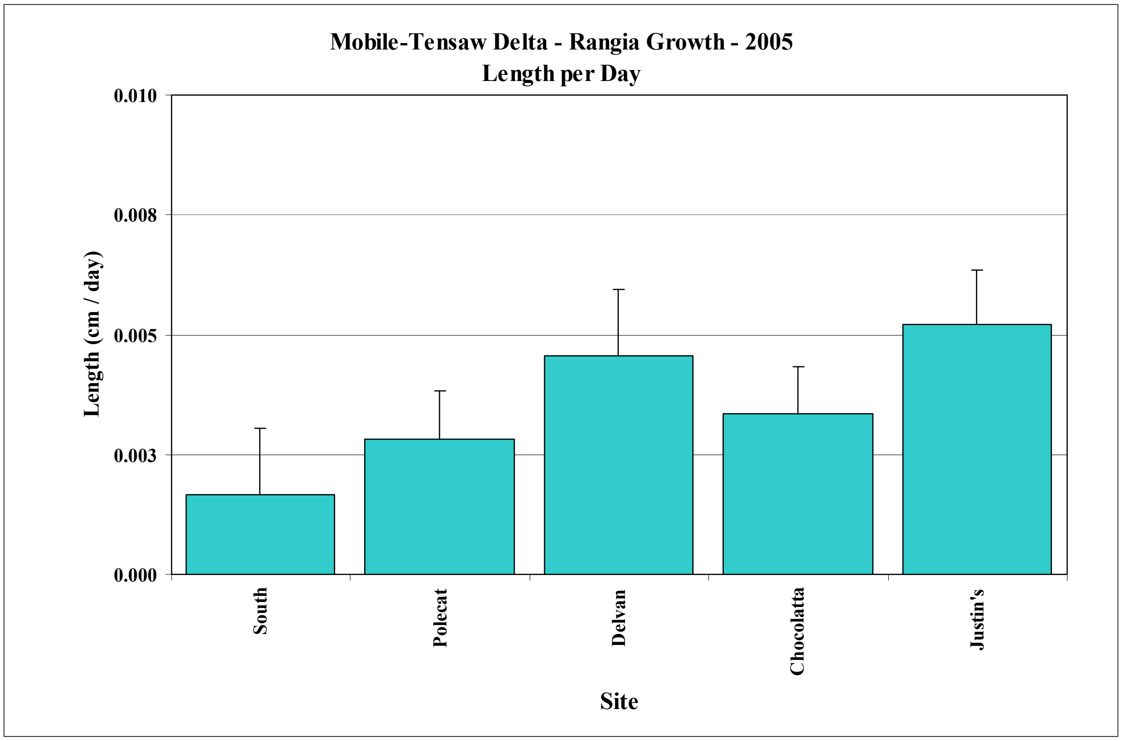

Figure 2. Change in *Rangia* length per day (±1 std) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

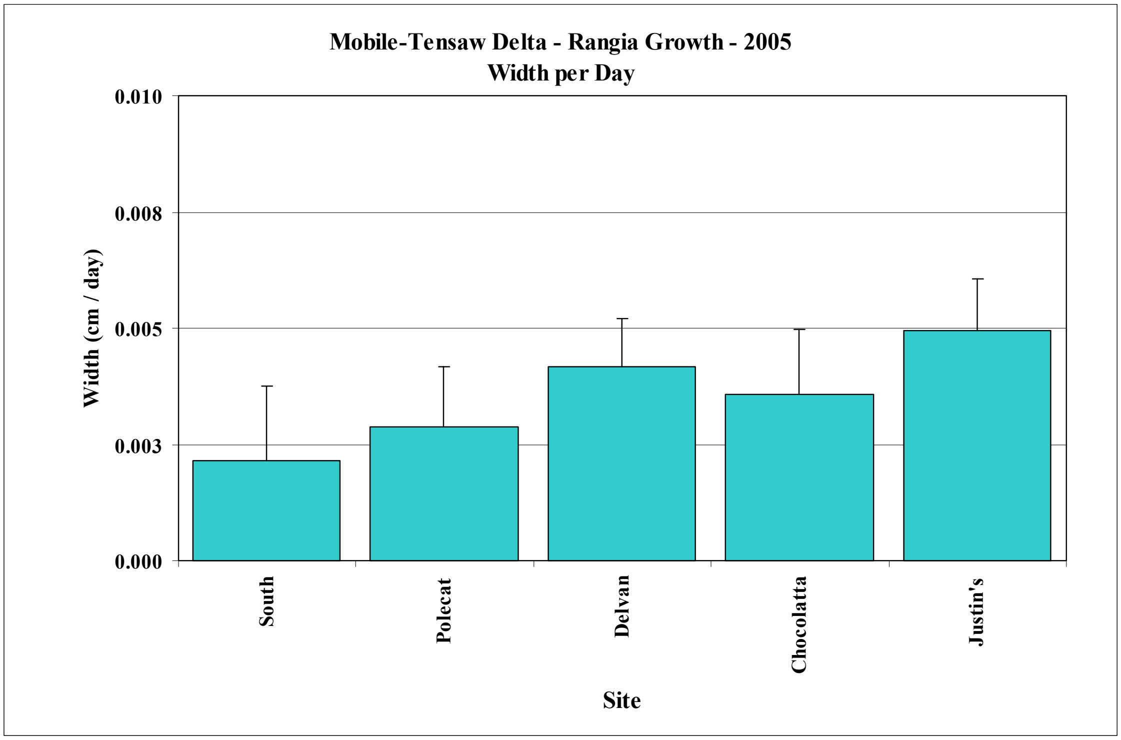

Figure 3. Change in *Rangia* width per day (±1 std) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

Metal Analyses

Results of the sediment and *Rangia* metal analyses are presented by location in Table 5 and by site in Table 6. *Rangia* and sediment metal concentrations are also graphically presented by site and location in Figures 4 through 27. The figures are found following the *Rangia* metals results.

Reference Sites 2004 and 2005

Metals concentrations measured in *Rangia* tissues collected at the reference site were higher in 2005 than in 2004. A paired-samples t test which compared concentrations between years found significant differences to exist for concentrations of arsenic (t=5.808, df=2, p=0.028), copper (t=5.085, df=2, p=0.037) and mercury (t=4.612, df=2, p=0.044). Levels of zinc (t=3.952, df=2, p=0.058), chromium (t=3.836, df=2, p=0.062), lead (t=3.769, df=2, p=0.064) and aluminum (t=3.008, df=2, p=0.095) were marginally significantly higher in 2005 than in 2004. No differences were detected for cadmium (t=2.600, df=2, p=0.122) (Table 2).

Sediment Metals

All sediment metal concentrations, except cadmium, varied significantly with causeway location (Tables 2 and 5). Sediments collected north of the causeway had higher levels of arsenic (F=4.861, df=5, 12, p=0.012), chromium (F= 10.662, df=5, 12, p=0.000), copper (F= 11.630, df=5, 12, p=0.000), lead (F=9.343, df=5, 12, p=0.001), zinc (F=8.680, df=5, 12, p=0.001), aluminum (F=12.216, df=5, 12, p=0.000), and mercury (F= 3.587, df=5, 12, p=0.032) than did sediments collected south of the causeway. Sediment cadmium levels did not differ with causeway location (F=1.050, df=5, 12, p=0.433) (Figs. 4 – 27).

Sediment metal concentrations also varied significantly among sites (Figs. 4 – 27). Sediments in Justin's Bay had the highest arsenic, chromium, copper, zinc, aluminum, and second highest for lead and mercury (Tables 6 and 7). Chocolatta Bay sediments had the second highest concentrations of arsenic, chromium, copper, zinc and aluminum. After that, individual metals concentrations varied inconsistently with site. While Delvan Bay sediments, for example, contained the highest lead and mercury levels they had the lowest concentrations of arsenic, chromium, copper, zinc and aluminum. Reference sediments had lower arsenic, chromium, copper, lead, zinc and aluminum concentrations than any of the other sites (Figs. 4 – 27).

Table 5. Sediment and *Rangia* metal concentrations (mg/kg dry weight) and standard deviations of arsenic, cadmium, chromium, copper, lead, zinc, aluminum and mercury are listed by location north or south of the causeway for the Mobile-Tensaw 2005 *Rangia* study.

Location	**Arsenic (mg/kg)**	**std Arsenic (mg/kg)**	**Cadmium (mg/kg)**	**std Cadmium (mg/kg)**	**Chromium (mg/kg)**	**std Chromium (mg/kg)**	**Copper (mg/kg)**	**std Copper (mg/kg)**
RANGIA								
North	3.13	0.27	0.13	0.17	1.63	0.71	16.42	3.29
South	3.15	0.21	0.10	0.14	0.70	0.99	18.50	2.12
Reference	4.87	0.35	0.53	0.35	3.13	1.40	18.67	6.35
SEDIMENT								
North	3.37	3.30	0.00	0.01	19.13	14.57	8.43	6.74
South	0.92	2.10	0.15	0.35	4.80	10.88	1.96	4.43

Location	**Lead (mg/kg)**	**std Lead (mg/kg)**	**Zinc (mg/kg)**	**std Zinc (mg/kg)**	**Aluminum (mg/kg)**	**std Aluminum (mg/kg)**	**Mercury (mg/kg)**	**std Mercury (mg/kg)**
RANGIA								
North	0.26	0.33	82.25	5.79	504.17	243.70	0.0053	0.0111
South	0.26	0.37	69.00	1.41	505.00	49.50	0.0100	0.0141
Reference	0.97	0.45	119.67	52.37	1140.00	654.83	0.0147	0.0055
SEDIMENT								
North	13.45	6.12	44.83	31.81	10020.00	8007.43	0.0426	0.0152
South	7.10	5.42	10.66	24.17	2328.33	5228.21	0.0325	0.0064

Table 6. Sediment and *Rangia* metal concentrations (mg/kg dry weight) and standard deviations of arsenic, cadmium, chromium, copper, lead, zinc, aluminum and mercury listed by site for the Mobile-Tensaw 2005 *Rangia* study.

Site	**Rangia**															
	Arsenic (mg/kg)	**std Arsenic (mg/kg)**	**Cadmium (mg/kg)**	**std Cadmium (mg/kg)**	**Chromium (mg/kg)**	**std Chromium (mg/kg)**	**Copper (mg/kg)**	**std Copper (mg/kg)**	**Lead (mg/kg)**	**std Lead (mg/kg)**	**Zinc (mg/kg)**	**std Zinc (mg/kg)**	**Aluminum (mg/kg)**	**std Aluminum (mg/kg)**	**Mercury (mg/kg)**	**std Mercury (mg/kg)**
South	3.15	0.21	0.10	0.14	0.70	0.99	18.50	2.12	0.26	0.37	69.00	1.41	505	49	0.0100	0.0141
Polecat	3.23	0.15	0.00	0.00	0.77	0.68	14.67	2.08	0.17	0.30	82.00	4.36	413	339	0.0120	0.0208
Delvan	3.17	0.15	0.22	0.22	1.93	0.06	19.33	5.03	0.64	0.16	82.00	1.73	583	121	0.0047	0.0081
Chocolatta	3.20	0.35	0.21	0.18	2.20	0.72	16.33	1.15	0.21	0.36	81.67	10.12	663	320	0.0000	0.0000
Justin's	2.93	0.40	0.09	0.15	1.63	0.15	15.33	3.06	0.00	0.00	83.33	7.57	357	49	0.0047	0.0081
Reference	4.87	1.44	0.53	0.35	3.13	1.40	18.67	6.35	0.97	0.45	119.67	52.37	1140	655	0.0147	0.0055

Site	**Sediment**															
	Arsenic (mg/kg)	**std Arsenic (mg/kg)**	**Cadmium (mg/kg)**	**std Cadmium (mg/kg)**	**Chromium (mg/kg)**	**std Chromium (mg/kg)**	**Copper (mg/kg)**	**std Copper (mg/kg)**	**Lead (mg/kg)**	**std Lead (mg/kg)**	**Zinc (mg/kg)**	**std Zinc (mg/kg)**	**Aluminum (mg/kg)**	**std Aluminum (mg/kg)**	**Mercury (mg/kg)**	**std Mercury (mg/kg)**
South	1.77	2.97	0.29	0.49	9.25	15.37	3.77	6.26	10.43	0.98	20.56	34.15	4470	7387	0.0327	0.0096
Polecat	1.53	1.55	0.00	0.00	15.00	4.36	6.17	2.29	6.10	2.08	42.00	14.73	7300	2339	0.0287	0.0125
Delvan	0.11	0.03	0.02	0.00	0.53	0.11	0.25	0.06	20.33	0.58	1.33	0.31	313	65	0.0573	0.0085
Chocolatta	5.40	3.99	0.00	0.00	24.00	8.72	10.30	4.12	11.03	5.19	59.00	21.79	12133	5116	0.0357	0.0083
Justin's	6.43	0.55	0.00	0.00	37.00	3.61	17.00	2.00	16.33	1.15	77.00	13.00	20333	1528	0.0487	0.0153
Reference	0.06	0.02	0.01	0.01	0.35	0.10	0.14	0.07	3.77	6.26	0.76	0.21	187	57	0.0323	0.0031

Table 7. *Rangia* and sediment arsenic, cadmium, chromium, copper, lead, zinc, aluminum and mercury concentrations, ranked from highest to lowest (1 = high and 6 = low) and listed by site for the Mobile-Tensaw 2005 *Rangia* study.

