SPATIAL AND TEMPORAL ASPECTS OF SEDIMENTARY CONTAMINANT CONCENTRATIONS IN THE TIDAL PORTIONS OF THE KENNEBEC/ANDROSCOGGIN RIVER SYSTEM

A Report to the

Surface Water Ambient Toxics Monitoring Program

Maine Department of Environmental Protection

by

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ABSTRACT

The concentrations of Cd, Cr, Cu, Ni, Pb, Sn and Zn in the surface sediments of 47 stations in the tidal Kennebec/Androscoggin system of the Gulf of Maine were determined. For data analysis purposes the region was divided into seven subregions consisting of five tributaries of Merrymeeting Bay, i.e. the Upper Kennebec, Muddy, Cathance, Abagadasset and Eastern Rivers, Merrymeeting Bay proper and the Lower Kennebec River connecting Merrymeeting Bay and the Gulf of Maine. Special emphasis was given to locating fine-grained depositional areas in this generally energetic, coarse grained system.

Most stations exhibited elevated metal concentrations. Statistically significant differences existed between the four small "local" tributaries and one or more of the three station groupings representing the main stem of the system. The distribution of metals indicated that the sources were the upstream Kennebec and Androscoggin watersheds. Metal levels in the upper reach of the lower Kennebec estuary were higher than found immediately upstream and downstream. This distribution can be explained by the existence of a turbidity maximum.

It is believed that the system is in a dynamic equilibrium with regard to particle and contaminant deposition and that further accumulation is negligible. This supports the hypothesis of Larsen and Gaudette (1995) that the Kennebec and Androscoggin watersheds are sources for contaminants observed in the nearshore Gulf of Maine.

INTRODUCTION

Elevated levels of toxic contaminants in the water, sediments and biota of several estuaries and embayments of the Gulf of Maine have been documented over the last three decades (Armstrong, *et al.*, 1976; Mayer and Fink, 1980; Lyons, *et. al.*, 1978; Goldberg, *et al.*, 1983; Larsen, *et al.*, 1983a, 1983b,1984; Ray and MacKnight, 1984; Gottholm and Turgeon; 1991, Larsen and Gaudette, 1995; Larsen, *et al.*, 1997; others). Taken together, these studies suggest considerable variability in the degree of enrichment as a function of source and transport mechanisms. A review of the environmental quality of the Gulf of Maine region (Larsen, 1992) suggests that the area between Cape Elizabeth and Boothbay is particularly complex and interesting. For instance, in the first comprehensive baseline survey of Casco Bay proper, Larsen, *et al.* (1983a) found all measured metals but cadmium to be elevated well above pre-industrial levels, as defined by Lyons, *et al.*, (1978). Geographic distributions suggested anthropogenic inputs associated with activities in and around the commercially important Portland Harbor. Subsequently, the NOAA National Status and Trends Program (NS&T) reported that Casco Bay sediments were moderately enriched with metals and other toxics and that metal levels in livers of non-migratory fish collected near Cape Small, not far from the mouth of the Kennebec estuary, ranked high on both a Gulf of Maine and national scale (Gottholm and Turgeon, 1991; Larsen 1992). Data from the EPA Mussel Watch Program indicated that mussels from the isolated and undeveloped Cape Newagen ranked surprisingly high in lead and zinc content (Goldberg, *et al.*, 1983; Larsen, 1992).

These patterns of toxics in both sediments and biota over a relatively large area demonstrate that the study area is affected by numerous sources and complex, dynamic processes. Surveys of limited geographic scope, while important for local management concerns, are inadequate for determining and evaluating larger scale processes which may dominate regional fluxes of contaminants. One such larger scale process that may be important in Maine's mid-coast region is the removal of contaminants from the large (27,700 km^2), industrialized Kennebec/Androscoggin River watershed and their passage through the tidal reaches of the system, including the energetic and ecologically important Merrymeeting Bay, into the nearshore Gulf of Maine. Evidence from the distribution of heavy minerals (Ross, 1967), hydrographic modeling (D.A. Brooks, personal communication) and anecdotal accounts of pulpwood drift support this possibility. Most recently, Stumpf and Goldschmidt (1992) used satellite imagery to show the development and dispersion of a sedimentary plume from the Kennebec River estuary into the Gulf of Maine as a result of a major (100 year) storm. This one event could have transported over 500,000 metric tons of sediments and associated toxics through the estuary (R. Stumpf, personal communication), and the dispersion of the plume in the days following the initial event could explain many of the contaminant distributions noted in the above site-specific studies. Clearly, baseline surveys were needed on appropriate scales to evaluate suspected operative mechanisms.

Prompted by the above reports of contaminant concentrations in sediments and biota from mid-coast Maine, Larsen and Gaudette (1995) undertook, in 1991, a broad scale surficial sediment sampling and analysis program. Their goals were to document geographic distributions of contaminants on a regional level and to gain insight into possible sources and transport mechanisms. Trace metals were used as surrogates for the suite of toxics moving through the region. Results reaffirmed the suspicion that the Kennebec/Androscoggin system may play a key role in regional contaminant dynamics. They concluded that more information was needed for both scientists and managers to understand the distribution and movements of contaminants in both space and time.

As an initial step in building a detailed understanding of the sources, movements and deposition of contaminants in the tidal Kennebec/Androscoggin system, Dr. Henri Gaudette of the University of New Hampshire and a graduate student undertook a focussed survey of the system. Sampling design and fieldwork was supervised by Dr. Peter Larsen as part of the Kennebec Area Research Endowment program. Once again, trace metals were used as surrogates for all contaminants that are associated with fine sediments and organic matter.

Considerable effort was expended to locate stations with sufficiently fine sediments to provide a valid characterization of metal levels and distributions.

The resulting 1992 data set consisted of 47 stations between Hallowell, ME (52 km inland) and the lower Kennebec River estuary. With the exception of the lower Kennebec estuary, this system may be characterized as tidal fresh water. The distribution of stations within river segments is as follows: Lower Kennebec River(9), Merrymeeting Bay (includes lower Androscoggin River) (6), Upper Kennebec River (13), Muddy River (4), Cathance River (7), Abagadasset River (3) and Eastern River (5). The lower Androscoggin River is included as part of Merrymeeting Bay because no natural demarcation between them is evident. On the other hand, whereas it is commonly accepted that the northern limit of Merrymeeting Bay on the Kennebec River is the Richmond Bridge, we followed the convention of nautical charts and topographic maps and called everything north of Abagadasset Point the upper Kennebec River. Abagadasset Point is such a strong constriction that we assumed that the water above it is Kennebec water with only a slight dilution from the Eastern River. Fine sediments were sampled in the above areas and analyzed for seven trace metals (Cd, Cr, Cu, Pb, Zn, Sn and Ni) as well as major metals, grain size and organic carbon content.
Specific goals of the investigation included:

- Documentation of geographic distribution of metals in the dynamic Kennebec/Androscoggin system. The distribution of organic contaminants such as PAHs and dioxin should mirror the metal distribution because of similar affinities for fine grained sediments and organic particles.
- To gain insights into locations of possible sources.
- To gain insights into the generic activities which may produce the contamination.
- To gain insights into temporal trends in sediment metal concentrations.

