Freshwater Sediment Contamination in the Vicinity of Merrymeeting Bay:
Analysis of Sediment Chemistry Data

Final Report

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Final Report Submitted to Friends of Merrymeeting Bay
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INTRODUCTION

Friends of Merrymeeting Bay (FOMB) is an environmental conservation group whose stated mission is to preserve, protect, and improve the unique ecosystems of Merrymeeting Bay. They fulfill this mission through education, research, and the promotion and stewardship of environmental resources considered at risk. In many cases, important information is lacking and risk assessments therefore problematic. In the fall of 1999 and 2000, FOMB volunteers collected sediment samples that were later chemically analyzed for a better understanding of toxic contaminant levels in freshwater sediment areas of Merrymeeting Bay that have not been well characterized. Samples collected in 1999 were analyzed for metals. Samples collected in 2000 were analyzed for organics and pesticides. Concern has been raised that, although concentrations may be decreasing (if they really are), loading may actually be increasing due to discharge flows. In particular, the fine grained sediment data have not been interpreted in sufficient detail. FOMB was interested in collecting and analyzing freshwater sediments from the following areas: Abbagadassett River, Androscoggin River, Kennebec River, Muddy River, Swan Island flats, and Whiskeag Creek.

MATERIALS & METHODS

Sediment Collection & Chemical Analyses

Sediment samples were collected from six depositional areas of fine tidal sediments in the vicinity of Merrymeeting Bay (Figure 1):

Abbagadassett River (AB) east of old wardens camp (N43°59.787, W69°51.073)
Androscoggin River (AR) in cove east side near mouth, across from Pleasant Pt. (N43°57.446, W69°51.591)
Kennebec River (KR) just south of Abby Pt. (N43°59.915, W69°49.826)
Muddy River (MR) north of narrow neck on Pleasant Pt. (N43°58.207, W69°52.871)
Swan Island flats (SI), south end, east side (N44°01.937, W69°48.680)
Whiskeag Creek (WC), 2nd cove downstream from road crossing east side (N43°56.169, W69°49.827)

A 100-m transect was established at each site. Three stations were located along each transect: at 0, 50 and 100 m from the beginning of the transect. Five sediment grabs were collected at each station. The contents of each grab were combined to create a composite sample. Because the sampling stations were always separated by 50 m, the sediment samples may not be considered true replicates. However, in our analysis of the data, we considered these three samples as replicates for each transect to allow for statistical comparisons and a better characterization of chemicals at each site.

Sediment samples were analyzed for several metals (arsenic, lead, zinc, and mercury), polychlorinated biphenyls (PCBs), seven dioxin congeners (2378 TCDD, 12378 PeCDD, 123478 HxCDD, 123678 HxCDD, 123789 HxCDD, 1234678 HpCDD, and OCDD), 10 furan congeners (2378 TCDF, 12378 PeCDF, 123478 HxCDF, 123678 HxCDF, 234678 HxCDF, 123789 HxCDF, 1234678 HpCDF, 1234789 HpCDF, and OCDF), and selected pesticides (hexachlorobenzene; Lindane; Heptaqchlor; Aldrin; Heptachlor Epoxide; 2,4 DDE; Endosulfan 1; a-Chlordane; Nonachlor; 4,4 DDE; Dieldrin; 2,4 DDD; Endosulfan II; 4,4, DDD; 2,4 DDT; 4,4 DDT, and Mirex). All analyses were conducted by the University of Maine, Orono.