Site	**Rangia**							
	Arsenic (mg/kg)	**Cadmium (mg/kg)**	**Chromium (mg/kg)**	**Copper (mg/kg)**	**Lead (mg/kg)**	**Zinc (mg/kg)**	**Aluminum (mg/kg)**	**Mercury (mg/kg)**
Polecat	2	6	5	6	5	3	5	2
Delvan	4	2	3	**1**	2	3	3	4
Chocolatta	3	3	2	4	4	4	2	5
Justin's	6	5	4	5	6	2	6	4
South	5	4	6	3	3	5	4	3
Reference	**1**	**1**	**1**	2	**1**	**1**	**1**	**1**

1= highest value; 6 = lowest value

Site	**Sediment**							
	Arsenic (mg/kg)	**Cadmium (mg/kg)**	**Chromium (mg/kg)**	**Copper (mg/kg)**	**Lead (mg/kg)**	**Zinc (mg/kg)**	**Aluminum (mg/kg)**	**Mercury (mg/kg)**
Polecat	4	4	3	3	5	3	3	6
Delvan	5	2	5	5	**1**	5	5	**1**
Chocolatta	2	4	2	2	3	2	2	3
Justin's	**1**	4	**1**	**1**	2	**1**	**1**	2
South	3	**1**	4	4	4	4	4	4
Reference	6	3	6	6	6	6	6	5

1= highest value; 6 = lowest value

Rangia Metal Accumulations

In contrast to sediment metal levels, *Rangia* tissue metal levels were relatively low and, with one exception, their uptake did not vary significantly with causeway location. *Rangia* chromium uptake was significantly (F= 3.735, df=4, 9, p=0.047) greater north of the causeway than south of the causeway (Tables 2 and 5). The uptake of arsenic (F=0.533, df=4, 9, p=0.715), cadmium (F=1.028, df=4, 9, p=0.443), copper (F=1.207, df=4, 9, p=0.372), lead (F=2.430, df=4, 9, p=0.124), zinc (F=1.884, df=4, 9, p=0.198), aluminum (F= 0.883, df=4, 9, p=0.511) and mercury (F=0.439, df=4, 9, p=0.778) did not vary significantly with causeway location (Tables 2 and 5, Figs. 4 – 27).

Rangia tissue metal levels were less variable among sites than were the sediment metal concentrations (Table 6 and Figs. 4 - 27). Oddly, the tissues of clams collected at the reference site had highest concentrations for arsenic, cadmium, chromium, lead, zinc, aluminum and mercury (Table 7). This is despite that fact that sediment concentrations were lowest for these metals at the reference site. The high metal concentrations of reference clam metal levels may be due in part to the fact that these clams were never removed from collection locations and thus had a longer sediment exposure time. In addition, reference clams did not receive the water changes during the processing period, which may have allowed the purging of accumulated metals. Site variations may reflect differences in feeding strategies used by clams (filter feeding verses deposit feeding) and thus differences in sediment ingestion. These differences may also reflect the characteristics of imported and exported sediments.

Clams placed in Delvan Bay had higher levels of copper in their tissues than were recorded from clams placed at other sites (Tables 6 and 7, Figs. 4 – 27). Justin's Bay *Rangia* tissues contained the lowest levels of arsenic, aluminum and lead. Polecat Bay *Rangia* tissues contained lowest levels of cadmium and copper. *Rangia* chromium and zinc were lowest in clams from the South site and mercury levels were lowest in Chocolatta Bay clams (Tables 6 and 7, Figs. 4 – 27).

Based on the sediment quality guidelines (SQGs) developed for the National Status and Trends Program, sediment and *Rangia* tissues metals were all less than the Effects Range-Low (ERL) values (Long et. al. 1995 from USEPA 2004). The ERLs (10th percentile) are defined as the concentration levels below which adverse effects on life are not anticipated. The ERM values (50th percentile) are the concentrations above which adverse biological effects frequently occur. Paradoxically, *Rangia* tissues collected at Reference #1 (180 mg/kg), located south of the causeway, and at an area of South #1 (210 mg/kg) had zinc levels greater then the sediment ERL (150 ug/g) and less than the ERM (410 ug/g) even though the sediment concentrations were below the ERL. The sediment arsenic level from Chocolatta Bay #1 (10.00mg/kg) was greater the ERL (8.20 ug/g) but was less than the ERM value of 70 ug/g.

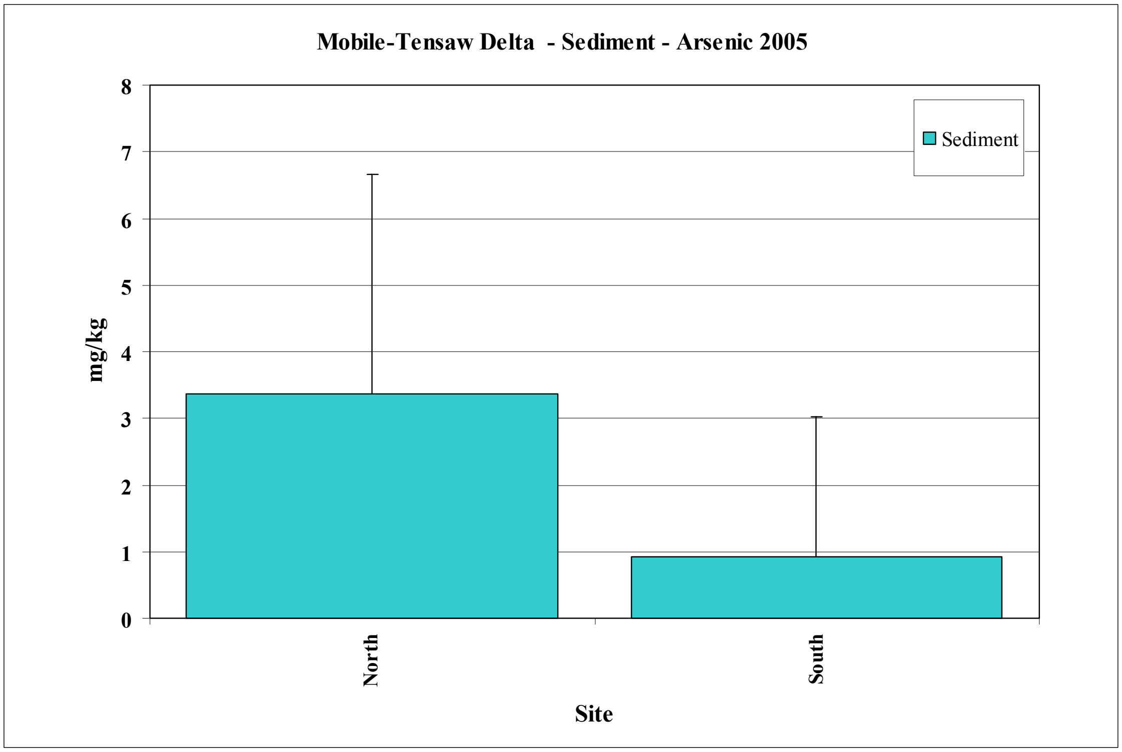

Figure 4. Sediment arsenic concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

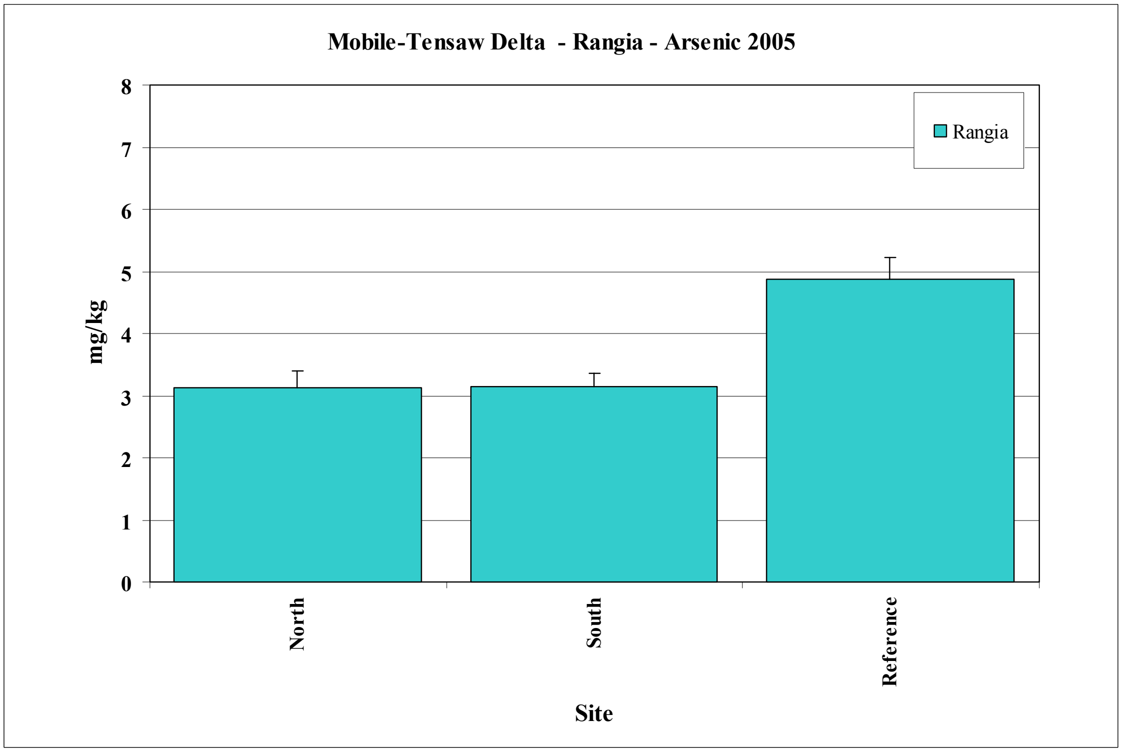

Figure 5. *Rangia* arsenic concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

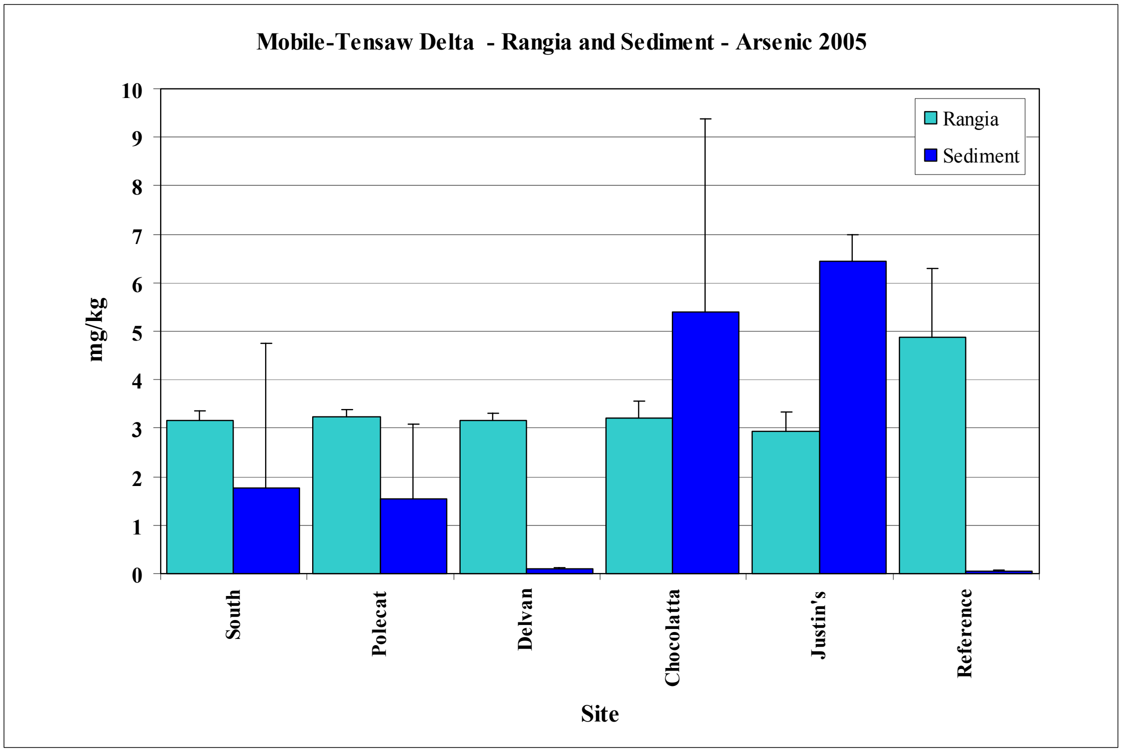

Figure 6. Sediment and *Rangia* arsenic concentrations (mg/kg±1 std dry weight) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