METHODS

Forty-seven stations (Fig. 1, Appendix 1) were sampled in the summer of 1992 using a small, acid-cleaned stainless steel grab sampler of our own design (HEG). Undisturbed, surface sediment sub-samples (top 5 cm) for trace metal analysis were taken from the grab with acid-cleaned plastic scoops, transferred to clean polyethylene zip-lock bags and stored on ice for return to the laboratory. Separate sub-samples were taken for grain size analysis and organic matter determination.

Grain size distributions were determined by standard sieving and pipette methods (Folk, 1968). Organic matter in the sediments is expressed as percent weight loss on ignition obtained by heating a representative, dried subsample of the sediment to 540°C for 24 hours.

Trace metals were stripped off the sediment particle surfaces using the same strong acid leach process as Larsen, *et al.* (1983a). In brief, approximately 3 grams of dried sediment (60°C,

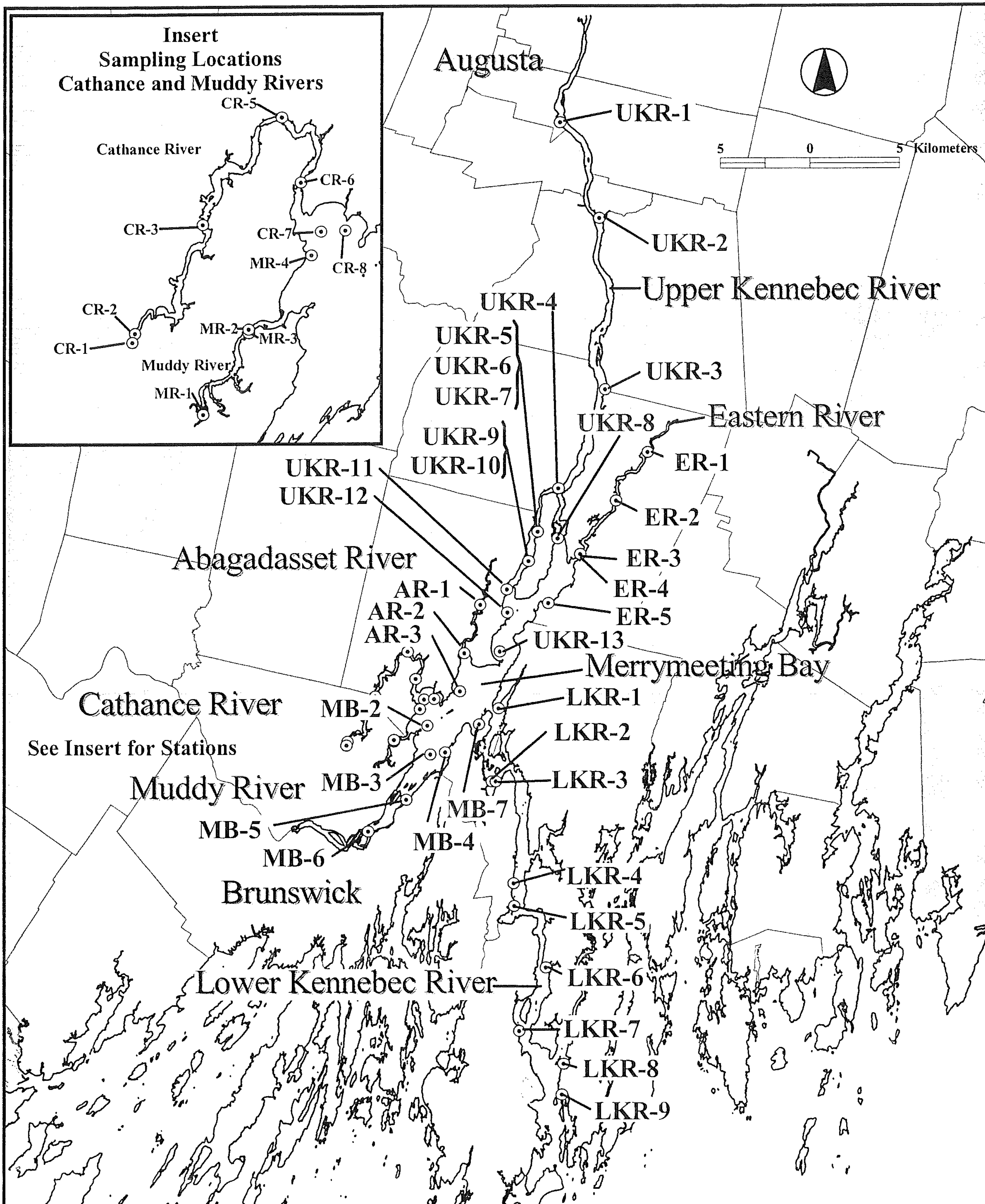

Fig. 1. Locations of trace metal sampling stations in the Kennebec/Androscoggin River system.

18-24 hours) were accurately weighed into a 100 ml glass beaker. Ten ml of concentrated reagent HNO_3 were added, and the samples evaporated to dryness. When cooled, each sample received 5 ml of 8% NH_4Cl (w/v), 5 ml of 0.02 M $Ca(NO_3)_2 \cdot 4H_2O$, and 15 ml of an acid solution (80 ml concentrated HNO_3 plus 20 ml concentrated HCl diluted to 1 liter with MilliQ water), and the volumes were reduced on a hot plate to 10-15 ml. Cooled samples were filtered using "Q" water; sediment trapped on the filter paper was washed several times with "Q" water, and the filtrate was brought to 50 ml total volume. These procedures have been shown to remove "environmentally available" metals without destruction of the mineral matrix (Tessler, *et al.*, 1979; Olsen, *et al.*, 1993).

The filtrates were analyzed by Atomic Absorption Spectrometry (AA) for Fe, Mn, Cd, Cr, Cu, Ni, Pb, Sn, and Zn, and concentrations as ug/gram dry weight sediment were calculated. Analytical variability could not be determined by replicate analysis of standard sediment samples (U.S. Geological Survey standard MAG-1 (Marine Mud) and National Institute of Standards and Technology SRM 1646 (estuarine mud)) since our extraction procedure differed from the total dissolution procedures used to determine the certified values. Therefore, we have made within sample replicate analyses to estimate analytical error. These are: Cd 13.4%; Cr 4.4%; Cu 1.8%; Pb 4.8%; Zn 2.1%; Sn 20.9%; Ni 2.4%; Fe 5.9%; and Mn 1.3%. These uncertainty values are typical of AA analyses with the exception of Sn which was influenced by an outlier in the replicated samples.