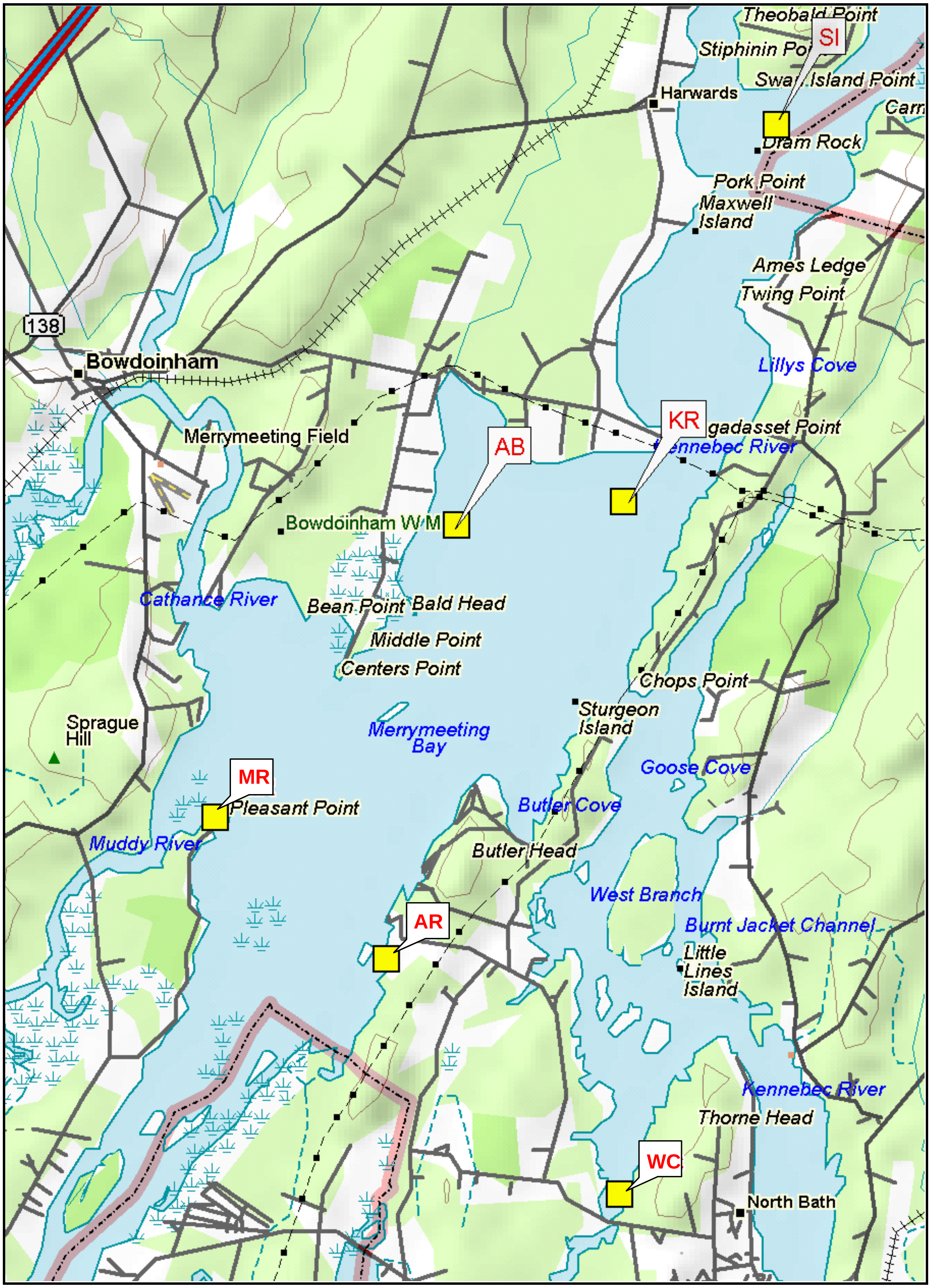

Figure 1. FOMB sediment sampling sites - November 1999 and 2000.

The samples collected in 1999 provided only enough material for metals analyses. Therefore, sediment samples were collected again in the fall of 2000, and these samples were analyzed for all organics. The laboratory analyzed all the 1999 sediment samples for metals and all the 2000 sediment samples for PCBs. Only selected samples collected in 2000 were analyzed for pesticides and dioxins/furans, as determined by the Department of Environmental Protection:

Pesticides: all samples except SI-2 and SI-3,
Dioxins/Furans: only samples AB-3, AR-1,2,3, KR-3, MR-2, SI-2, WC-2,3.

Data Analysis & Interpretation

The data for the three samples collected at a given site (or the number of samples analyzed) were averaged and used to represent conditions at that site. A step-wise approach to data analysis was used during this review to determine if selected contaminants are present at concentrations which are potentially toxicity to humans, fish and shellfish, or wildlife. First, the sediment chemistry data were summarized by site, and descriptive statistics such as mean, standard deviation, and 95% confidence interval (CI) were calculated. Bar graphs were created for metals, total PCBs (as determined for homologs and Aroclors), and total dioxin/furans. These bar graphs, with 95% CIs, were used to identify areas with the highest and lowest means. Bar graphs were not created for pesticides because of the extreme number of non-detects. Comparative statistics (i.e., Analysis of Variance (ANOVA) were used to determine if there were differences in metals concentrations among sites. For the organics, no statistical analyses were conducted because of the large number of non-detects (e.g., PCBs and pesticides) or because of insufficient data, as was the case with dioxin/furans. This lack of "replication" increased the uncertainty in the significance of the results and precluded any meaningful statistical analysis for the dioxin/furan data.

Mean concentrations of each metal, total PCBs, and pesticides were compared to the most recent and relevant consensus-based screening guidelines provided in MacDonald et al. (2000). Several different screening values are presented in MacDonald et al. (2000), with the consensus-based threshold effects concentration being the most relevant for this review. For total dioxin/furans, the mean concentration at each site was compared to the screening guidelines provided by the Canadian Council of Ministers of the Environment (1999). In their document, CCME state that the data used to calculate both the threshold effect level and the probable effects level did not adequately represent a diverse body of evidence regarding effects of sediment associated dioxins/furans. To address this issue, the CCME incorporated an uncertainty factor, resulting in an adjusted threshold effect level and an adjusted probable effects level.

This analysis should be viewed as a screening level assessment because the comparison of sediment chemistry values to sediment quality guidelines does not directly address bioavailability or causality. In addition, most sediment quality guidelines are intended to be used with traditional assessment methods such as laboratory toxicity tests, bioaccumulation tests, and assessments of benthic community structure. Although some advocates of these guidelines have suggested that the guidelines can be used for much more, it is the stated position of the US Army Corps of Engineers that sediment guidelines should not be used alone for regulatory decisions for the reasons stated previously. A more recent re-evaluation of water quality criteria through a SETAC workshop has identified the need for harmonization of water, sediment and tissue quality criteria and guidelines.

RESULTS

Results are presented by major chemical grouping, with the metals first, followed by dioxins/furans, pesticides, and PCBs.

Metals

The concentration of each metal by site are summarized in Table 1, along with the percent moisture and total organic carbon (TOC) in each sample.

Arsenic

The mean concentrations of arsenic ranged from a low of 5.82 ug/g dw for the Androscoggin River to a high of 8.91 ug/g dw on the Kennebec River (Table 1; Figure 2). All of these mean values were below the consensus-based threshold effects concentration (TEC) of 9.79 ug/g dw. These data suggest that no effects are expected, based on sediment chemistry alone. The analysis of variance (ANOVA) suggests that there were statistically significant differences among sites ($P = 0.0019$). The multiple comparison test showed that arsenic concentrations in sediments from the Androscoggin River site were significantly lower than all the others ($p<0.05$). Arsenic concentrations were similar for all remaining sites.

Lead

The mean concentration of lead ranged from a low of about 21.5 ug/g dw for the Abbagadassett River, Androscoggin River, and Kennebec River to a high of about 32 ug/g dw on the Muddy River and Whiskeag Creek (Table 1; Figure 3). All of these mean values were below the consensus-based threshold effects concentration (TEC) of 35.8 ug/g dw. These data suggest that no effects are expected, based on sediment chemistry alone. The analysis of variance (ANOVA) suggests that there were statistically significant differences among sites ($P < 0.0001$). The multiple comparison test identified two groups and showed that lead concentrations in sediments from the Androscoggin River, Swan Island, and Kennebec River, were similar and significantly lower than concentrations at Muddy River and Whiskeag Creek. Lead concentrations in sediments from the Abbagadassett River were in the mid-range, making this site comparable to both groups.

Zinc

The mean concentrations of zinc ranged from a low of about 95 ug/g dw for the Kennebec River and Swan Island to a high of about 130 ug/g dw on the Muddy River and Whiskeag Creek (Table 1; Figure 4). Mean zinc values for the Muddy River and Whiskeag Creek, 127.9 ug/g dw and 129.6 ug/g dw respectively, were the only values above the consensus-based threshold effects concentration (TEC) of 121 ug/g dw. These data suggest that some adverse effects might be expected based on sediment chemistry alone. The analysis of variance (ANOVA) suggests that there were statistically significant differences among sites ($P = 0.002$). The multiple comparison test identified two groups and showed that zinc concentrations in sediments from the Kennebec River and Swan Island were similar and significantly lower than concentrations at Muddy River and Whiskeag Creek. Zinc concentrations in sediments from the Androscoggin River and the Abbagadassett River were in the mid-range, making these sites comparable to both groups.