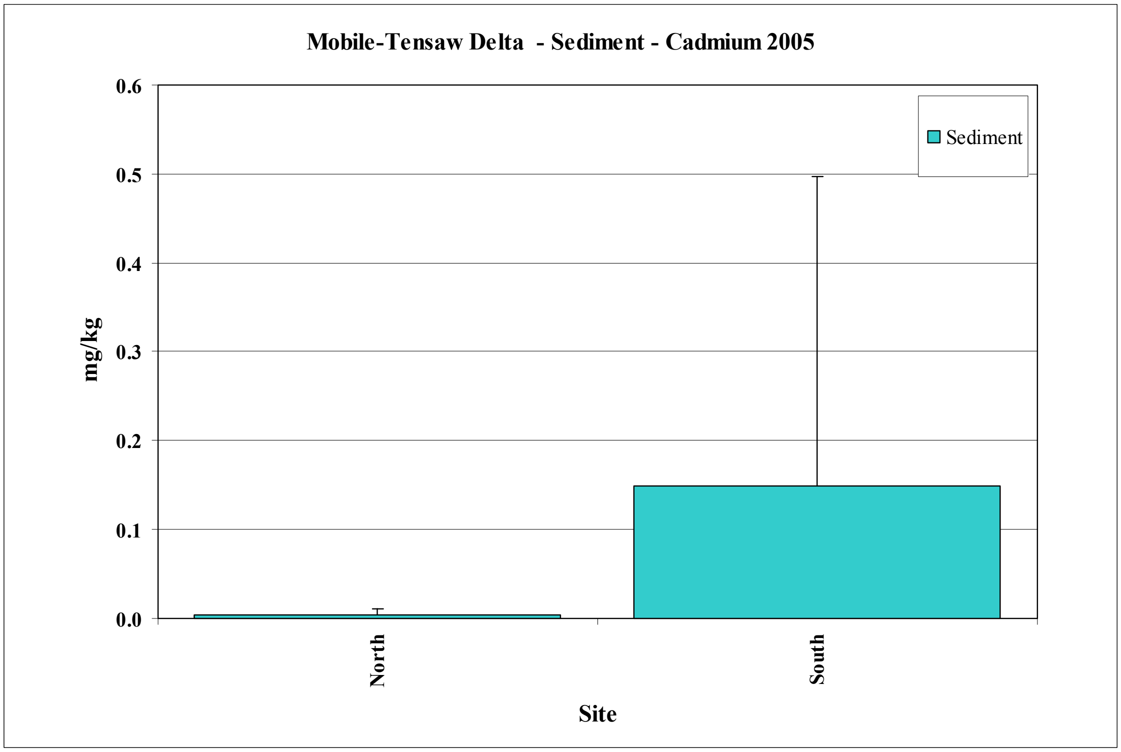

Figure 7. Sediment cadmium concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

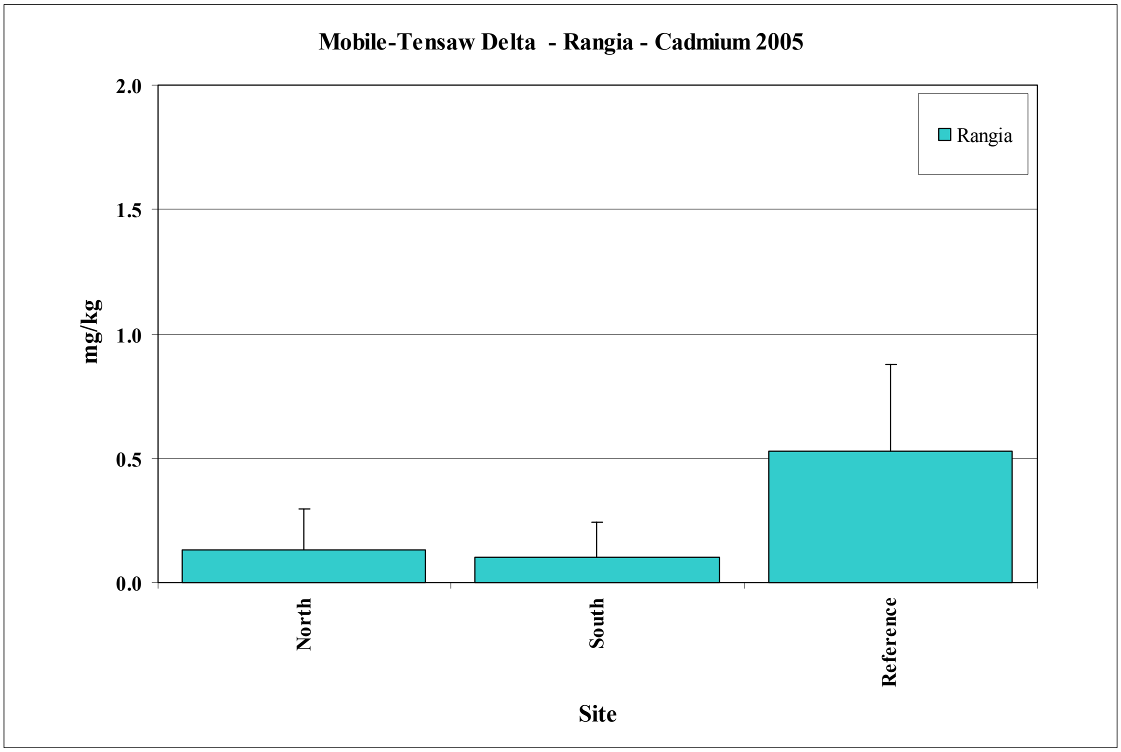

Figure 8. *Rangia* cadmium concentrations (mg/kg+1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

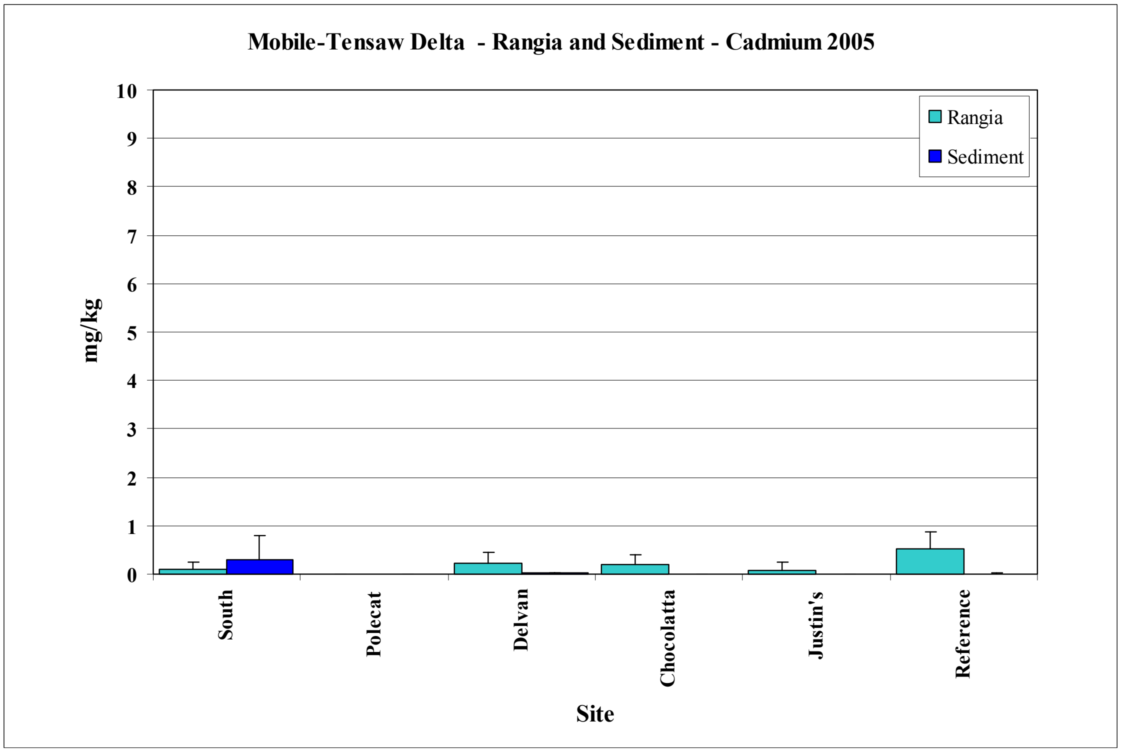

Figure 9. Sediment and *Rangia* cadmium concentrations (mg/kg+1 std dry weight) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

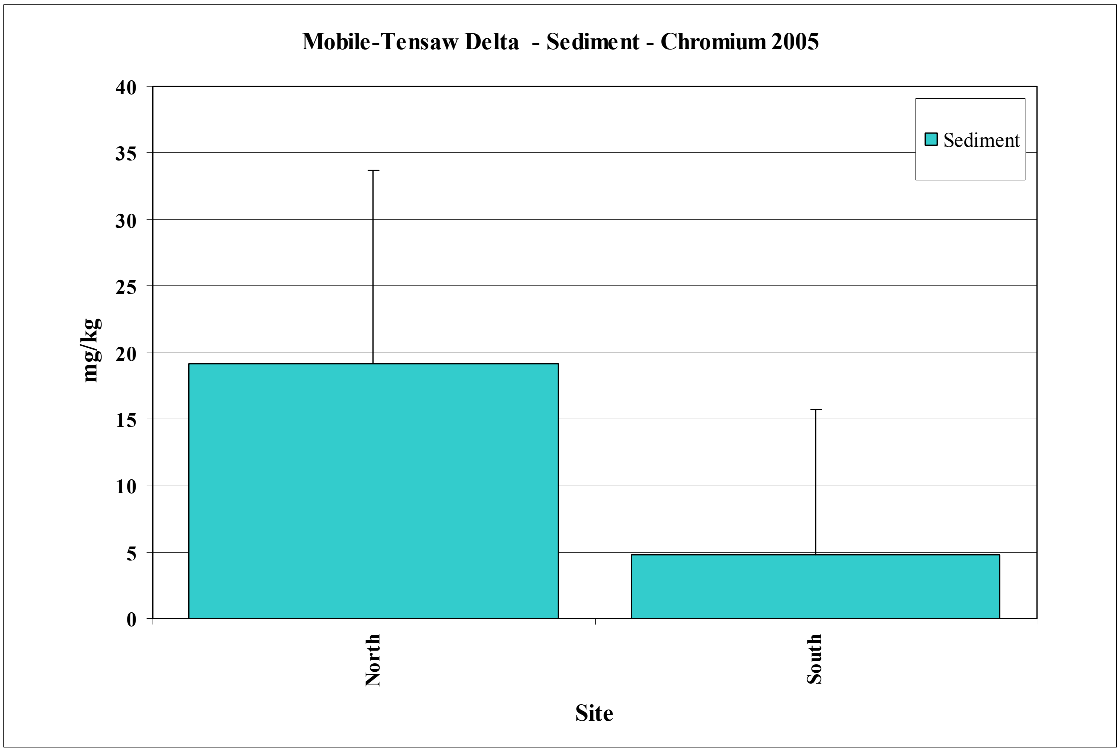

Figure 10. Sediment chromium concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