The data were normalized to the fine sediment fraction by dividing the metal concentrations by the fraction of the sediment <63 μm (NOAA, 1988).

RESULTS

Results of the sediment metal analyses with the percentages of fine sediments and loss on ignition are presented in Table 1. Background material on concentrations of major metals, pre-normalized trace metal concentrations, grain size calculations and data and loss on ignition calculations are presented in Appendices 2-5, respectively. Examination of the summary statistics at the bottom of Table 1 demonstrates that the individual metal concentrations were distributed widely around the means. Nevertheless, only in the case of Pb does the standard deviation exceed the mean. Perusal of the Pb column reveals one very hardy outlier at Station UKR-4 located in the Kennebec River just upstream of Swans Island.

A linear correlation matrix, using unnormalized data of trace metals, major metals and salient environmental variables was constructed to gain insight into the relationships among them (Table 2). Nearly all of the correlations between the trace metals, Mn, Fe, percent fines and LOI are extremely significant. Pb correlations are low and not significant with percent fines and LOI at n=47. The removal of the above-mentioned outlier at UKR-4, however, resulted in

Table 1. Normalized concentrations of metals (ppm dry wt.) in surface sediments with percentage of sediment <63 μm and percentage weight loss on ignition.

River	Station #	Cd	Cr	Cu	Pb	Zn	Sn	Ni	Fe	Mn	%<63 μm	% LOI
Muddy River	MR-1	0.74	57.6	29.7	29.8	119.4	13.4	30.1	12150.9	125.7	46.7	10.1
	MR-2	0.65	58.3	31.4	28.8	128.7	10.5	32.9	14514.5	143.9	49.4	5.8
	MR-3	0.43	37.7	20.3	14.4	88.2	10.7	24.8	8864.0	78.8	72.8	7.0
	MR-4	0.75	49.9	28.9	25.7	128.7	8.7	26.2	10637.3	122.8	77.2	8.9
Cathance River	CR-1	0.20	60.2	31.9	26.3	144.6	16.0	41.2	22346.9	229.9	17.2	4.0
	CR-2	0.20	42.6	23.6	16.4	100.7	14.0	33.6	13969.1	186.3	47.6	4.3
	CR-3	0.51	47.5	22.4	20.1	96.4	11.1	24.2	8405.3	94.1	77.8	7.1
	CR-5	0.79	46.5	28.6	26.7	121.9	14.9	26.8	11565.3	117.9	75.4	9.1
	CR-6	0.37	45.3	24.7	22.3	101.6	7.5	31.1	11044.9	102.6	60.8	4.2
	CR-7	0.86	50.7	29.1	24.6	144.0	6.7	29.8	16537.0	127.2	33.6	2.5
	CR-8	0.33	25.6	13.5	9.5	64.0	6.1	18.8	6053.2	37.8	48.1	1.7
Abagadasset River	AR-1	0.58	72.6	29.6	21.0	127.6	15.3	39.9	16647.0	104.1	39.3	4.1
	AR-2	0.59	57.8	30.6	25.5	121.0	16.3	32.9	12839.7	127.6	66.8	7.8
	AR-3	0.42	47.0	26.6	24.3	115.3	9.3	26.3	9584.5	101.3	79.9	6.5
Eastern River	ER-1	0.24	40.2	19.2	15.8	97.3	13.1	29.5	13813.2	135.4	49.8	3.4
	ER-2	0.42	42.1	21.2	21.2	94.8	12.8	31.5	12166.3	144.4	71.3	5.9
	ER-3	0.37	40.4	19.8	21.2	91.2	13.9	30.1	11956.2	137.3	71.6	4.9
	ER-4	0.47	48.1	24.8	21.8	107.3	11.7	33.7	13158.4	157.5	66.2	6.6
	ER-5	0.48	45.1	22.6	23.0	93.2	16.2	31.7	12418.4	116.3	54.1	4.0
Upper Kennebec River	UKR-1	0.98	84.6	58.7	111.2	185.8	28.8	66.7	24110.3	257.7	33.7	3.4
	UKR-2	0.53	175.1	78.3	80.5	400.5	34.6	145.0	48967.9	657.7	12.8	5.3
	UKR-3	0.62	90.6	41.5	19.9	198.8	17.8	78.8	27029.0	366.2	22.5	4.9
	UKR-4	0.96	102.5	49.9	284.7	248.5	36.4	79.4	37214.5	458.0	20.1	2.3
	UKR-5	0.40	49.9	27.4	25.4	113.8	9.0	35.0	11597.9	118.1	48.6	4.8
	UKR-6	0.65	50.5	27.5	24.6	39.8	11.6	31.8	11764.1	145.7	59.5	4.0
	UKR-7	0.48	46.6	26.1	27.3	102.3	10.8	29.3	10023.0	105.4	59.5	4.4
	UKR-8	1.82	218.5	98.4	94.3	474.6	92.1	184.2	72132.0	583.3	8.9	2.8
	UKR-9	0.64	73.2	40.9	46.6	172.9	20.5	52.7	21052.9	244.8	41.2	3.4
	UKR-10	0.62	66.6	35.1	38.8	154.4	21.2	45.7	20530.5	201.2	39.9	3.1
	UKR-11	0.19	44.2	23.4	29.7	87.0	18.8	33.3	14248.6	134.5	59.9	2.5
	UKR-12	0.21	30.8	15.7	10.0	56.1	7.6	23.3	10802.2	76.0	61.4	2.9
	UKR-13	0.67	63.7	32.7	32.3	155.3	22.8	39.5	17387.0	153.3	37.8	3.9
Merrymeeting Bay	MB-2	0.76	60.3	31.6	34.2	142.3	13.4	34.4	12811.6	136.8	33.6	3.4
	MB-3	1.13	145.1	71.1	61.2	440.5	31.0	89.3	46427.9	406.1	11.5	2.5
	MB-4	1.13	85.6	46.8	40.5	256.9	19.4	53.3	23039.4	224.6	21.1	3.5
	MB-5	1.31	106.0	64.4	66.4	343.7	34.9	58.8	32214.5	159.7	17.8	3.4
	MB-6	1.26	108.6	64.0	67.9	320.2	34.6	73.8	27869.9	344.9	13.3	1.8
	MB-7	0.59	53.6	27.0	27.0	132.4	9.2	30.2	13454.7	81.8	38.0	3.0
Lower Kennebec River	LKR-1	1.04	97.4	51.3	40.9	236.9	34.5	69.1	32386.1	217.8	19.7	3.5
	LKR-2	0.99	74.6	45.1	39.6	209.5	27.3	50.9	23333.9	170.8	31.9	3.8
	LKR-3	0.67	90.4	48.9	35.4	215.2	30.0	64.7	28630.4	242.2	22.5	2.9
	LKR-4	1.24	121.1	69.8	46.2	276.8	41.3	95.4	39313.1	176.9	12.7	2.0
	LKR-5	0.51	59.2	33.5	31.6	126.6	11.9	37.5	14437.1	88.4	40.6	5.0
	LKR-6	0.89	88.4	55.7	57.2	179.5	26.9	60.1	26261.3	138.6	19.5	3.1
	LKR-7	0.54	104.7	42.6	44.9	140.6	32.3	52.0	21963.6	115.8	30.7	4.9
	LKR-8	0.66	56.0	29.4	18.3	116.6	20.4	33.7	14924.3	63.7	49.4	4.5
	LKR-9	0.82	86.5	45.2	37.3	180.9	31.9	55.9	24452.2	118.8	29.5	4.2
	Mean	0.68	73.2	38.4	41.7	170.4	21.3	50.3	20950.8	188.6	40.9	4.1
	Min	0.19	25.6	13.5	9.5	39.8	6.1	18.8	6053.2	37.8	8.9	1.7
	Max	1.82	218.5	98.4	284.7	474.6	92.1	184.2	72132.0	657.7	79.9	9.1
	SD	0.37	41.4	19.6	49.0	109.7	15.5	34.8	13783.8	144.0	21.4	1.7