Table 1. Concentrations of metals (ug/g dw), moisture, and total organic carbon (TOC) in sediments

	As	Pb	Zn	Hg	% moisture	% TOC
AB-1	7.89	24.86	108.13	0.257	57.7	3.0
AB-2	8.32	27.03	117.85	0.328	60.5	3.5
AB-3	7.58	27.80	117.30	0.307	62.3	3.4
mean	**7.93**	**26.57**	**114.43**	**0.297**	**60.13**	**3.32**
stdev	0.37	1.53	5.46	0.036	2.30	0.25
n	3	3	3	3	3	3
95% CI	0.42	1.73	6.18	0.041	2.61	0.28
AR-1	6.84	24.89	123.09	0.355	58.9	4.0
AR-2	5.64	21.40	112.35	0.321	54.288	2.83/3.13
AR-3	4.98	17.42	94.82	0.322	46.671	2.700
mean	**5.82**	**21.24**	**110.09**	**0.333**	**53.29**	**3.36**
stdev	0.95	3.73	14.27	0.019	6.18	0.93
n	3	3	3	3	3	2
95% CI	1.07	4.22	16.14	0.022	7.00	1.28
KR-1	9.46	23.38	102.03	0.231	59.7	3.6
KR-2	8.28	20.71	90.8	0.211	56.1	3.1
KR-3	8.99	21.16	91.5	0.247	57.0	3.03/3.10
mean	**8.91**	**21.75**	**94.8**	**0.230**	**57.58**	**3.34**
stdev	0.59	1.43	6.30	0.018	1.90	0.36
n	3	3	3	3	3	2
95% CI	0.67	1.62	7.12	0.020	2.15	0.50
MR-1	8.53	32.28	130.8	0.417	69.3	3.0
MR-2	7.57	32.94	127.4	0.406	66.6	6.5
MR-3	8.42	30.42	125.5	0.363	72.1	4.8
mean	**8.17**	**31.88**	**127.9**	**0.396**	**69.34**	**4.76**
stdev	0.52	1.31	2.69	0.029	2.74	1.78
n	3	3	3	3	3	3
95% CI	0.59	1.48	3.04	0.032	3.10	2.01
SI-1	7.18	20.27	90.6	0.196	56.1	2.8
SI-2	8.22	20.75	95.7	0.195	56.1	2.6
SI-3	8.99	22.61	100.7	0.216	61.8	3.5
mean	**8.13**	**21.21**	**95.7**	**0.203**	**58.03**	**2.95**
stdev	0.91	1.24	5.05	0.012	3.29	0.50
n	3	3	3	3	3	3
95% CI	1.03	1.40	5.71	0.013	3.72	0.56
WC-1	7.34	33.92	129.1	0.401	70.3	5.8
WC-2	7.66	31.06	133.8	0.450	67.7	4.7
WC-3	7.86	30.28	125.9	0.451	61.0	4.5
mean	**7.62**	**31.75**	**129.6**	**0.434**	**66.33**	**4.99**
stdev	0.26	1.92	3.95	0.029	4.83	0.67
n	3	3	3	3	3	3
95% CI	0.30	2.17	4.46	0.033	5.46	0.76

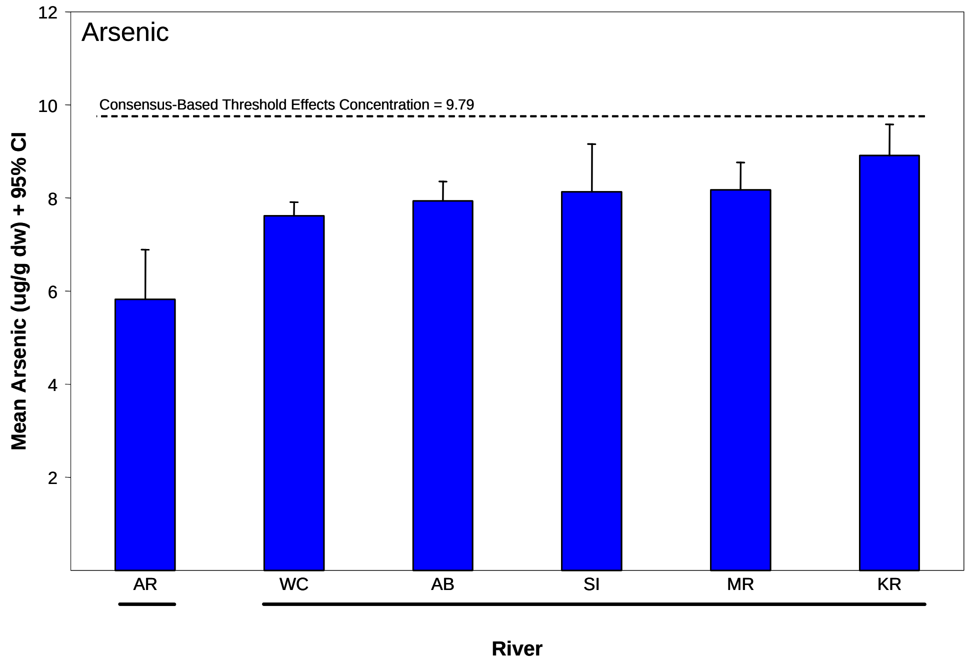

Figure 2. Concentration of arsenic (ug/g dw ± 95% CI) in river sediments. Underlined sites are statistically similar.