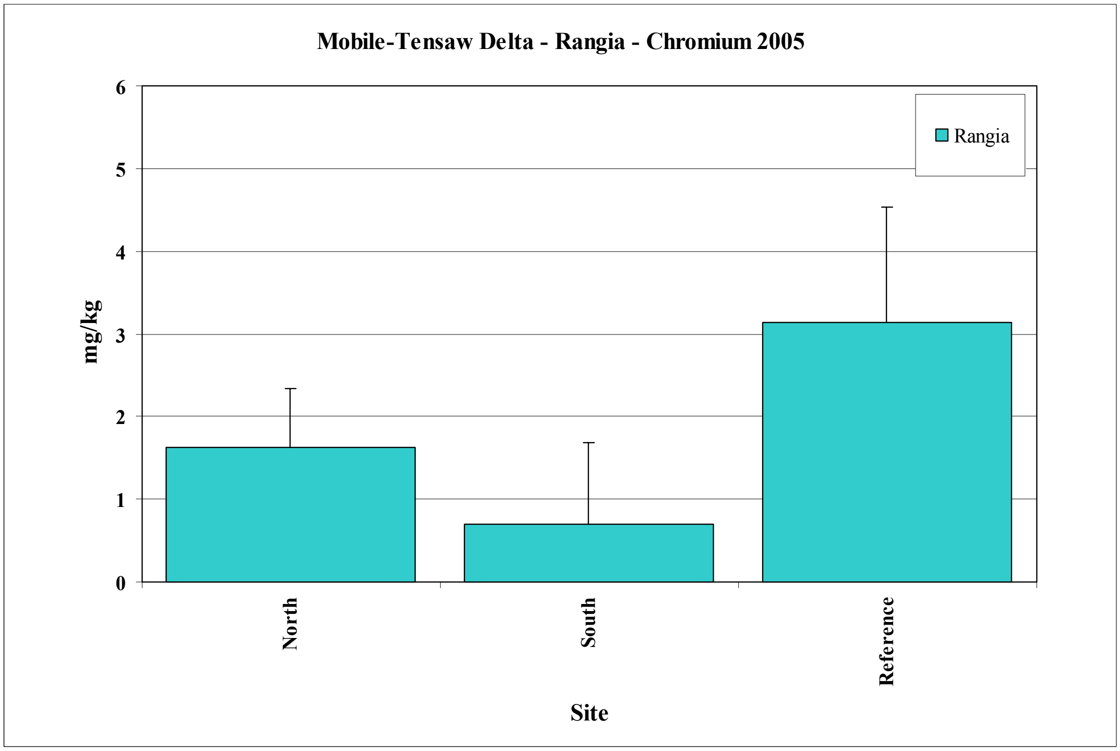

Figure 11. *Rangia* chromium concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

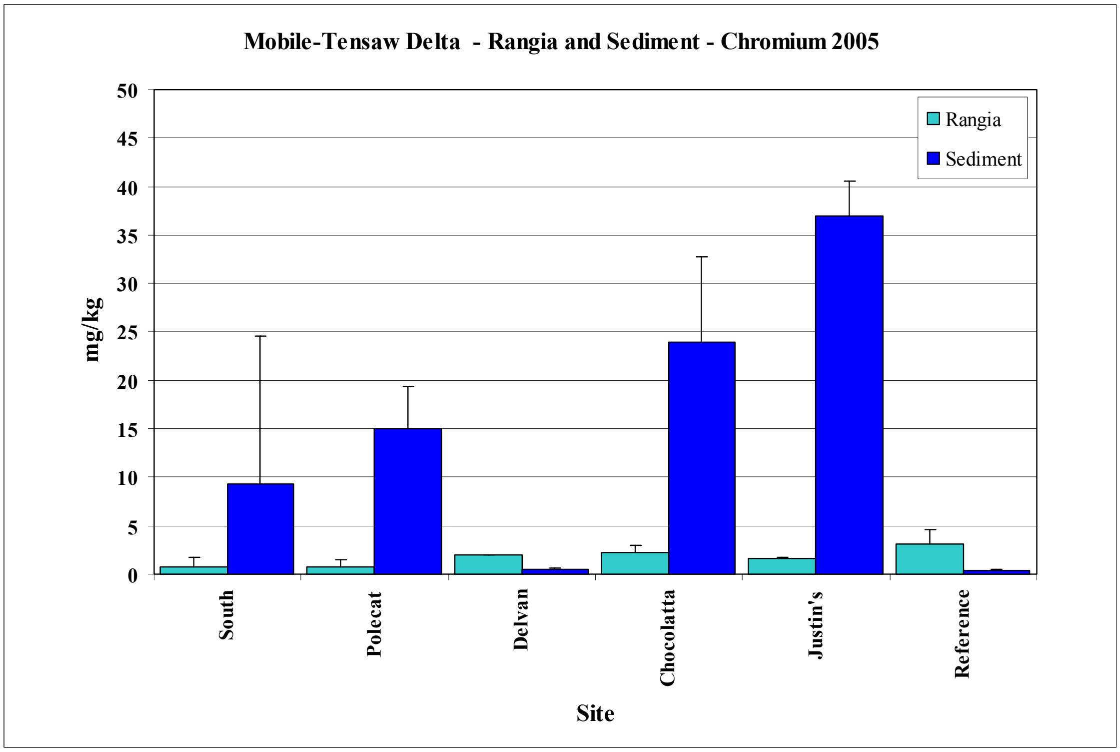

Figure 12. Sediment and *Rangia* chromium concentrations (mg/kg±1 std dry weight) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

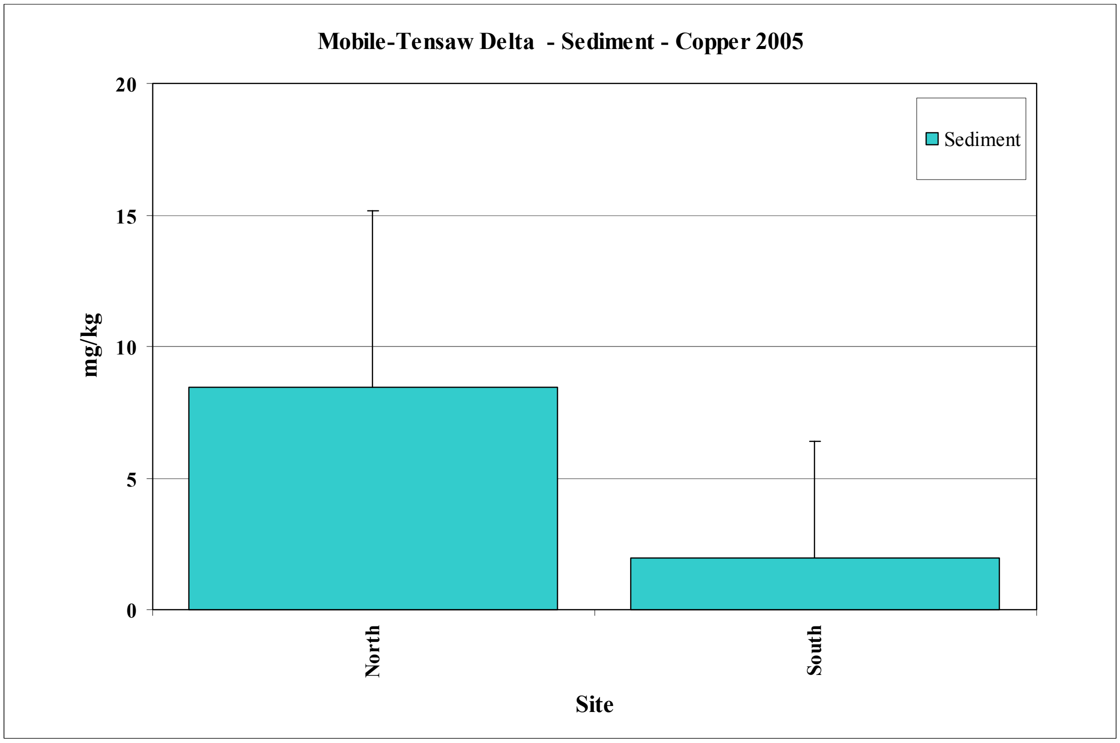

Figure 13. Sediment copper concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

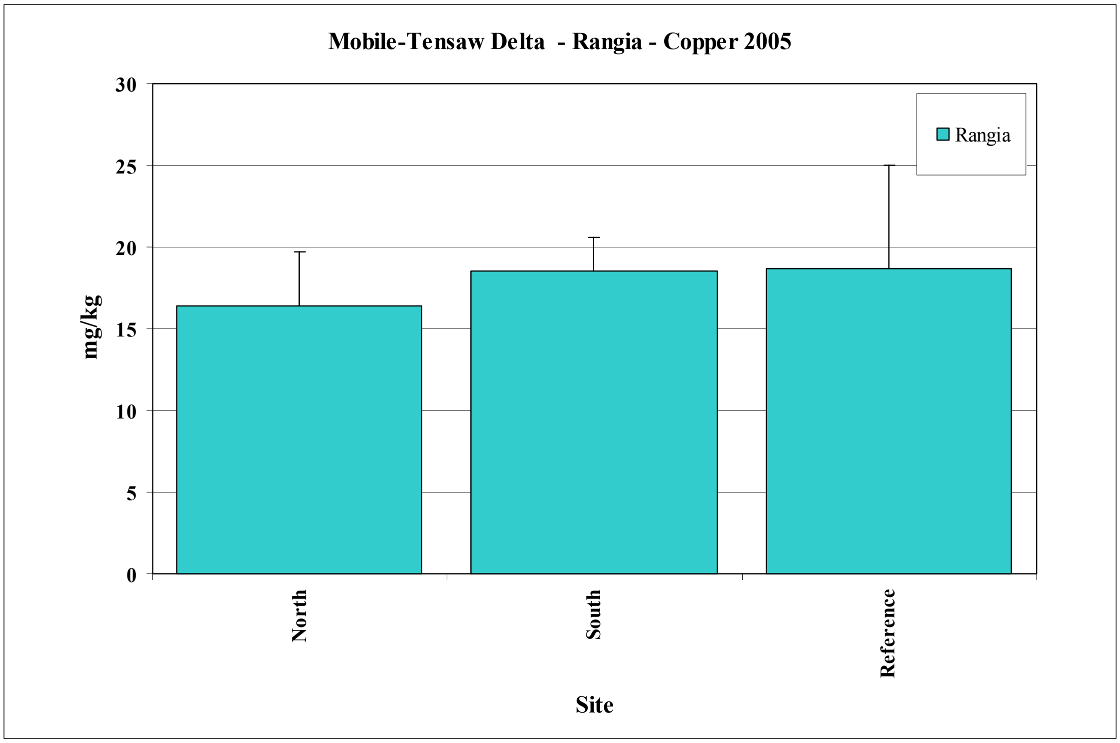

Figure 14. *Rangia* copper concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

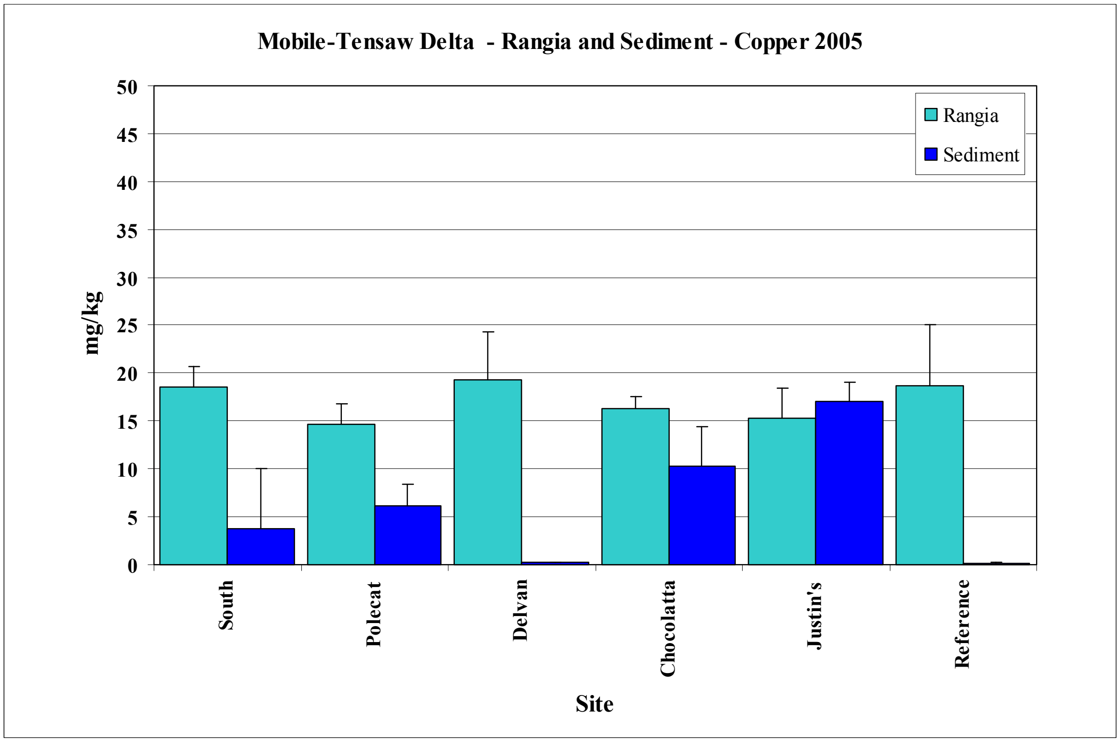

Figure 15. Sediment and *Rangia* copper concentrations (mg/kg±1 std dry weight) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