Table 2. Correlation matrix of Kennebec/Androscoggin data set. *significant, **very significant, ***extremely significant

	Cd	Cr	Cu	Pb	Zn	Sn	Ni	Mn	Fe	% Fines	LOI
Cd	XXX										
Cr	0.7456***	XXX									
Cu	0.8289***	0.9303***	XXX								
Pb	0.3281*	0.3746**	0.4389***	XXX							
Zn	0.7373***	0.7844***	0.8297***	0.3562*	XXX						
Sn	0.4450**	0.6611***	0.6266***	0.3970**	0.4942***	XXX					
Ni	0.4917***	0.8374***	0.7982***	0.4386**	0.6432***	0.7069***	XXX				
Mn	0.3760**	0.6045***	0.5921***	0.5019***	0.5490***	0.4576**	0.8074***	XXX			
Fe	0.4874***	0.7629***	0.7367***	0.4738***	0.6473***	0.7904***	0.8843***	0.7512***	XXX		
% Fines	0.6225***	0.7469***	0.7225***	0.4338**	0.6036***	0.4241**	0.6406***	0.5118***	0.5400***	XXX	
LOI	0.7491***	0.7923***	0.7740***	0.4766***	0.6868***	0.4564**	0.5450***	0.4720***	0.5117***	0.7114***	XXX

Note - n=47; Pb vs. fines and LOI correlations were not significant at n=47, removal of one outlier resulted in significant correlations improved Pb correlations with every variable. With the noted exception of Pb, the correlation matrix indicates that the trace metals are normally distributed in association with the fine grained and organic particles perhaps mediated by hydrous oxide coatings of Mn and Fe.

Grouping the stations by river segments and examining the summary statistics indicates that there is a clear and consistent geographic pattern exhibited by each of the seven trace metals (Table 3; Fig. 2). Trace metal concentrations are higher in the Upper Kennebec River (UKR), Merrymeeting Bay (MB) and Lower Kennebec River (LKR), the groupings that constitute the main stem of the system. Metal levels are uniformly lower in the four "local" Merrymeeting Bay tributaries, i.e. the Muddy (MR), Cathance (CR), Abagadasset (AR) and Eastern Rivers (ER).

An analysis to determine if the apparent differences in metal concentrations are statistically significant cannot be performed at the seven group level because MR and AR are represented by too few stations. These two small tributaries, together with CR, are located on the western side of Merrymeeting Bay. They have contiguous watersheds and have especially uniform trace metal loads with the standard errors of the means overlapping in each case save one (Cr between CR and AR)(Fig. 3, Table 3). Data from these three tributaries, therefore, can be grouped together to increase the power of statistical analysis. The new grouping is called western tributaries (WT). The means and standard errors of the resulting five groups are plotted in Fig.4.

A Kruskal-Wallis test, a nonparametric analysis of variance, for each metal across the five geographic groupings of stations indicates that there are very significant or extremely significant statistical differences between the levels of metals in the groups (Table 4). The nonparametric test is used because parametric analysis of variance assumes identical standard deviations. Bartlett's test suggests that there are the differences between standard deviations are significant in each case.

Table 4. The level of significance of differences in levels of each of the seven metals over the five geographic groups.

Metal	Significance Level
Cd	Very Significant
Cr	Extremely Significant
Cu	Extremely Significant
Pb	Extremely Significant
Zn	Extremely Significant
Sn	Very Significant
Ni	Extremely Significant

Table 3. Trace metal concentrations by subarea.

LOCATION	Fines	Cd	Cr	Cu	Pb	Zn	Sn	Ni
Muddy River	Mean	0.64	50.9	27.6	24.7	116.2	10.8	28.5
	Min	0.43	37.7	20.3	14.4	88.2	8.7	24.8
	Max	0.75	58.3	31.4	29.8	128.7	13.4	32.9
	SD	0.15	9.6	4.9	7.1	19.2	1.9	3.7
	SEM	0.07	4.8	2.5	3.5	9.6	1.0	1.8
Cathance River	Mean	0.46	45.5	24.8	20.8	110.5	10.9	29.4
	Min	0.20	25.6	13.5	9.5	64.0	6.1	18.8
	Max	0.86	60.2	31.9	26.7	144.6	16.0	41.2
	SD	0.27	10.4	6.0	6.2	28.7	4.2	7.1
	SEM	0.10	3.9	2.3	2.3	10.9	1.6	2.7
Abagadasset River	Mean	0.53	59.2	28.9	23.6	121.3	13.6	33.0
	Min	0.42	47.0	26.6	21.0	115.3	9.3	26.3
	Max	0.59	72.6	30.6	25.5	127.6	16.3	39.9
	SD	0.09	12.9	2.1	2.3	6.2	3.8	6.8
	SEM	0.05	7.4	1.2	1.3	3.6	2.2	3.9
Eastern River	Mean	0.40	43.2	21.5	20.6	96.7	13.5	31.3
	Min	0.24	40.2	19.2	15.8	91.2	11.7	29.5
	Max	0.48	48.1	24.8	23.0	107.3	16.2	33.7
	SD	0.10	3.4	2.2	2.8	6.3	1.7	1.6
	SEM	0.04	1.5	1.0	1.3	2.8	0.7	0.7
Upper Kennebec River	Mean	0.67	84.4	42.7	63.5	183.8	25.5	65.0
	Min	0.19	30.8	15.7	10.0	39.8	7.6	23.3
	Max	1.82	218.5	98.4	284.7	474.6	92.1	184.2
	SD	0.42	54.6	23.6	73.3	127.7	22.0	48.5
	SEM	0.12	15.1	6.5	20.3	35.4	6.1	13.4
Merrymeeting Bay	Mean	1.03	93.2	50.8	49.5	272.7	23.7	56.6
	Min	0.59	53.6	27.0	27.0	132.4	9.2	30.2
	Max	1.31	145.1	71.1	67.9	440.5	34.9	89.3
	SD	0.29	34.1	18.5	17.8	120.3	11.3	22.7
	SEM	0.12	13.9	7.6	7.3	49.1	4.6	9.3
Lower Kennebec River	Mean	0.82	86.5	46.8	39.0	186.9	28.5	57.7
	Min	0.51	56.0	29.4	18.3	116.6	11.9	33.7
	Max	1.24	121.1	69.8	57.2	276.8	41.3	95.4
	SD	0.24	20.9	11.9	10.7	53.3	8.5	18.3
	SEM	0.08	7.0	4.0	3.6	17.8	2.8	6.1