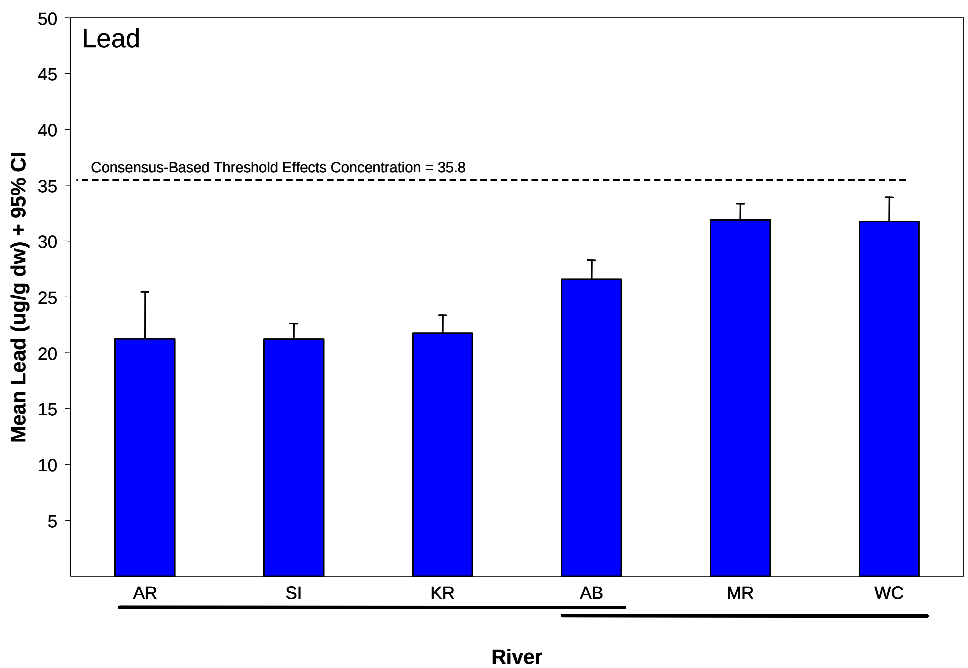

Figure 3. Concentration of lead (ug/g dw ± 95% CI) in river sediments. Underlined sites are statistically similar.

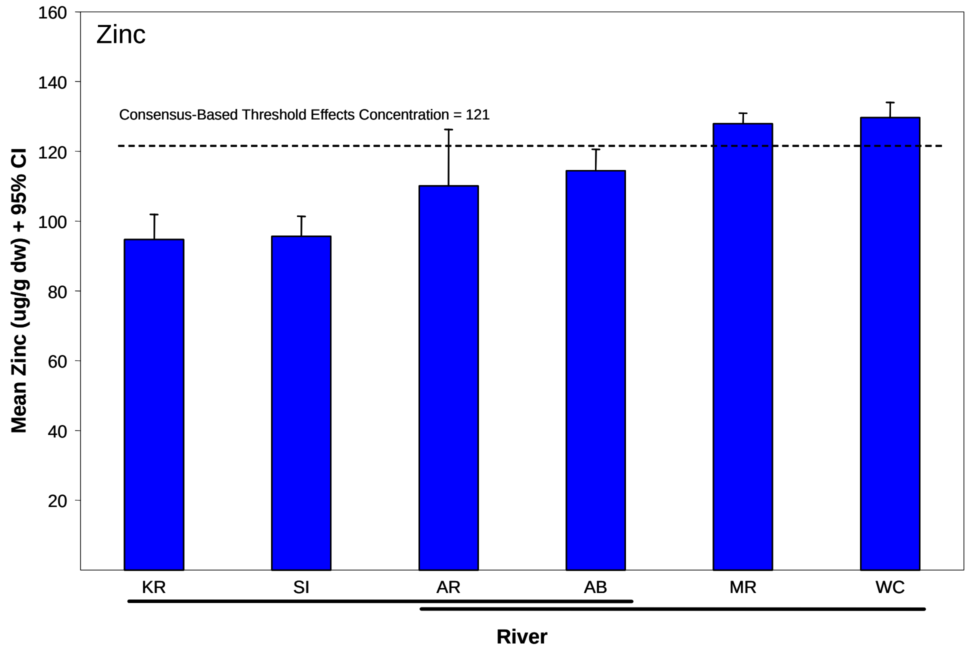

Figure 4. Concentration of zinc (ug/g dw ± 95% CI) in river sediments.
Underlined sites are statistically similar.

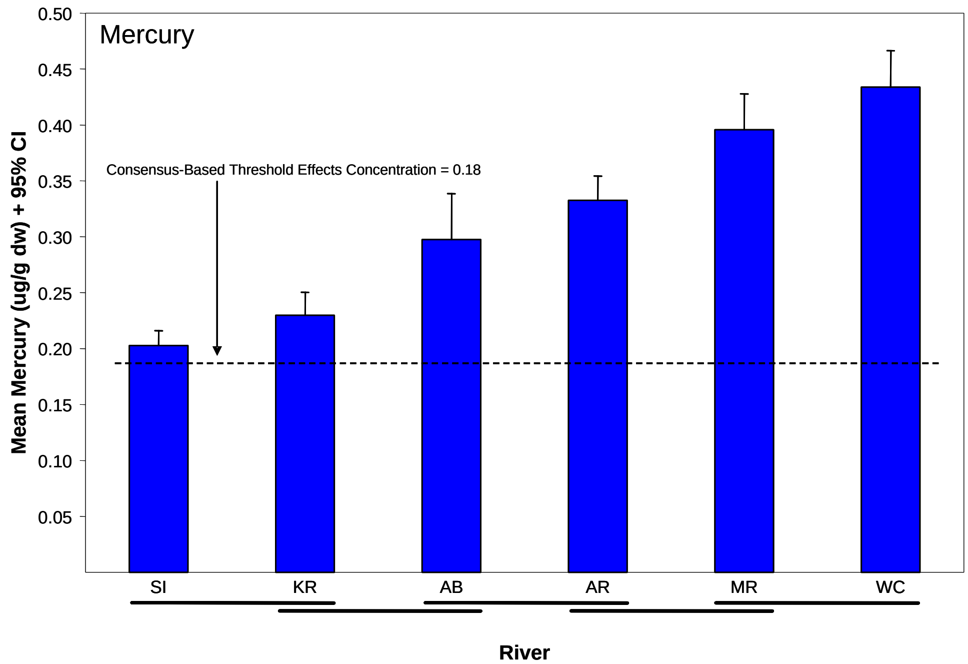

Figure 5. Concentration of mercury (ug/g dw ± 95% CI) in river sediments.
Underlined sites are statistically similar.

Mercury

The mean concentrations of mercury ranged from a low of 0.203 ug/g dw for Swan Island to a high of 0.434 ug/g dw on Whiskeag Creek (Table 1; Figure 5). Mercury was the only metal measured where all mean values exceeded the consensus-based threshold effects concentration (TEC) of 0.18 ug/g dw. These data suggest that some adverse effects might be expected based on sediment chemistry alone. The most severe effects might be expected at the Muddy River and Whiskeag Creek sites. The analysis of variance (ANOVA) suggests that there were statistically significant differences among sites ($P < 0.0001$). The multiple comparison test showed several different groupings of two sites each: Swan Island and Kennebec, Kennebec and Abbagadassett, Abbagadassett and Androscoggin, Androscoggin and Muddy, Muddy and Whiskeag Creek.