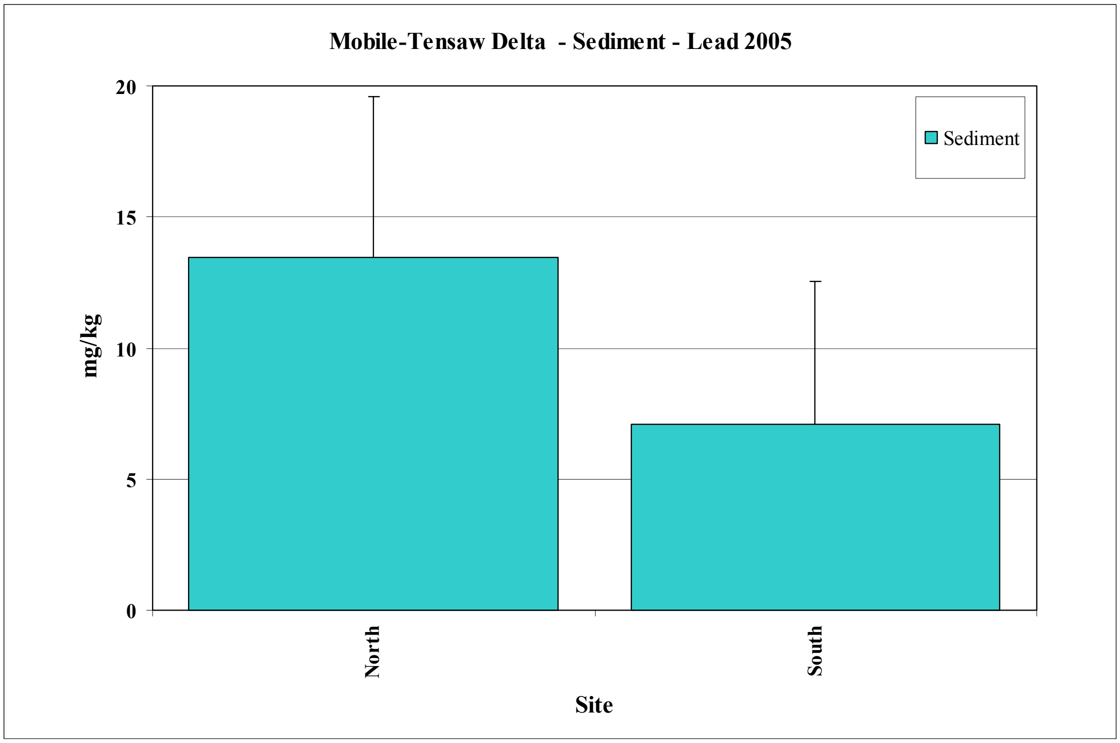

Figure 16. Sediment lead concentrations (mg/kg+1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

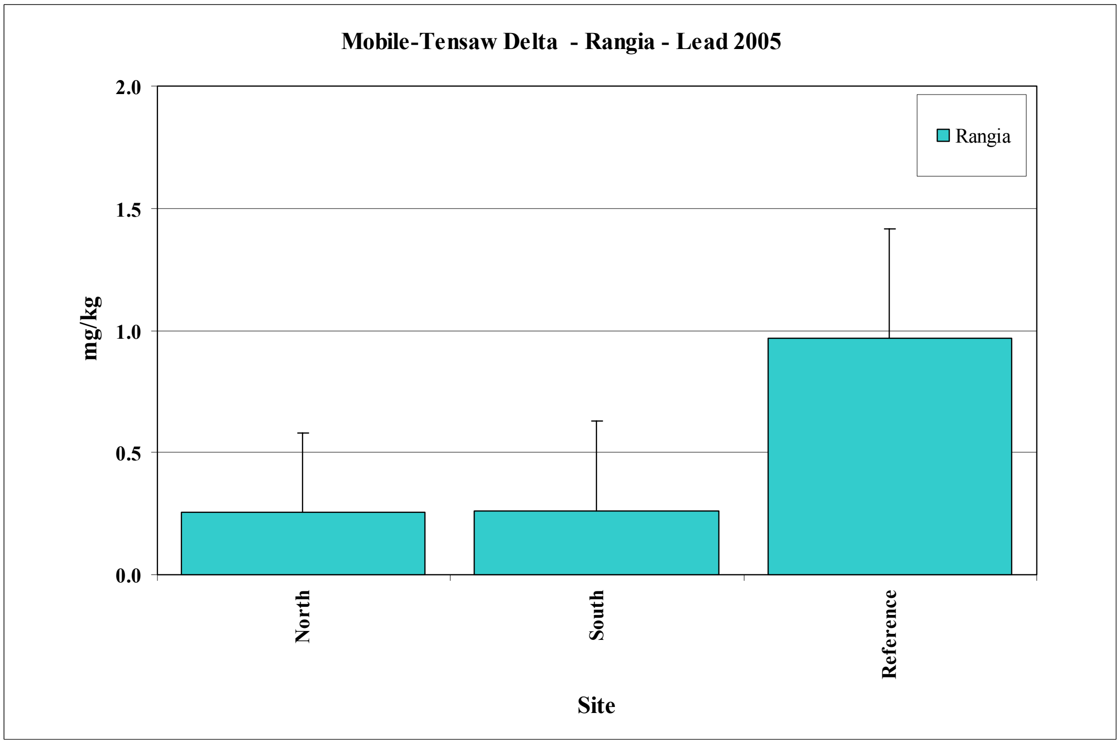

Figure 17. *Rangia* lead concentrations (mg/kg+1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

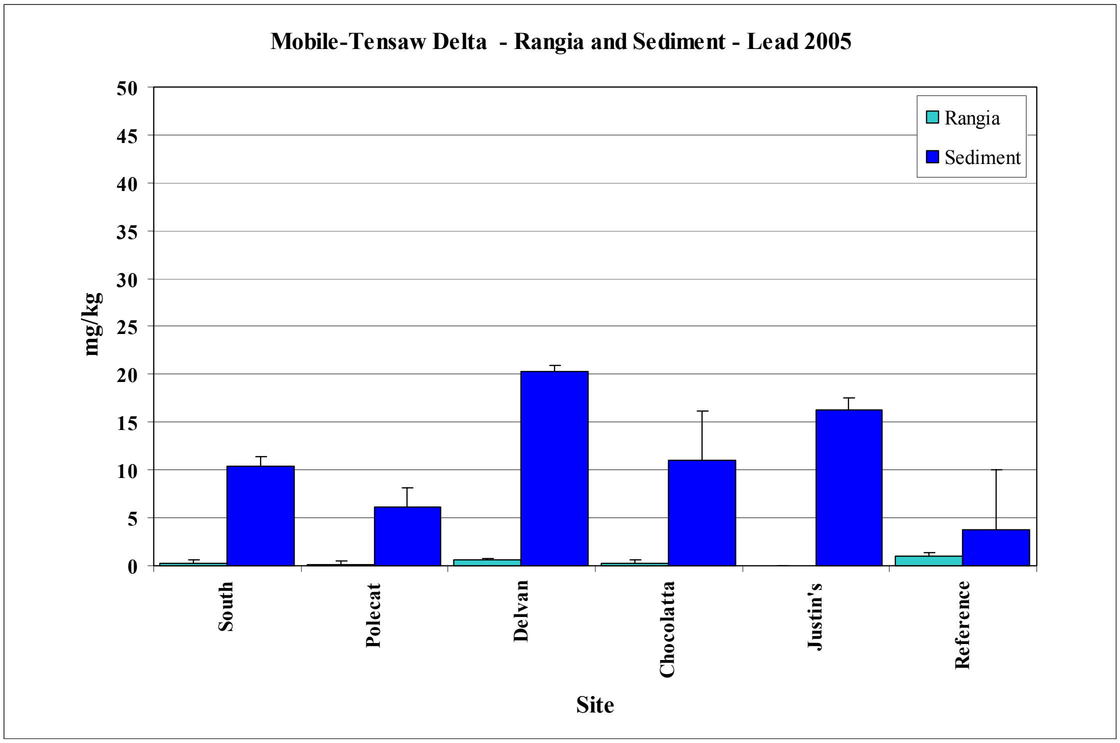

Figure 18. Sediment and *Rangia* lead concentrations (mg/kg±1 std dry weight) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

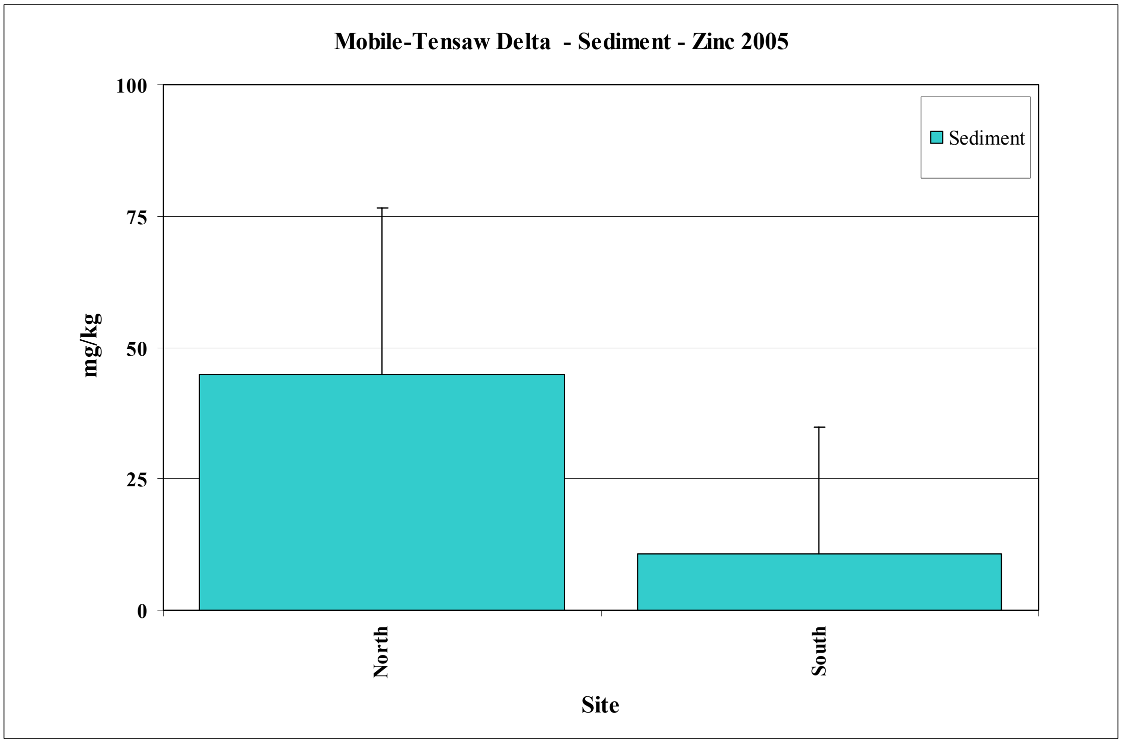

Figure 19. Sediment zinc concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