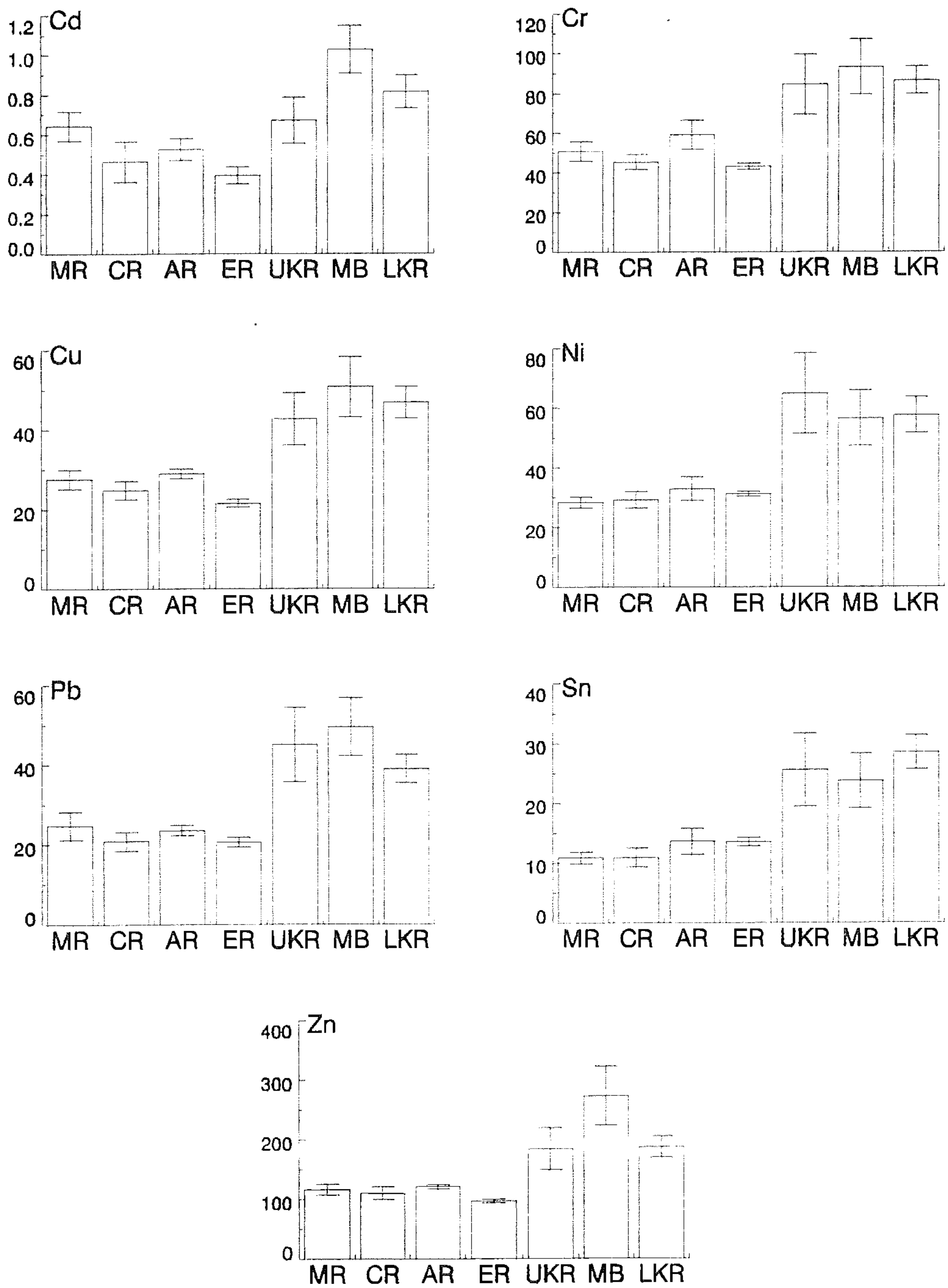

FIGURE 2

MEAN AND STANDARD ERROR OF METALS IN SEVEN RIVER SEGMENTS

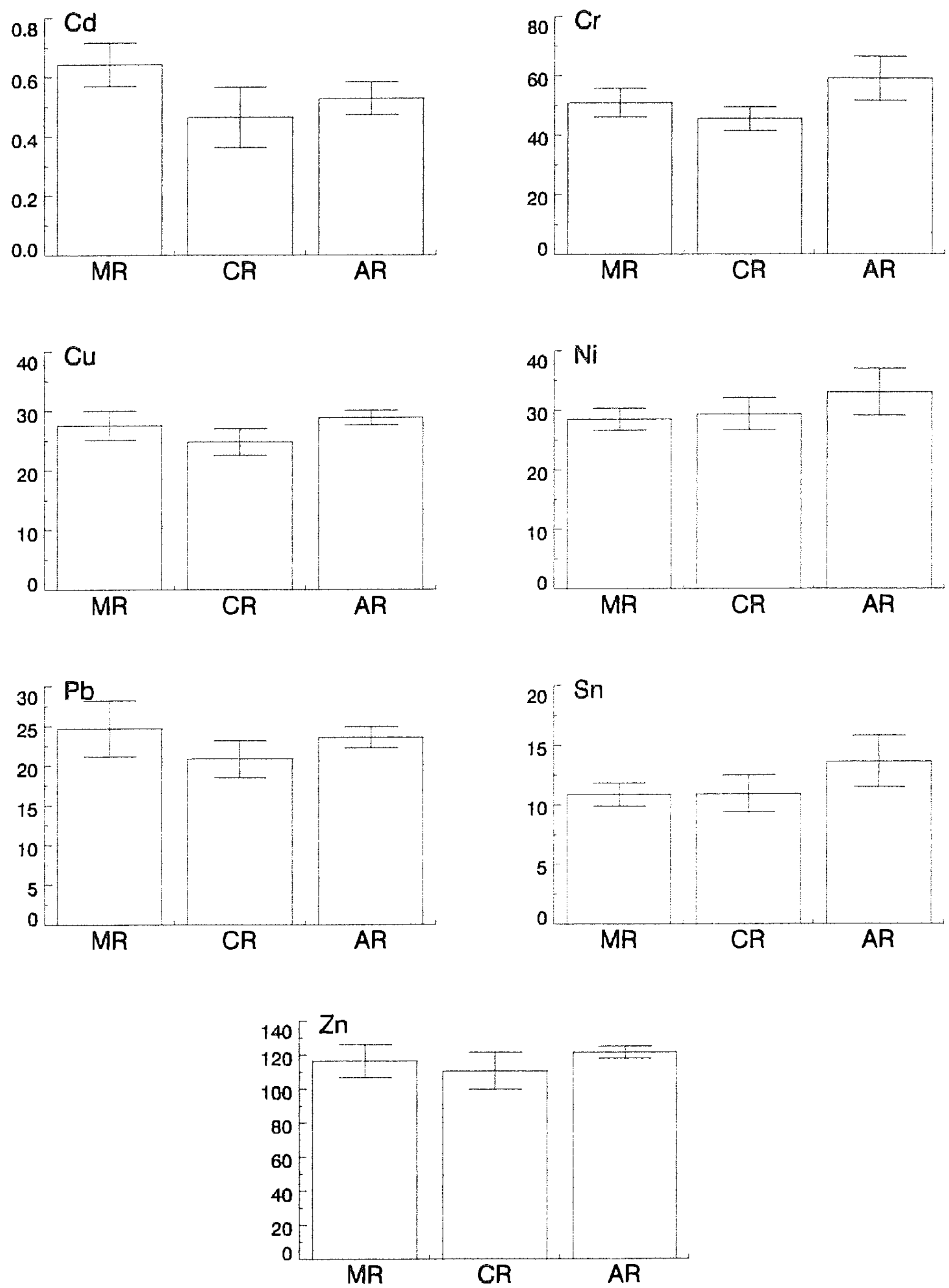

FIGURE 3

MEAN AND STANDARD ERROR OF METALS IN THE THREE WESTERN TRIBUTARIES OF MERRYMEETING BAY

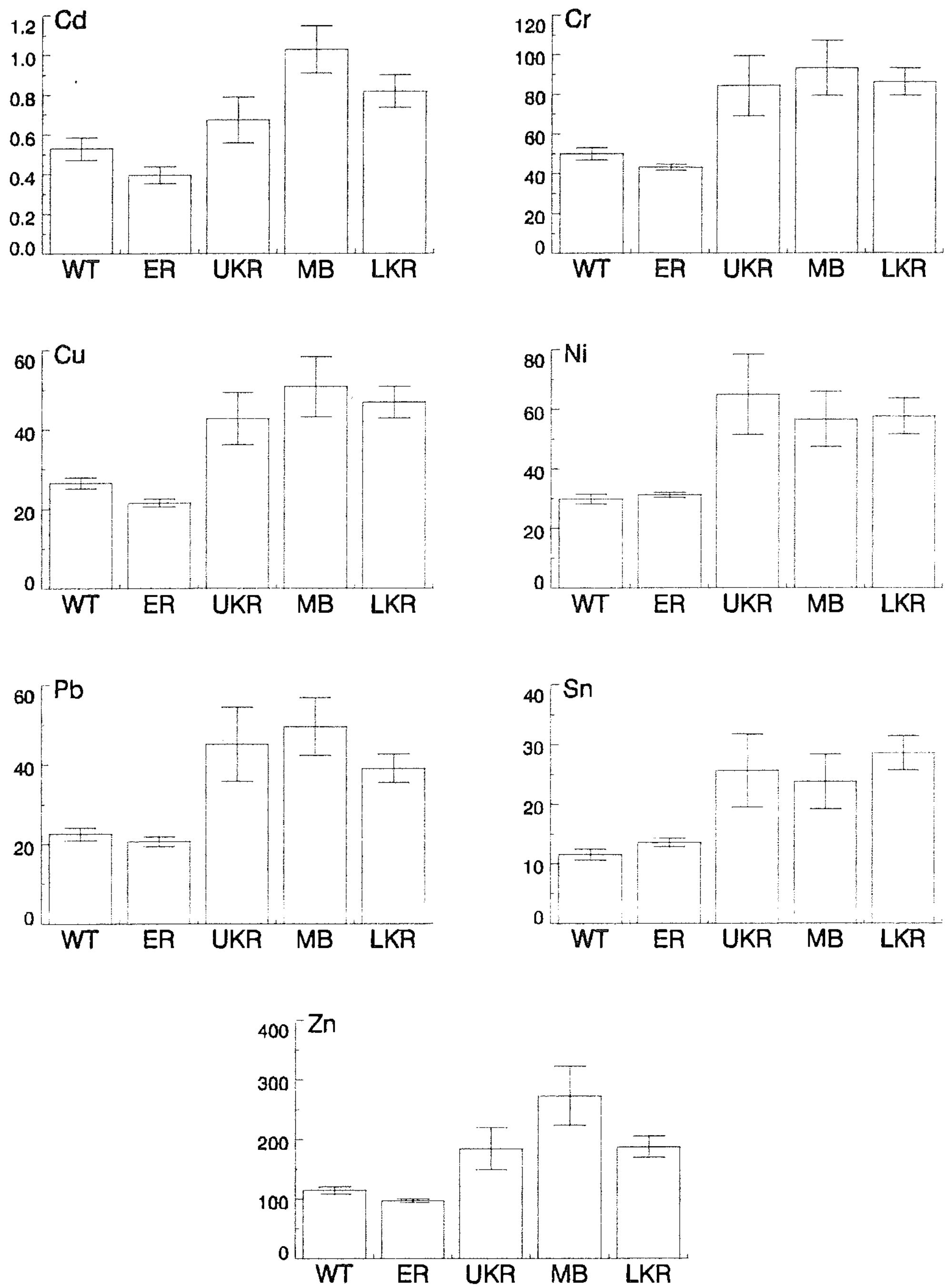

FIGURE 4
MEAN AND STANDARD ERROR OF METALS IN FIVE GEOGRAPHIC GROUPS

The results of Dunn's Multiple Comparisons Tests are presented in Table 5. This test examines the results of the Kruskal-Wallis tests to determine which contrasts between geographic groupings are responsible for the statistically significant results. In each case the significant differences are between one of the "local" tributaries, WT or ER, and one of the main stem groupings. To look at it another way, there is never a statistically significant difference detected between the "local" tributaries or between the main stem groupings.

A rank score analysis is applied to highlight the distributions of the metals over the entire study area. It this process, the stations are ranked for each metal from the highest concentration to the lowest (Tables 6-12). The results are presented in a geographical context in Figs. 5-11. Examination of the tables and figures indicates that there is considerable correspondence between the distribution of metals, i.e. a station with a high concentration of one metal is likely to have a high concentration of the other metals. In addition, the stations with the highest metal concentrations tend to be located along the main stem of the system, i.e. the Upper Kennebec River Channel, that western portion of Merrymeeting Bay, where Androscoggin River water enters, and in the Lower Kennebec River. With few exceptions, stations in the Western Tributaries and the Eastern River are in the third or fourth quartile of stations.