Dioxins/Furans

Sediments were analyzed for 10 furan congeners and seven dioxin congeners (Table 2). All 17 congeners were detected in samples from the Androscoggin and Kennebec Rivers. Sediments from Swan Island and Whiskeag Creek contained 15 and 16 of the congeners, respectively, while sediments from the Abbagadassett and Muddy Rivers only contained 6 and 7 congeners, respectively. The distribution of congeners of in sediment samples by site (Figure 6) shows that OCDD was the dominant congener at each location.

Total PCDD/PCDF concentrations ranged from a low of 192 ng/kg dw at Swan Island to a high of 3504 ng/kg in the Androscoggin River (Table 2) and were primarily a function of the OCDD concentration. Although statistical comparisons could not be made due to insufficient replication at most of the sites, the sites fell into three separate groups:

Total PCDD/PCDF concentrations <1000 ng/kg - Swan Island and Whiskeag Creek
Total PCDD/PCDF concentrations 1000 to 2000 ng/kg - Kennebec and Abbagadassett
Total PCDD/PCDF concentrations 3000 to 3500 ng/kg - Muddy and Androscoggin

The potential toxicity of the various dioxin and furan congeners is not equal for each congener, and toxicity equivalency factors (TEFs) have been developed to express the magnitude of toxicity relative to 2378-TCDD. This approach takes into consideration the unique concentrations and toxicities of the individual congeners present. Several sets of TEFs are available, with some representing toxicity to mammalian, avian, and fish species. The World Health Organization TEFs (Van den Berg 1998) were used to calculate the toxic equivalency units (TEQs) to assess the toxicity of measured dioxin and furan compounds to humans and mammals. On a TEQ basis, the site groupings were different (Figure 7). The Androscoggin River stood alone at about 10. The next group included the Kennebec and Muddy Rivers with values between 5.3 to 5.8. The third group included Whiskeag Creek and the Abbagadassett River with values between 2.8 and 2.2, respectively. Finally, Swan Island appeared to be a group by itself at 1.2.

Table 2. Concentration (ng/kg dw) of dioxin and furan congeners in sediment samples, and TEQs based on World Health Organization TEFs.

Congener (ng/kg dw)	AR	SI	KR	WC	AB	MR
2378-TCDF	3.88	1.17	5.68	1.36	0.00	0.00
12378-PeCDF	1.15	0.21	1.79	0.40	0.00	0.00
23478-PeCDF	1.34	0.26	1.73	0.40	0.00	0.00
123478-HxCDF	5.17	0.77	2.52	0.60	0.00	0.00
123678-HxCDF	4.38	0.58	2.03	0.63	0.00	0.00
234678-HxCDF	2.19	0.23	1.19	0.23	1.05	3.02
123789-HxCDF	0.56	0.00	0.71	0.00	2.26	4.98
1234678-HpCDF	138.11	14.93	27.52	13.14	66.5	112
1234789-HpCDF	15.98	0.72	2.25	0.49	0.00	6.95
OCDF	221.48	8.77	85.35	36.12	117	156
2378-TCDD	0.37	0.07	0.59	0.81	0.00	0.00
12378-PeCDD	0.83	0.00	0.83	0.35	0.00	0.00
123478-HxCDD	1.85	0.40	1.07	0.34	0.00	0.00
123678-HxCDD	13.84	1.61	3.20	2.17	0.00	0.00
123789-HxCDD	9.90	1.56	2.60	1.78	0.00	0.00
1234678-HpCDD	207.05	19.86	54.30	54.73	106	332
OCDD	2876	141	1329	638	1776	2550
Total PCDD/PCDF	3504	192	1523	752	2069	3165
No Samples:	3	1	1	2	1	1

TEQs based on TEFs for Humans and mammals

	AR	SI	KR	WC	AB	MR
2378-TCDF	0.3883	0.1169	0.5680	0.1356	0.0000	0.0000
12378-PeCDF	0.0573	0.0105	0.0893	0.0202	0.0000	0.0000
23478-PeCDF	0.6706	0.1308	0.8649	0.2015	0.0000	0.0000
123478-HxCDF	0.5170	0.0773	0.2522	0.0597	0.0000	0.0000
123678-HxCDF	0.4382	0.0577	0.2035	0.0627	0.0000	0.0000
123789-HxCDF	0.2188	0.0226	0.1194	0.0227	0.1050	0.3021
234678-HxCDF	0.0565	0.0000	0.0714	0.0000	0.2260	0.4982
1234678-HpCDF	1.3811	0.1493	0.2752	0.1314	0.6650	1.1200
1234789-HpCDF	0.1598	0.0072	0.0225	0.0049	0.0000	0.0695
12346789-OCDF	0.0221	0.0009	0.0085	0.0036	0.0117	0.0156
2378-TCDD	0.3694	0.0716	0.5882	0.8108	0.0000	0.0000
12378-PeCDD	0.8262	0.0000	0.8317	0.3465	0.0000	0.0000
123478-HxCDD	0.1849	0.0404	0.1074	0.0336	0.0000	0.0000
123678-HxCDD	1.3839	0.1613	0.3204	0.2168	0.0000	0.0000
123789-HxCDD	0.9898	0.1563	0.2601	0.1779	0.0000	0.0000
1234678-HpCDD	2.0705	0.1986	0.5430	0.5473	1.0600	3.3200
12346789-OCDD	0.2876	0.0141	0.1329	0.0638	0.1776	0.2550
Total TEQ	***10.0221***	***1.2156***	***5.2588***	***2.8390***	***2.2453***	***5.5804***

No consensus-based sediment quality guidelines are currently available to place these measurements in the proper perspective. At the present time, the interim guidelines developed by Environment Canada, found on the internet (http://lists.essential.org/dioxin-l/msg01104.html), are currently the most appropriate screening values. All sites exceed the adjusted threshold effects level of 1.0, but only the Androscoggin River exceeds the preliminary threshold effects level of 10. None of the sites approach the adjusted probable effects level of 18.9 (Figure 7).