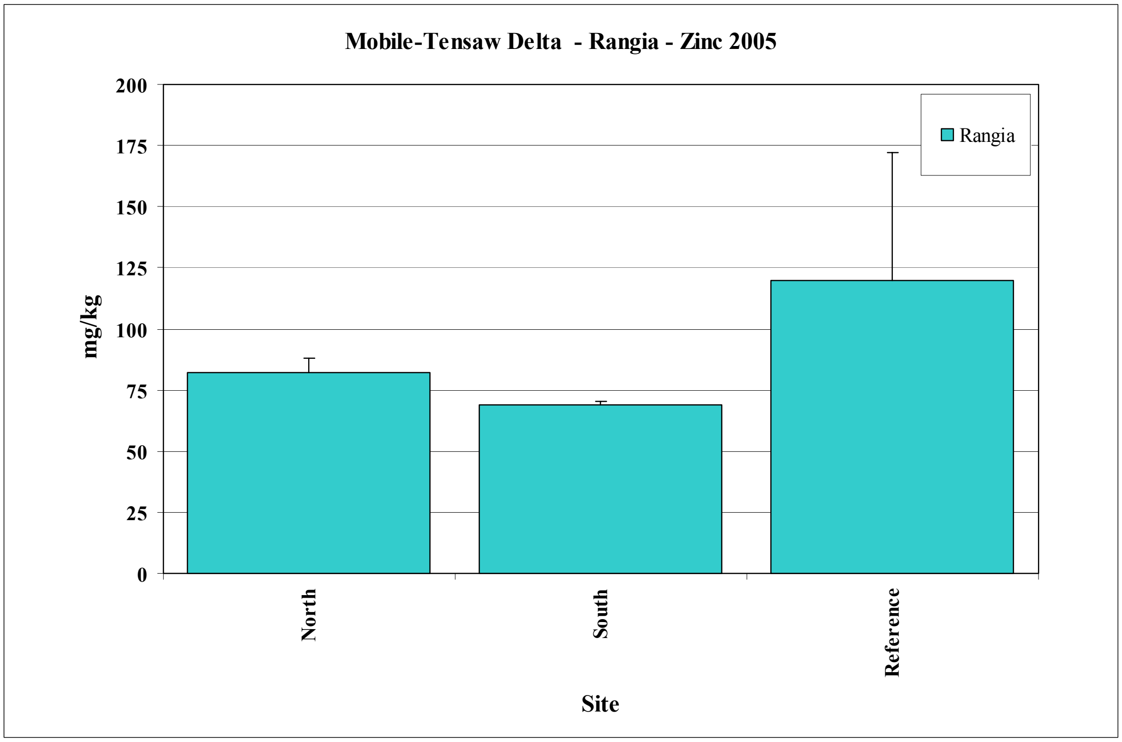

Figure 20. *Rangia* zinc concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

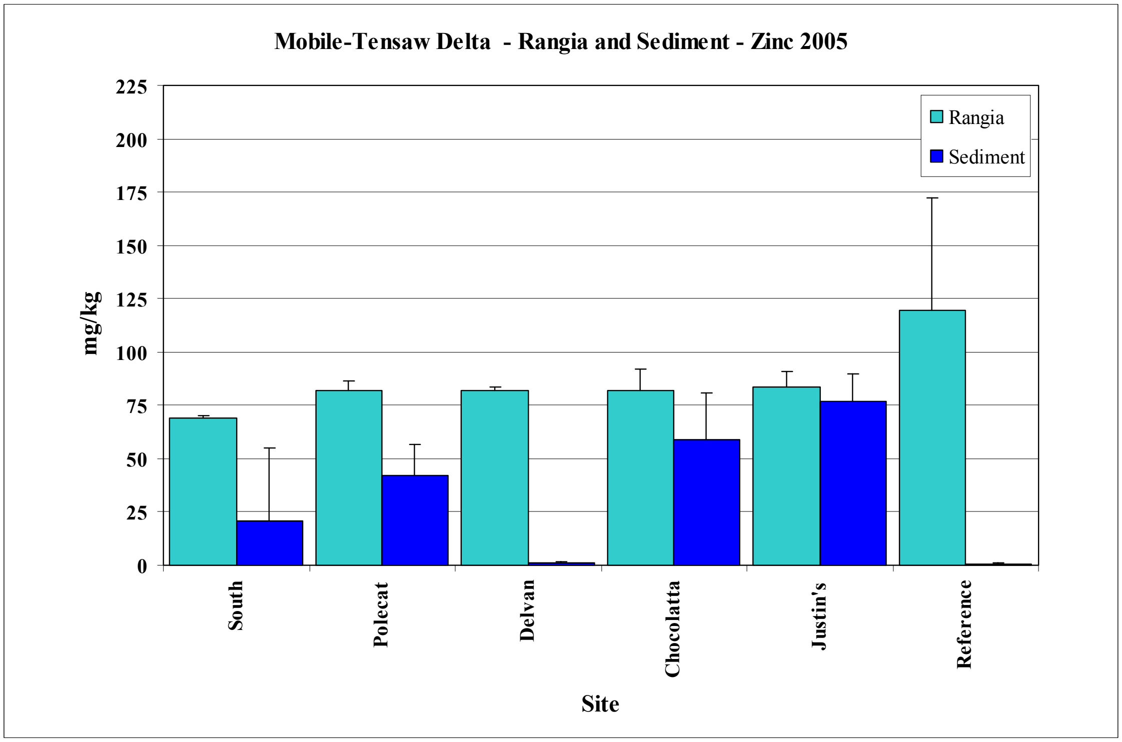

Figure 21. Sediment and *Rangia* zinc concentrations (mg/kg±1 std dry weight) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

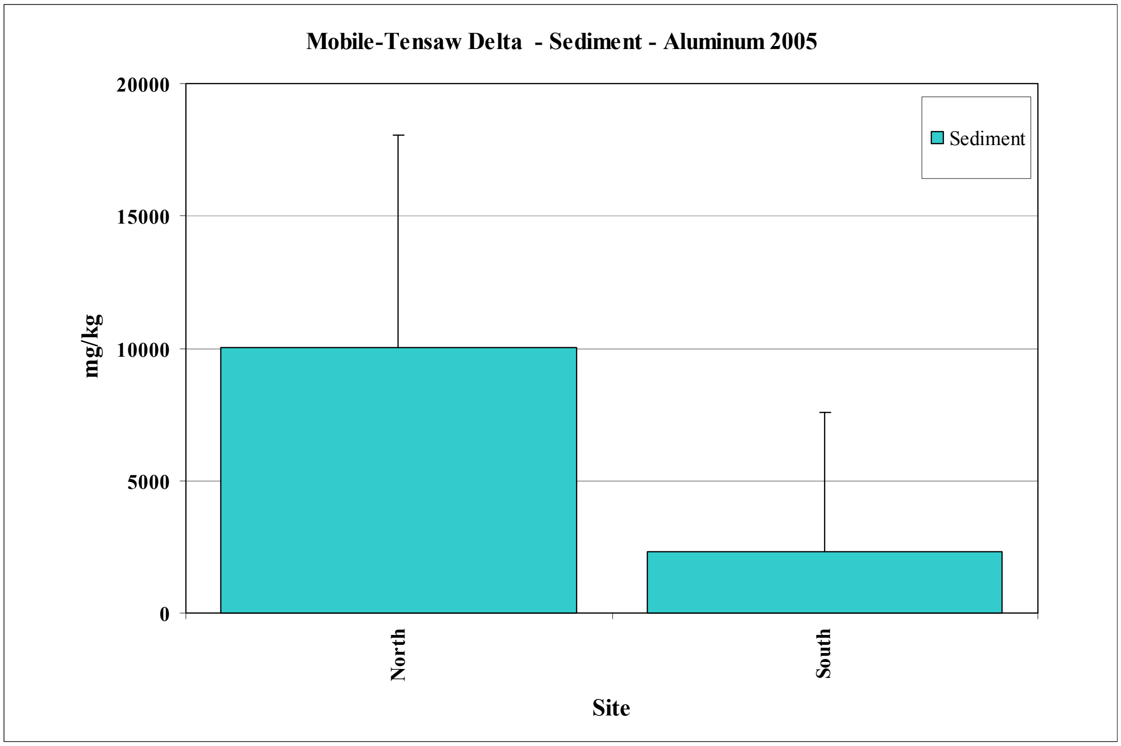

Figure 22. Sediment aluminum concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

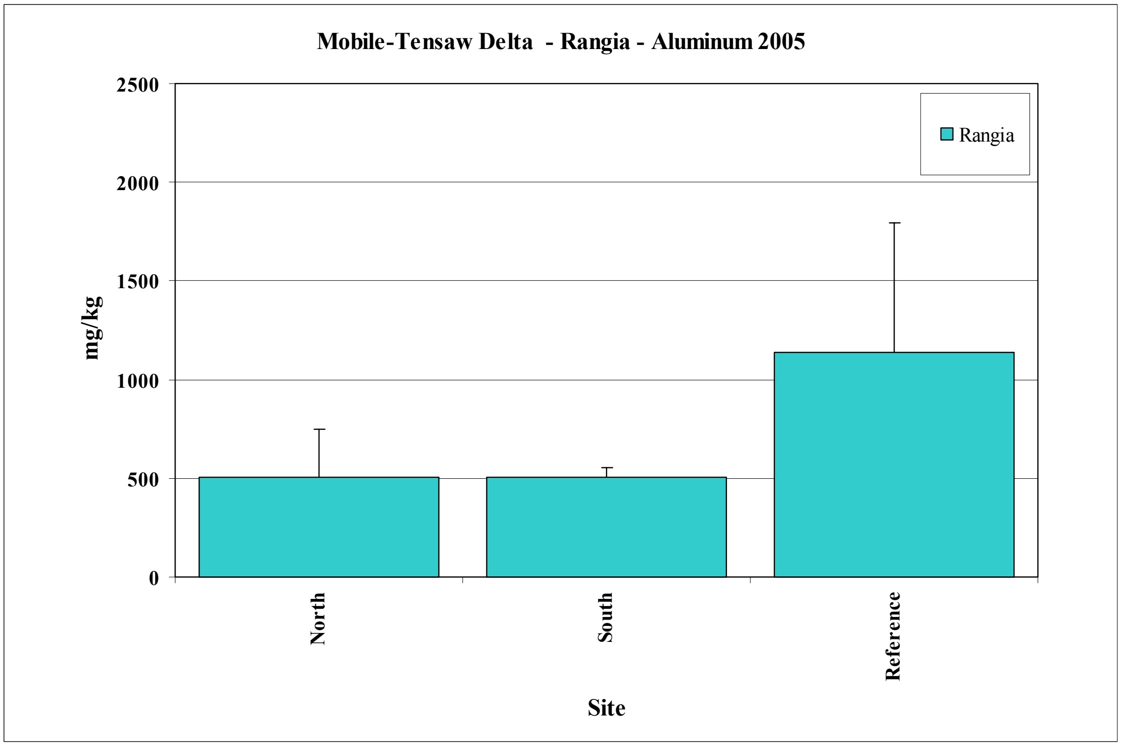

Figure 23. *Rangia* aluminum concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

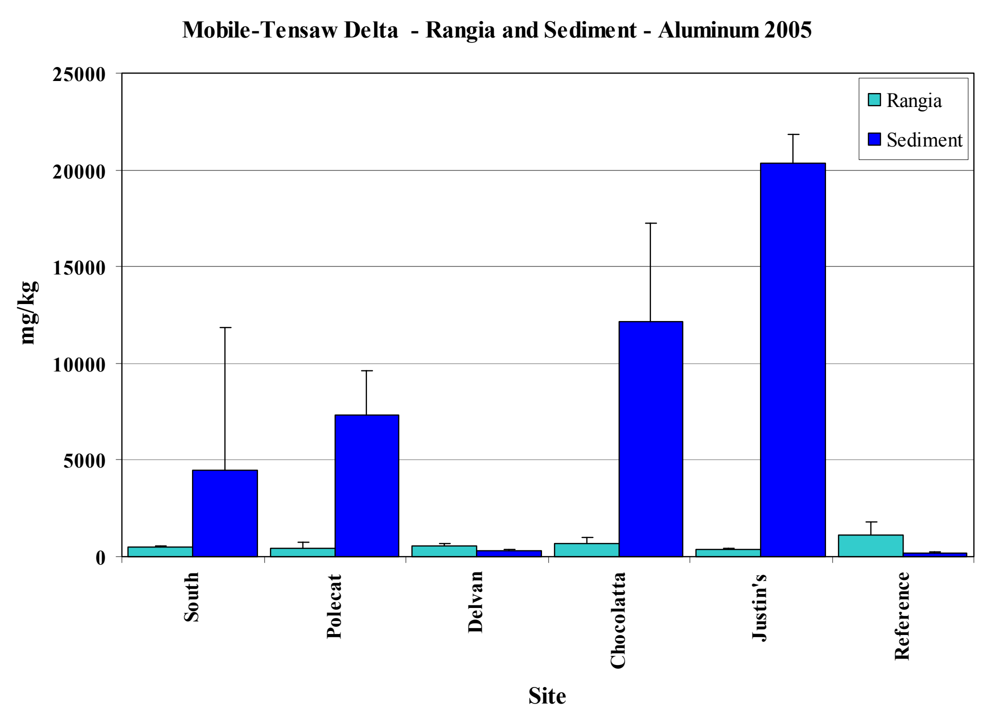

Figure 24. Sediment and *Rangia* aluminum concentrations (mg/kg±1 std dry weight) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