The data can be further reduced by summing the rankings across the seven metals (Table 13). For instance, Station UKR-8 in the Kennebec River just north of Swans Island is ranked number 1 for six of the seven metals and number 3 for the seventh. Summing these rankings results in a score of 9. Hence, we can conclude that station UKR-8 has the highest trace metal burden of the 47 stations. Station MB-6 with a sum rank score of 33 is second, LKR-4 with a total score of 34 is third, and so on through the 47 stations. The geographic distribution of these rankings by quartile is presented in Fig.12.

Several important insights are revealed by this summed rank score analysis. The 20 highest ranked stations are located in UKR, MB and LKR (Table 13). Furthermore, the most highly ranked stations among these are found in the UKR above Swans Island, in the confluence of the Androscoggin River and MB, and in the upper reaches of the LKR (Fig. 12). Stations in the minor tributaries are generally ranked in the third and fourth quartile. In fact, four of the five ER stations and four of the seven CR stations are in the lowest quartile. Stations from UKR, MB and LKR ranked in the lower two quartiles are located at sheltered sites.

Table 5. Results of Dunn's Multiple Comparisons Tests. * indicates significance at the <0.05 level; ** at the <0.01 level.

Metal	Comparison	Significance Level
Cd	WT vs. MB	*
	ER vs. MB	**
	ER vs. LKR	*
Cr	WT vs. MB	*
	WT vs. LKR	*
	ER vs. MB	**
	ER vs. LKR	**
Cu	WT vs. LKR	*
	ER vs. UKR	*
	ER vs. MB	**
	ER vs. LKR	**
Pb	WT vs. MB	*
	WT vs. LKR	*
	ER vs. MB	*
	ER vs. LKR	*
Zn	WT vs. MB	*
	ER vs. MB	**
	ER vs. LKR	*
Sn	WT vs. LKR	**
Ni	WT vs. UKR	*
	WT vs. MB	*
	WT vs. LKR	**

Table 6. Stations ranked by the concentration of Cd.

Rank	Station	Cd Conc.	Quartile
1	UKR-8	1.820	1
2	MB-5	1.309	1
3	MB-6	1.263	1
4	LKR-4	1.236	1
5	MB-3	1.130	1
6	MB-4	1.128	1
7	LKR-1	1.036	1
8	LKR-2	0.991	1
9	UKR-1	0.976	1
10	UKR-4	0.955	1
11	LKR-6	0.892	1
12	CR-7	0.863	1
13	LKR-9	0.824	2
14	CR-5	0.789	2
15	MB-2	0.756	2
16	MR-4	0.751	2
17	MR-1	0.739	2
18	UKR-13	0.675	2
19	LKR-3	0.671	2
20	LKR-8	0.658	2
21	UKR-6	0.652	2
22	MR-2	0.648	2
23	UKR-9	0.636	2
24	UKR-3	0.622	2
25	UKR-10	0.622	2
26	MB-7	0.589	3
27	AR-2	0.588	3
28	AR-1	0.575	3
29	LKR-7	0.544	3
30	UKR-2	0.531	3
31	LKR-5	0.507	3
32	CR-3	0.505	3
33	UKR-7	0.484	3
34	ER-5	0.481	3
35	ER-4	0.465	3
36	MR-3	0.433	3
37	ER-2	0.421	4
38	AR-3	0.418	4
39	UKR-5	0.395	4
40	ER-3	0.369	4
41	CR-6	0.367	4
42	CR-8	0.328	4
43	ER-1	0.241	4
44	UKR-12	0.205	4
45	CR-2	0.200	4
46	CR-1	0.198	4
47	UKR-11	0.189	4

Table 7. Stations ranked by the concentration of Cr.

Rank	Station	Cr Conc	Quartile
1	UKR-8	218.54	1
2	UKR-2	175.08	1
3	MB-3	145.13	1
4	LKR-4	121.10	1
5	MB-6	108.57	1
6	MB-5	106.01	1
7	LKR-7	104.66	1
8	UKR-4	102.54	1
9	LKR-1	97.36	1
10	UKR-3	90.58	1
11	LKR-3	90.40	1
12	LKR-6	88.36	1
13	LKR-9	86.54	2
14	MB-4	85.64	2
15	UKR-1	84.57	2
16	LKR-2	74.64	2
17	UKR-9	73.20	2
18	AR-1	72.65	2
19	UKR-10	66.59	2
20	UKR-13	63.68	2
21	MB-2	60.33	2
22	CR-1	60.23	2
23	LKR-5	59.16	2
24	MR-2	58.30	2
25	AR-2	57.80	3
26	MR-1	57.58	3
27	LKR-8	55.95	3
28	MB-7	53.58	3
29	CR-7	50.71	3
30	UKR-6	50.45	3
31	MR-4	49.94	3
32	UKR-5	49.90	3
33	ER-4	48.13	3
34	CR-3	47.48	3
35	AR-3	47.05	3
36	UKR-7	46.61	3
37	CR-5	46.53	4
38	CR-6	45.33	4
39	ER-5	45.12	4
40	UKR-11	44.19	4
41	CR-2	42.56	4
42	ER-2	42.13	4
43	ER-3	40.41	4
44	ER-1	40.22	4
45	MR-3	37.71	4
46	UKR-12	30.80	4
47	CR-8	25.61	4

Table 8. Stations ranked by the concentration of Cu.

Rank	Station	Cu Conc	Quartile
1	UKR-8	98.43	1
2	UKR-2	78.28	1
3	MB-3	71.13	1
4	LKR-4	69.76	1
5	MB-5	64.38	1
6	MB-6	63.98	1
7	UKR-1	58.69	1
8	LKR-6	55.74	1
9	LKR-1	51.32	1
10	UKR-4	49.85	1
11	LKR-3	48.89	1
12	MB-4	46.78	1
13	LKR-9	45.19	2
14	LKR-2	45.14	2
15	LKR-7	42.64	2
16	UKR-3	41.51	2
17	UKR-9	40.95	2
18	UKR-10	35.14	2
19	LKR-5	33.52	2
20	UKR-13	32.67	2
21	CR-1	31.92	2
22	MB-2	31.64	2
23	MR-2	31.36	2
24	AR-2	30.61	2
25	MR-1	29.66	3
26	AR-1	29.59	3
27	LKR-8	29.39	3
28	CR-7	29.11	3
29	MR-4	28.91	3
30	CR-5	28.59	3
31	UKR-6	27.50	3
32	UKR-5	27.41	3
33	MB-7	27.03	3
34	AR-3	26.56	3
35	UKR-7	26.13	3
36	ER-4	24.80	3
37	CR-6	24.65	4
38	CR-2	23.63	4
39	UKR-11	23.37	4
40	ER-5	22.55	4
41	CR-3	22.44	4
42	ER-2	21.16	4
43	MR-3	20.34	4
44	ER-3	19.78	4
45	ER-1	19.24	4
46	UKR-12	15.70	4
47	CR-8	13.45	4

Table 9. Stations ranked by the concentration of Pb.