Pesticides

Only DDE, DDD, and DDT were detected in any of the sediment samples (Table 3). DDE and DDD are "break down products" or metabolites of DDT. All other pesticides were at concentrations below the detection limit. The concentrations of 2,4-DDT were higher than any of the other pesticides, with the highest concentrations were measured in sediments from the Abbagadassett River (1.08 to 1.13 ug/kg-dw in individual samples) and Swan Island (1.15 to 1.68 ug/kg-dw in individual samples). The concentrations of 4,4-DDT were about an order of magnitude lower than the 2,4-DDT concentrations. Interestingly, not all sediment samples from a given site contained DDT or its metabolites. In most cases, these compounds were only detected in one sample from a site. Consensus-based threshold effects have been developed for selected pesticides (MacDonald et al. 2000), and as shown in Table 3, none of the sediment samples approach the threshold concentrations for either the DDD or DDT compounds. The reported concentrations of these pesticides in sediments were about an order of magnitude lower than the threshold effects concentrations.

PCBs

A PCB Congener is any single, unique, chemical compound in the PCB category. The name of a congener specifies the total number of chlorine substituents and the position of each chlorine. There are 209 possible unique PCB congeners. Of the 20 PCB congeners on the analyte list, only seven were detected in sediment samples (Table 4). Nearly all sediment samples contained at least one of the three high-molecular weight PCBs 2,2',3,3',4,4',5,6-Octachlorobiphenyl, 2,2',3,3',4,5',6,6'-Octachlorobiphenyl, and 2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl. The highest concentrations, between 0.79 and 2.26 ug/kg-dw, were measured in sediments from the Androscoggin River. One sample from the Kennebec River (KR-1) contained 2,2',5-Trichlorobiphenyl and 2,4,4'-Trichlorobiphenyl, two low-molecular weight PCBs, at concentrations of 3.60 and 6.35 ug/kg-dw, respectively. TEFs have been developed for 14 PCB congeners, but none of these were included in the list of analytes.

In addition to individual congener analysis, the sediments were analyzed for total PCBs. Two different approaches were used; one based on homologs and the other based on Aroclors. PCB homologs are subcategories of PCBs, representing all congeners having an equal numbers of chlorine substituents (i.e., the "Tetrachlorobiphenyls" or "Tetras") are all PCB congeners with exactly 4 chlorine substituents in any arrangement. PCB Aroclor refers to manufactured complex mixture of congeners. While PCB was manufactured and sold under many names, the most common were the "Aroclor" series (the Monsanto trade name).

The difference in total PCBs as determined by homologs and Aroclors is shown in Figure 8. The two approaches yielded similar results, with total PCBs ranging from a low of 6.95 ug/kg-dw (homolog-based) in sediments from Whiskeag Creek to a high of 36 ug/kg-dw (Aroclor-based) in sediments from the Androscoggin River. Total PCBs in neither the individual samples or site means exceeded the consensus-based threshold effects concentration of 59.8 ug/kg-dw (MacDonald et al. 2000). Consensus-based threshold effects concentrations are not available for the individual congeners.

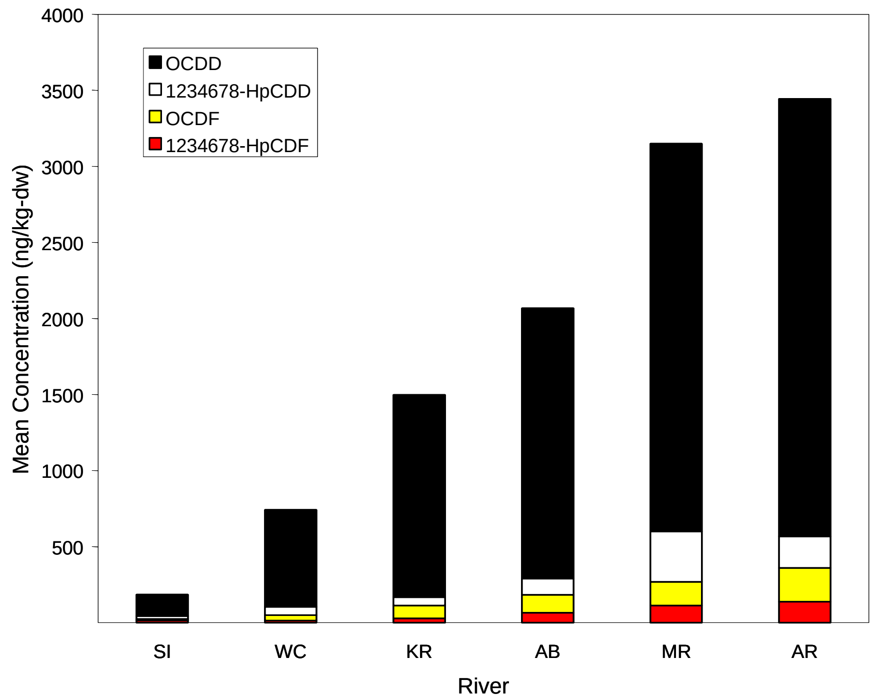

Figure 6. Concentrations (ng/kg-dw) of the four most prominent dioxin and furan congeners in river sediments.

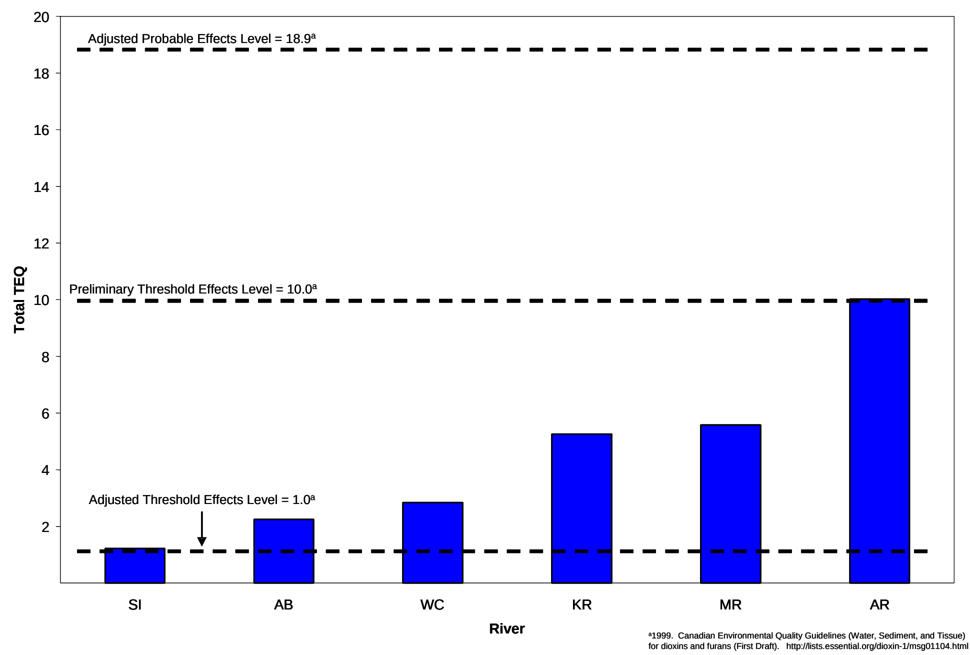

Figure 7. Total dioxin/furan TEQ by site compared to the preliminary threshold effects level, adjusted threshold effects level, and adjusted probable effects level.