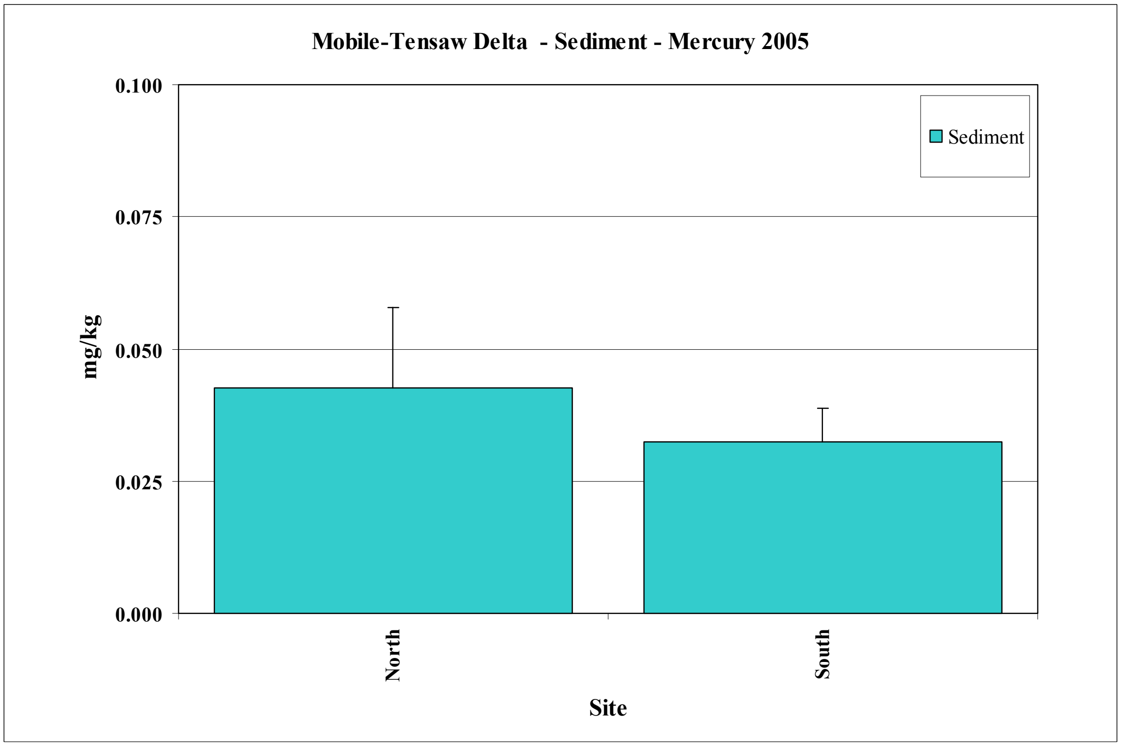

Figure 25. Sediment mercury concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

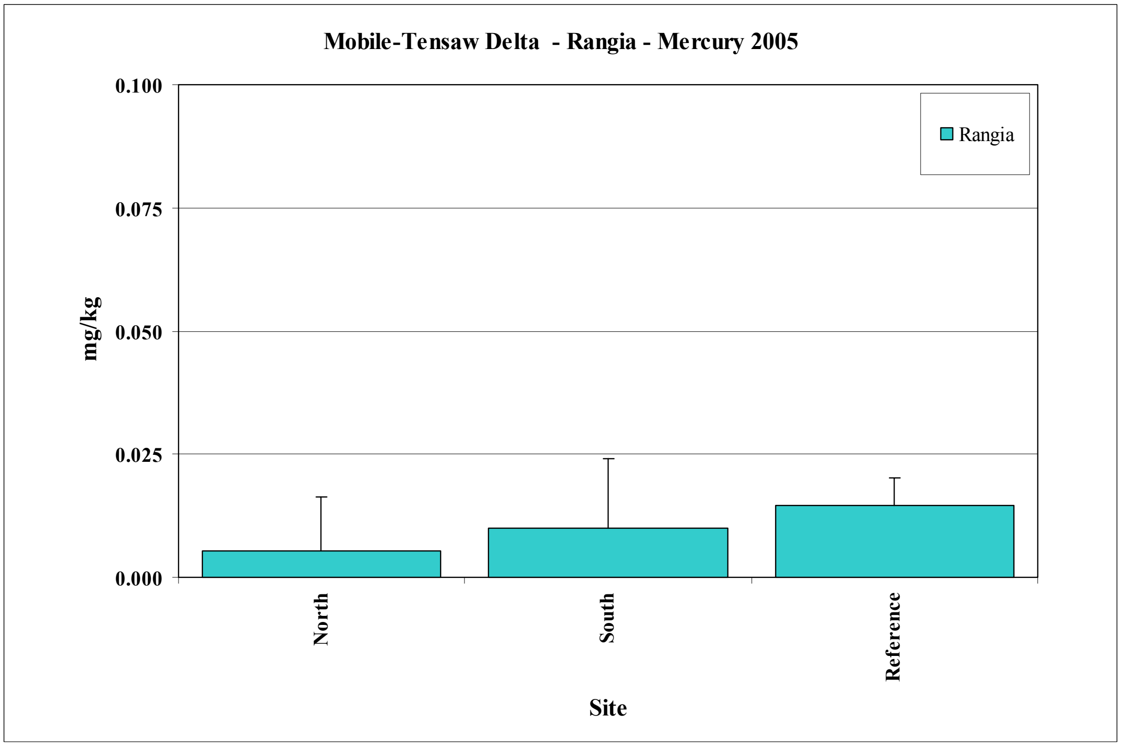

Figure 26. *Rangia* mercury concentrations (mg/kg±1 std dry weight) plotted by location for the 2005 Mobile-Tensaw *Rangia* study.

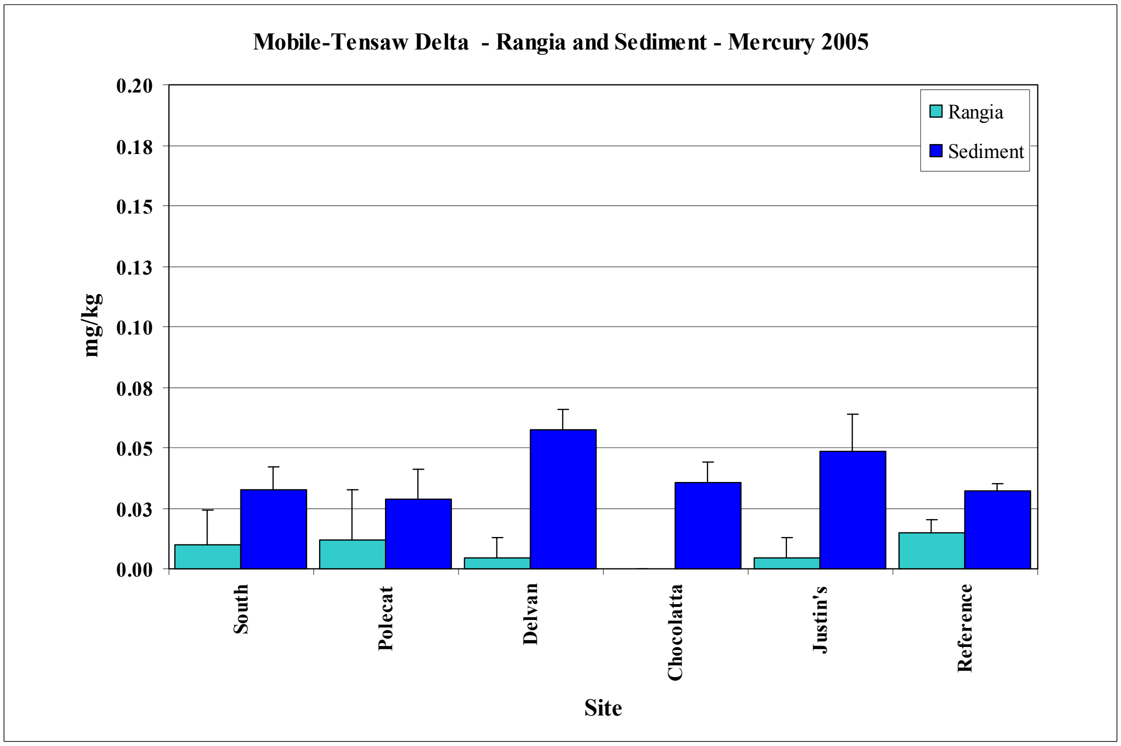

Figure 27. Sediment and *Rangia* mercury concentrations (mg/kg±1 std dry weight) plotted by site for the 2005 Mobile-Tensaw *Rangia* study.

Discussion

The Mobile-Tensaw *Rangia* transplant study revealed significant spatial variation in sediment and *Rangia* metal concentrations, as well as *Rangia* growth and survival rates. All sediment metal concentrations, except cadmium, were found to vary significantly with higher concentrations detected north of the causeway. North of the Causeway, Justin's Bay and Chocolatta Bay had the highest concentrations of arsenic, chromium, copper, zinc, aluminum while Delvan Bay sediments had the lowest concentrations of these metals. Surprisingly, clam survival and growth rate was marginally higher north of the causeway with highest growth (length and width) occurring in Justin's Bay and Delvan Bay. In contrast to sediment metal levels, *Rangia* tissue metal levels were relatively low and, with one exception, their uptake did not vary significantly with causeway location. *Rangia* tissue metal levels were less variable among sites than were the sediment metal concentrations. Oddly, the tissues of the reference clams had highest concentrations for arsenic, cadmium, chromium, lead, zinc, aluminum and mercury. Reference sediments had lower arsenic, chromium, copper, lead, zinc and aluminum concentrations than any of the other sites.

Overall, the metals concentrations in sediments and clams collected in our study areas were not exceedingly high and were not found to be at levels that are considered to be indicative of highly contaminated areas or to have adverse biological effects. Based on sediment quality guidelines (SQGs) developed for the National Status and Trends Program, Delta sediment and *Rangia* metal concentrations were all less than the Effects Range-Low (ERL) values (Long *et. al.* 1995 from USEPA 2004). Three individual cages had *Rangia* (zinc - Reference #1 and South #1) or sediment (arsenic - Chocolatta Bay #1) levels which were higher than the ERL but lower that the ERM suggesting within site spatial variability. Comparisons of collected *Rangia* tissue metal levels with those of organisms included in the USEPA bioaccumulation tables (USEPA 2000) suggest the tissue metal concentrations are below the acute and chronic levels. *Rangia* copper levels all fell below freshwater and marine $\text{NOEC}_{\text{tissue}}$ values (Salazar and Salazar 2002). *Rangia* zinc levels also fell below the marine threshold effects level for growth except for the clams collected from the reference site, which fell in the middle of the range for growth effects (Salazar and Salazar 2002).

Metals concentrations and bioavailability can be influenced by numerous factors including chemical form (McConnell and Harrel 1995, Allen 1994, Warren and Zimmerman 1993, USEPA 2000), sediment grainsize (Warren and Zimmerman 1993, Wells and Hill 2005), organic material (McConnell and Harrel 1995, Warren and Zimmerman 1993, Kordel *et. al.* 1997, Kordel *et. al.* 1997, USEPA 2000), environmental physical and chemical parameters (Warren and Zimmerman 1993, Kordel *et. al*. 1997, USEPA 2000, Griscom and Fisher 2004), presence of reducing bacteria (i.e. arsenic; USEPA 2000, Griscom and Fisher 2004) and acid volatile sulfides (USEPA 2000). Sediment grainsize and TOC analyses were conducted in 2004 and 2005 (Figs. 28 – 31). During both years, sites located north of the causeway had greater amounts of silt, clay and organic matter (AFDW) than did sites south of the causeway. These northern areas of fine silt accumulation were also sites of elevated sediment metals accumulation. Sediment metals concentrations were not linearly related to metals uptake by *Rangia*. Regression plots of sediment metals concentrations on Rangia tissue metals concentrations were not significant ($R^2 \leq 0.5809$ by site). This suggests these metals may be tightly bound (e.g. lead, cadmium, zinc; USEPA 2000) to the sediments and not bioavailable to the *Rangia* or other infauna.