Table 3. Concentration (ug/kg dw) of measured pesticides in sediment samples. Black boxes indicated detected pesticide in sample. <DL = below detection limit.

	Hexachlorobenzene	Lindane	Heptachlor	Aldrin	Heptachlor Epoxide	2,4-DDE	Endosulfan I	a-Chlordane	Nonachlor	4,4-DDE	Dieldrin	2,4-DDD	Endosulfan II	4,4-DDD	2,4-DDT	4,4-DDT	Mirex
AB-1	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.40	<DL	0.18	<DL	<DL	1.13	<DL	<DL
AB-2	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
AB-3	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	1.08	0.28	<DL
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.13***	***0***	***0.06***	***0***	***0***	***0.737***	***0.093***	***0***
AR-1	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
AR-2	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.92	<DL	<DL
AR-3	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.307***	***0***	***0***
KR-1	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.27	<DL
KR-2	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
KR-3	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.75	<DL
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.34***	***0***
MR-1	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
MR-2	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0.51	<DL	0.60	<DL	<DL	<DL	0.66	<DL
MR-3	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.17***	***0***	***0.2***	***0***	***0***	***0***	***0.22***	***0***
SI-1	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
SI-2	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	na	<DL	na	1.15	na	<DL
SI-3	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	na	<DL	na	1.68	na	<DL
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.943***	***0***	***0***
WC-1	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WC-2	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
WC-3	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***

Consensus-Based Threshold Effects Concentration: Sum DDD =4.88
Consensus-Based Threshold Effects Concentration: Sum DDT =4.16

TECs from: MacDonald, Ingersoll & Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxicol. 39:20-31

na = data not available

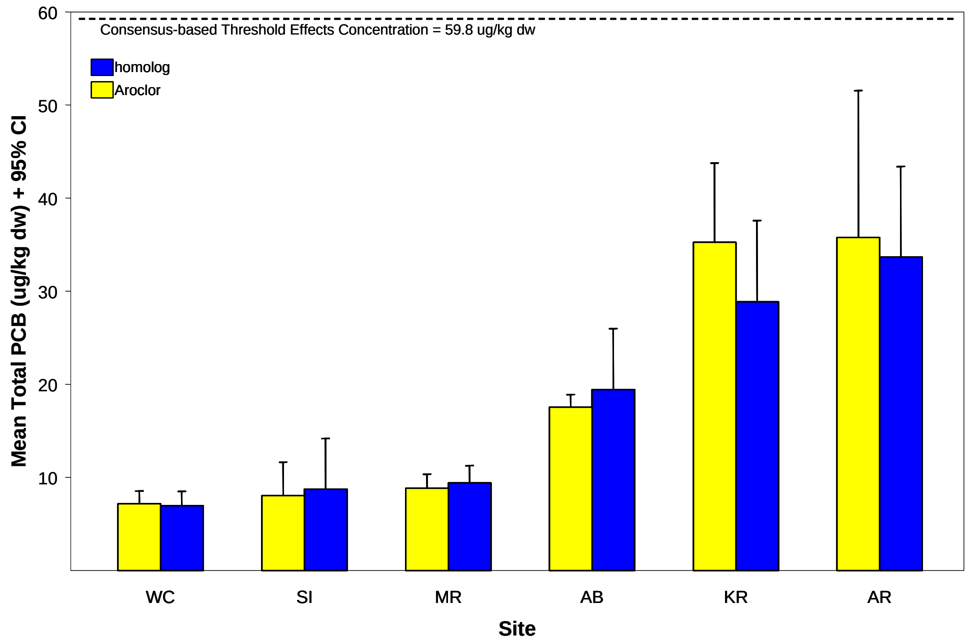

Figure 8. Concentration (ug/kg-dw) of total PCBs in sediments based on homologs and Aroclors. Concentrations compared to the consensus-based threshold effects concentration.

Table 4. Concentration (ug/kg dw) of measured PCBs in sediment samples. Black boxes indicated detected congener in sample. Concentrations below detection limit replaced with a “0.”

	2,4'-Dichlorobiphenyl	2,2',5-Trichlorobiphenyl	2,4,4'-Trichlorobiphenyl	2,4,5-Trichlorobiphenyl	2,2',3,5'-Tetrachlorobiphenyl	2,2',4,6-Tetrachlorobiphenyl	2,2',5,5'-Tetrachlorobiphenyl	2,3',4,4'-Tetrachlorobiphenyl	2,2',3,4,5'-Pentachlorobiphenyl	2,2',4,5,5'-Pentachlorobiphenyl	2,2',4,6,6'-Pentachlorobiphenyl	2,2',3,3',4,4'-Hexachlorobiphenyl	2,2',3,4,4',5'-Hexachlorobiphenyl	2,2',4,4',5,5'-Hexachlorobiphenyl	2,2',4,4',5,6'-Hexachlorobiphenyl	2,2',3,4',5,5',6-Heptachlorobiphenyl	2,2',3,4',5,6,6'-Heptachlorobiphenyl	2,2',3,3',4,4',5,6-Octachlorobiphenyl	2,2',3,3',4,5',6,6'-Octachlorobiphenyl	2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl	Total PCBs (homolog)	Total PCBs (Aroclor)
AB-1	0	0	0	0	0	0	0	0	0	0	0	0	1.55	0	0	0	0	0	0.60	1.66	18.3	18
AB-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25.7	19
AB-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.69	14.3	16
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.52***	***0***	***0***	***0***	***0***	***0***	***0.2***	***1.12***	***19.4***	***18***
AR-1	0	0	0	0	0	0	0	0	0	0	0	0	1.56	0	0	0	0	2.26	1.75	2.25	25.6	22
AR-2	0	0	0	0	0	0	0	0	0	0	0	0	2.98	0	0	0	0	1.14	0.79	0.91	32.7	36
AR-3	0	0	0	0	0	0	0	0	0	0	0	0	1.04	0	0	0	0	0.84	1.05	1.88	42.7	50
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***1.86***	***0***	***0***	***0***	***0***	***1.41***	***1.2***	***1.68***	***33.7***	***36***
KR-1	0	3.60	[illegible]	0	0	0	0	0.24	0	0	0	0	0	0	0	0	0	0	0	1.47	36.7	44
KR-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.68	0	21.3	30
KR-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.81	28.6	32
mean	***0***	***1.2***	***2.12***	***0***	***0***	***0***	***0***	***0.08***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.23***	***1.09***	***28.9***	***35***
MR-1	0	0	0	0	0	0	0	0	0	0	0	0	0.78	0	0	0	0	0.60	0	2.24	8.51	7.7
MR-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.67	0	0	11.3	8.6
MR-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.35	0	1.63	8.44	10
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.26***	***0***	***0***	***0***	***0***	***0.54***	***0***	***1.29***	***8.44***	***8.8***
SI-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.67	0	0	14.1	12
SI-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.24	5.3
SI-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.81	7.4
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***1.22***	***0***	***0***	***8.72***	***8***
WC-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.72	1.33	6.44	8.6
WC-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.91	6.3
WC-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.67	8.51	6.7
mean	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0.24***	***1***	***6.95***	***7.2***

Consensus-Based Threshold Effects Concentration: Total PCBs =59.8

TECs from: MacDonald, Ingersoll & Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Arch. Environ. Contam. Toxicol. 39:20-31.

DISCUSSION

Among the metals, the only one exhibiting extreme cause for concern was mercury which exceeded the threshold effects concentration at all sites, and at Muddy River and Whiskeag Creek by a factor of two. Again, it should be made very clear that all of this mercury may not be biologically available. On the other hand, such extreme elevations are cause for concern and further study. Additional studies should be conducted on mercury in these areas, particularly with respect to methylmercury, because it is the most toxic form. Methylmercury has the potential to elicit long term effects at low concentrations. This is also an issue of bioavailability and causality.

Zinc only exceeded the threshold effects concentration at two sites, Muddy River and Whiskeag Creek. This brings up another issue with respect to additive toxicity wherein all the potential toxicity could be manifested even if all the metals were below the threshold effects concentration. For example, even though all the arsenic concentrations were below the threshold effects concentration, it is possible that the additive effects of mercury, zinc, and arsenic could become toxic, particularly at sites where the arsenic concentration is approaching the threshold level, as it has at the Muddy River, for example. The same is true for lead where all the concentrations were below the threshold, but concentrations were approaching the threshold at the Muddy River and Whiskeag Creek. Collectively, the results suggest that the two sites which were highest for most metals were the Muddy River and Whiskeag Creek. More work should be done at these sites in particular, with respect to metal concentrations in water, sediment, and biota and potential effects.

Larsen & Gaudette (2002) concluded that metal concentrations in the Bay's smaller tributaries were significantly lower than in the main stem rivers, and some results from this study suggest concentrations in smaller tributaries may be higher. However, the results of the two studies are not all directly comparable. In the Larsen & Gaudette (2002) study, sampling sites may have been different, the suite of metals was clearly different (Pb, Cd, Cr, Sn, Ni, Zn, vs Pb, As, Hg, Zn), and some of the high values (particularly in the Kennebec between Augusta and Swan Island, an area not sampled in this study) may be a result of tidal backwash and lower water velocities and proximity to more urban areas. Interestingly, in areas that are comparable, the range of metal concentrations are similar. Again, more work should be done here to clarify apparent similarities and differences between the two reports and other available data.

Although the results for dioxins/furans are even more tenuous, given the provisional nature of the sediment quality guidelines, the fact that all of the measurements are above the adjusted threshold values is cause for concern. Given the potential endocrine disrupting ability of dioxins/furans and far reaching effects that are generally beyond those of most metals (except mercury), more work should be done regarding the temporal and spatial variability in dioxin/furan exposure and effects with sufficient replication to make statistical comparisons and a better analysis of the data.

To understand the relative degree of contamination at each of the sampling sites, the sites were ranked based on each of the chemicals measured in sediments (Table 5). For each chemical, or group of chemicals as in total dioxins/furans and PCBs, a rank was assigned to the site with 1 assigned to the site where the chemical had the lowest concentration and 6 assigned to the site with the highest concentration. If sites were tied, the average of the ranks was assigned. Once the individual ranks were assigned, a total was determined for each site based on the sum of the individual ranks. Using this process, Swan Island has the lowest total ranks, indicating that each of the measured chemicals was present at a lower concentration than at the other sites. In general, the Swan Island area could be considered less contaminated than the other sites. The most contaminated area, based on the Site Total, is the Muddy River. The concentrations of the individual metals and total dioxins/furans were generally higher here than at any of the other sites. Although metals concentrations were generally lower for the Androscoggin River site, this site had high ranks for dioxins/furans and PCBs. The Abbagadassett River has moderately high ranks for all chemicals, suggesting this area may receive chemical contamination from a variety of sources. The rankings provided in this review should only be used to assess the relative degree of chemical contamination across sites. The overall consequence to human health and environmental receptors due to exposure to these chemicals cannot be determined without further investigation and study. As suggested earlier, several chemicals are present at concentrations below current screening guidelines, but this does not eliminate the possibility for additive toxicity wherein all the potential toxicity could be manifested even if all the chemicals were below their respective threshold effects concentration.

Table 5. Relative rankings of sediment sites based on concentrations of measured chemicals. 1 = lowest, 6 = highest rank. Site total based on sum of individual ranks.

	As	Pb	Zn	Hg	metal sub total	total dioxins furans	Pesticides (2,4-DDT)	total PCBs	Site Total
Abbagadassett River	3	4	4	3	***14***	4	5	4	**27**
Androscoggin River	1	2	3	4	***10***	6	4	6	**26**
Kennebec River	6	3	1	2	***12***	3	2	5	**22**
Muddy River	5	6	5	5	***21***	5	2	3	**31**
Swan Island	4	1	2	1	***8***	1	6	2	**17**
Whiskeag Creek	2	5	6	6	***19***	2	2	1	**24**

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