Accumulation of metals in *Rangia* tissues may be influenced by factors such as dietary uptake (arsenic, copper, lead; USEPA 2000, Griscom and Fisher 2004) and assimilation efficiency (Griscom and Fisher 2004), production of metal binding protein leading to resistance (McConnell and Harrel 1995) and exposure time (Griscom and Fisher 2004). Site variations within the Mobile-Tensaw study area may reflect differences in clam feeding strategies (filter feeding verses deposit feeding) and thus differences in sediment ingestion. High turbidity levels were documented within the study area in an ongoing study, which may also influence the amount of ingested suspended materials. Site differences with regard to *Rangia* metals accumulation may also be reflective of the characteristics and quantities of imported and exported sediments (e.g. hurricanes). Finally, although our experiment lasted approximately 2 months, the exposure time for metals accumulation and subsequent biologically adverse effects to occur may fall within a longer time-scale (i.e. 6 months; Griscom and Fisher 2004).

Within the Mobile-Tensaw study area, possible sources of contaminants include runoff from the Causeway and Bayway; shoreline industrial and commercial areas; dredging activities; boating and recreational activities; and natural events related to the import and export of sediments. Year to year variation in *Rangia* metals levels in the reference area may have been the result of Hurricane Ivan impacts through the redistribution of sediment containing high metal concentrations. Hurricane Dennis may have had similar impacts during the transplant study. The two cages with high clam mortality occurred close to the western channel areas and may have experienced greater disruption and flushing compared with other study areas. Sites such as Justin's Bay and Chocolatta Bay, located close to the influences of roadway runoff had high *Rangia* metals concentrations. These areas also experience lower flushing and thus lower sediment and water exchange. Delvan Bay clams were located furthest from the impacts of the roadways and shoreline runoff (industry and development) and generally contained the lowest sediment and R*angia* metals concentrations. When taken together the results of this pilot study do show causeway induced impacts on sediment metals concentrations. Most were significantly greater to the north of the causeway where sediment grain sizes, conducted in a companion study, are skewed towards fine grained silts and clays. Even so, we found no evidence in this preliminary study to indicate that these concentration levels are of ecological concern.

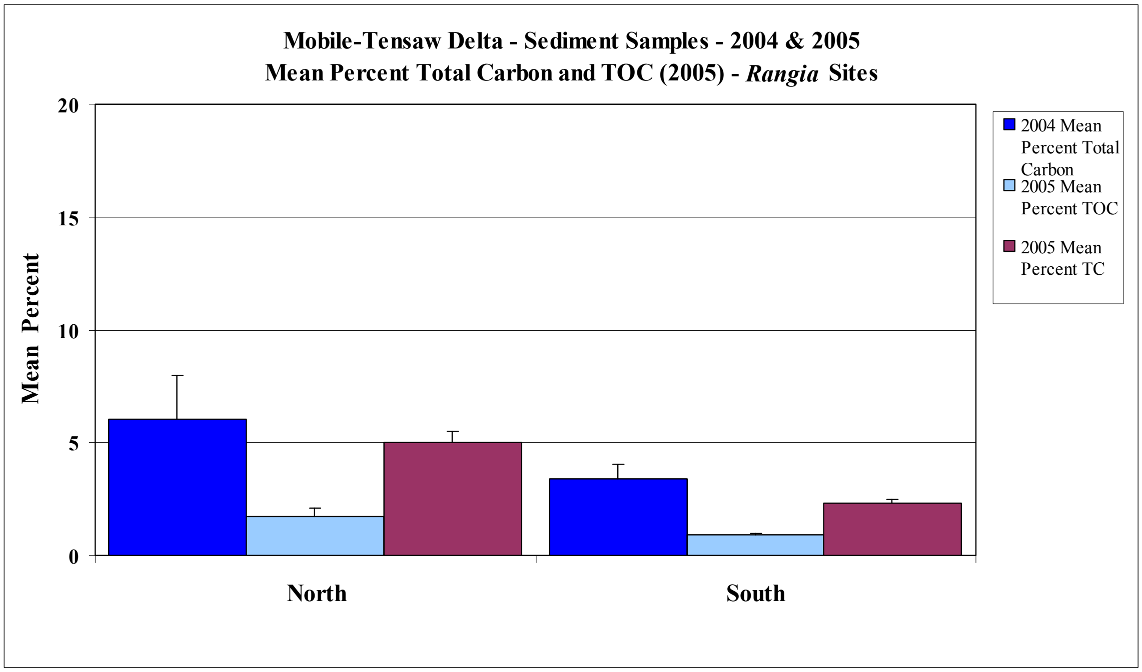

Figure 28. Sediment total carbon (TC - AFDW) and total organic carbon (TOC) plotted by location north and south of the causeway for the February 2004 and April 2005 sampling events.

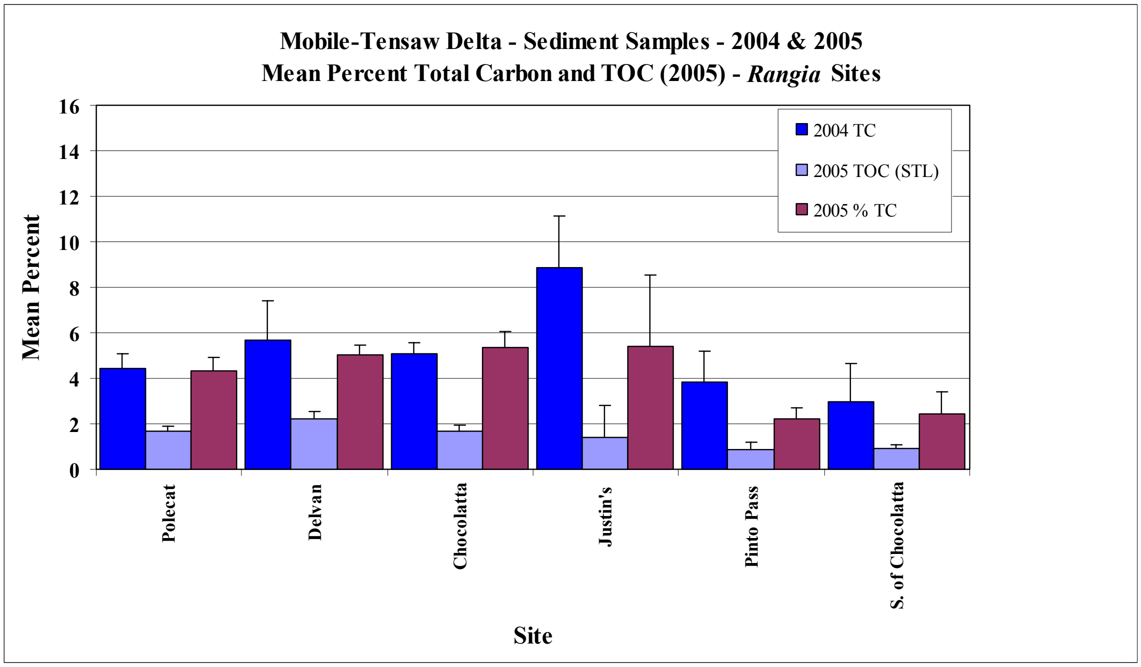

Figure 29. Sediment total carbon (TC - AFDW) and total organic carbon (TOC) plotted by site for the February 2004 and April sampling events. Polecat through Justin's Bay sites are located north of the causeway. Pinto Pass and South of Chocolatta sites are located south of the causeway.

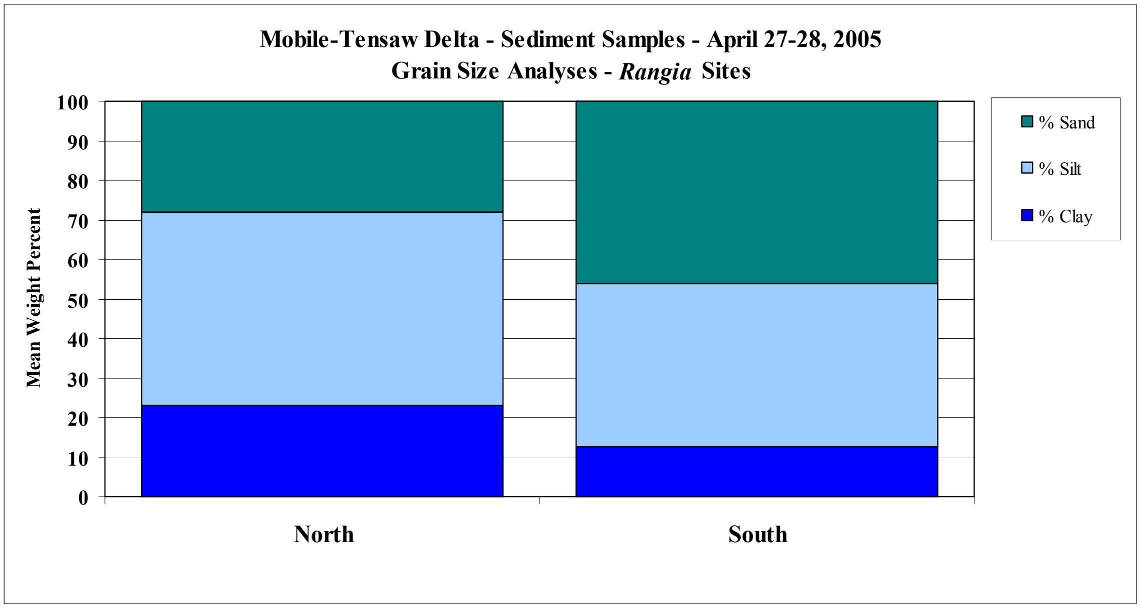

Figure 30. Sediment grain size (mean weight %) as gravel, sand, silt and clay are plotted by location north and south of the causeway for the April 2005 sampling event.

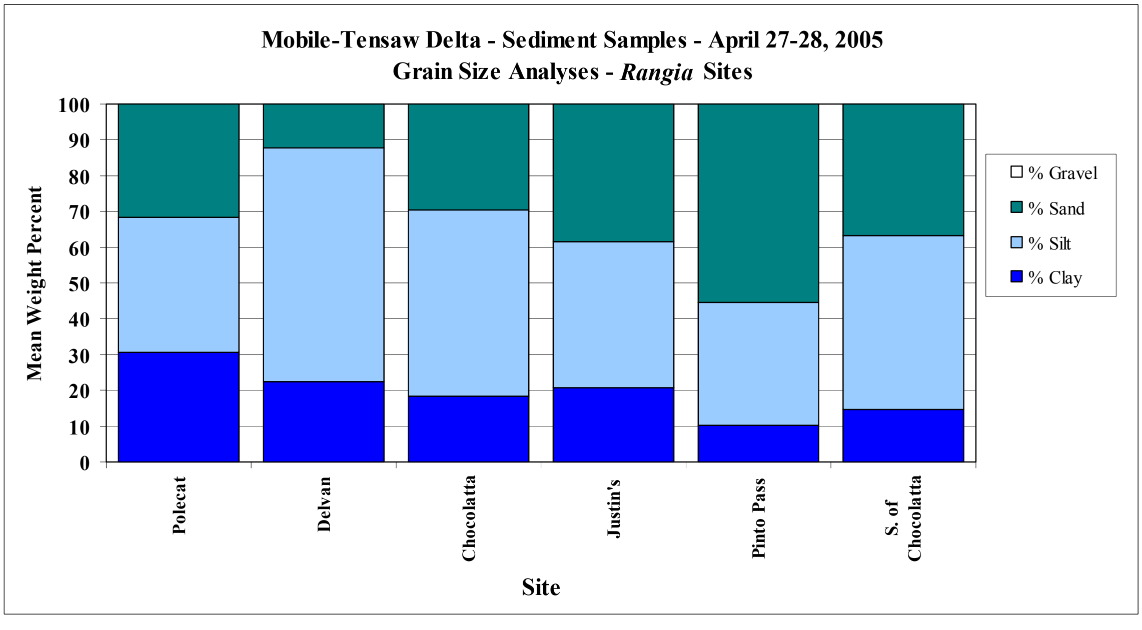

Figure 31. Sediment grain size (mean weight %) as gravel, sand, silt and clay are plotted by site for the April 2005 sampling event. Polecat through Justin's Bay sites are located north of the causeway. Pinto Pass and South of Chocolatta sites are located south of the causeway.

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