Rank	Station	Pb conc.	Quartile
1	UKR-4	284.68	1
2	UKR-1	111.25	1
3	UKR-8	94.27	1
4	UKR-2	80.47	1
5	MB-6	67.89	1
6	MB-5	66.40	1
7	MB-3	61.22	1
8	LKR-6	57.23	1
9	UKR-9	46.60	1
10	LKR-4	46.22	1
11	LKR-7	44.89	1
12	LKR-1	40.91	1
13	MB-4	40.52	2
14	LKR-2	39.59	2
15	UKR-10	38.85	2
16	LKR-9	37.29	2
17	LKR-3	35.38	2
18	MB-2	34.17	2
19	UKR-13	32.30	2
20	LKR-5	31.55	2
21	MR-1	29.81	2
22	UKR-11	29.72	2
23	MR-2	28.83	2
24	UKR-7	27.28	2
25	MB-7	27.03	3
26	CR-5	26.67	3
27	CR-1	26.34	3
28	MR-4	25.73	3
29	AR-2	25.46	3
30	UKR-5	25.39	3
31	CR-7	24.58	3
32	UKR-6	24.57	3
33	AR-3	24.29	3
34	ER-5	23.03	3
35	CR-6	22.27	3
36	ER-4	21.77	3
37	ER-2	21.19	4
38	ER-3	21.19	4
39	AR-1	20.97	4
40	CR-3	20.05	4
41	UKR-3	19.87	4
42	LKR-8	18.28	4
43	CR-2	16.45	4
44	ER-1	15.76	4
45	MR-3	14.40	4
46	UKR-12	10.05	4
47	CR-8	9.54	4

Table 10. Stations ranked by concentration of Zn.

Rank	Station	Zn conc	Quartile
1	UKR-8	474.61	1
2	MB-3	440.52	1
3	UKR-2	400.47	1
4	MB-5	343.71	1
5	MB-6	320.15	1
6	LKR-4	276.77	1
7	MB-4	256.92	1
8	UKR-4	248.46	1
9	LKR-1	236.85	1
10	LKR-3	215.24	1
11	LKR-2	209.47	1
12	UKR-3	198.84	1
13	UKR-1	185.79	2
14	LKR-9	180.88	2
15	LKR-6	179.49	2
16	UKR-9	172.91	2
17	UKR-13	155.29	2
18	UKR-10	154.41	2
19	CR-1	144.59	2
20	CR-7	143.99	2
21	MB-2	142.32	2
22	LKR-7	140.55	2
23	MB-7	132.39	2
24	MR-4	128.70	3
25	MR-2	128.70	3
26	AR-1	127.58	3
27	LKR-5	126.63	3
28	CR-5	121.86	3
29	AR-2	121.03	3
30	MR-1	119.36	3
31	LKR-8	116.56	3
32	AR-3	115.28	3
33	UKR-5	113.77	3
34	ER-4	107.28	3
35	UKR-7	102.25	3
36	CR-6	101.64	3
37	CR-2	100.71	4
38	ER-1	97.29	4
39	CR-3	96.41	4
40	ER-2	94.78	4
41	ER-5	93.16	4
42	ER-3	91.23	4
43	MR-3	88.21	4
44	UKR-11	86.96	4
45	CR-8	63.97	4
46	UKR-12	56.12	4
47	UKR-6	39.76	4

Table 11. Stations ranked by concentration of Sn.

Rank	Station	Sn Conc	Quartile
1	UKR-8	92.13	1
2	LKR-4	41.34	1
3	UKR-4	36.37	1
4	MB-5	34.89	1
5	UKR-2	34.61	1
6	MB-6	34.59	1
7	LKR-1	34.52	1
8	LKR-7	32.28	1
9	LKR-9	31.90	1
10	MB-3	31.04	1
11	LKR-3	30.04	1
12	UKR-1	28.84	1
13	LKR-2	27.30	2
14	LKR-6	26.87	2
15	UKR-13	22.78	2
16	UKR-10	21.23	2
17	UKR-9	20.46	2
18	LKR-8	20.38	2
19	MB-4	19.38	2
20	UKR-11	18.83	2
21	UKR-3	17.78	2
22	AR-2	16.26	2
23	ER-5	16.17	2
24	CR-1	15.99	2
25	AR-1	15.32	3
26	CR-5	14.91	3
27	CR-2	14.03	3
28	ER-3	13.90	3
29	MR-1	13.43	3
30	MB-2	13.36	3
31	ER-1	13.07	3
32	ER-2	12.82	3
33	LKR-5	11.95	3
34	ER-4	11.69	3
35	UKR-6	11.61	3
36	CR-3	11.14	3
37	UKR-7	10.76	4
38	MR-3	10.69	4
39	MR-2	10.55	4
40	AR-3	9.29	4
41	MB-7	9.16	4
42	UKR-5	9.03	4
43	MR-4	8.73	4
44	UKR-12	7.62	4
45	CR-6	7.52	4
46	CR-7	6.73	4
47	CR-8	6.11	4

Table 12. Stations ranked by the concentration of Ni.

Rank	Station	Ni Conc	Quartile
1	UKR-8	184.16	1
2	UKR-4	145.00	1
3	MB-6	95.35	1
4	LKR-4	89.30	1
5	LKR-7	79.35	1
6	UKR-1	78.80	1
7	UKR-2	73.76	1
8	LKR-9	69.14	1
9	LKR-2	66.68	1
10	MB-3	64.71	1
11	UKR-13	60.05	1
12	MB-5	58.82	1
13	LKR-6	55.90	2
14	LKR-1	53.27	2
15	UKR-10	52.72	2
16	AR-2	51.99	2
17	LKR-3	50.88	2
18	LKR-8	45.66	2
19	MB-4	41.16	2
20	CR-5	39.92	2
21	UKR-9	39.47	2
22	CR-2	37.54	2
23	LKR-5	35.04	2
24	UKR-3	34.43	2
25	ER-4	33.73	3
26	ER-1	33.68	3
27	UKR-7	33.59	3
28	UKR-12	33.29	3
29	AR-1	32.89	3
30	MR-1	32.87	3
31	CR-8	31.76	3
32	MB-7	31.66	3
33	AR-3	31.51	3
34	CR-3	31.12	3
35	ER-5	30.18	3
36	MB-2	30.06	3
37	UKR-5	30.06	3
38	UKR-11	29.79	4
39	MR-3	29.52	4
40	UKR-6	29.34	4
41	ER-3	26.82	4
42	ER-2	26.27	4
43	CR-1	26.19	4
44	MR-4	24.85	4
45	MR-2	24.22	4
46	CR-7	23.34	4
47	CR-6	18.79	4

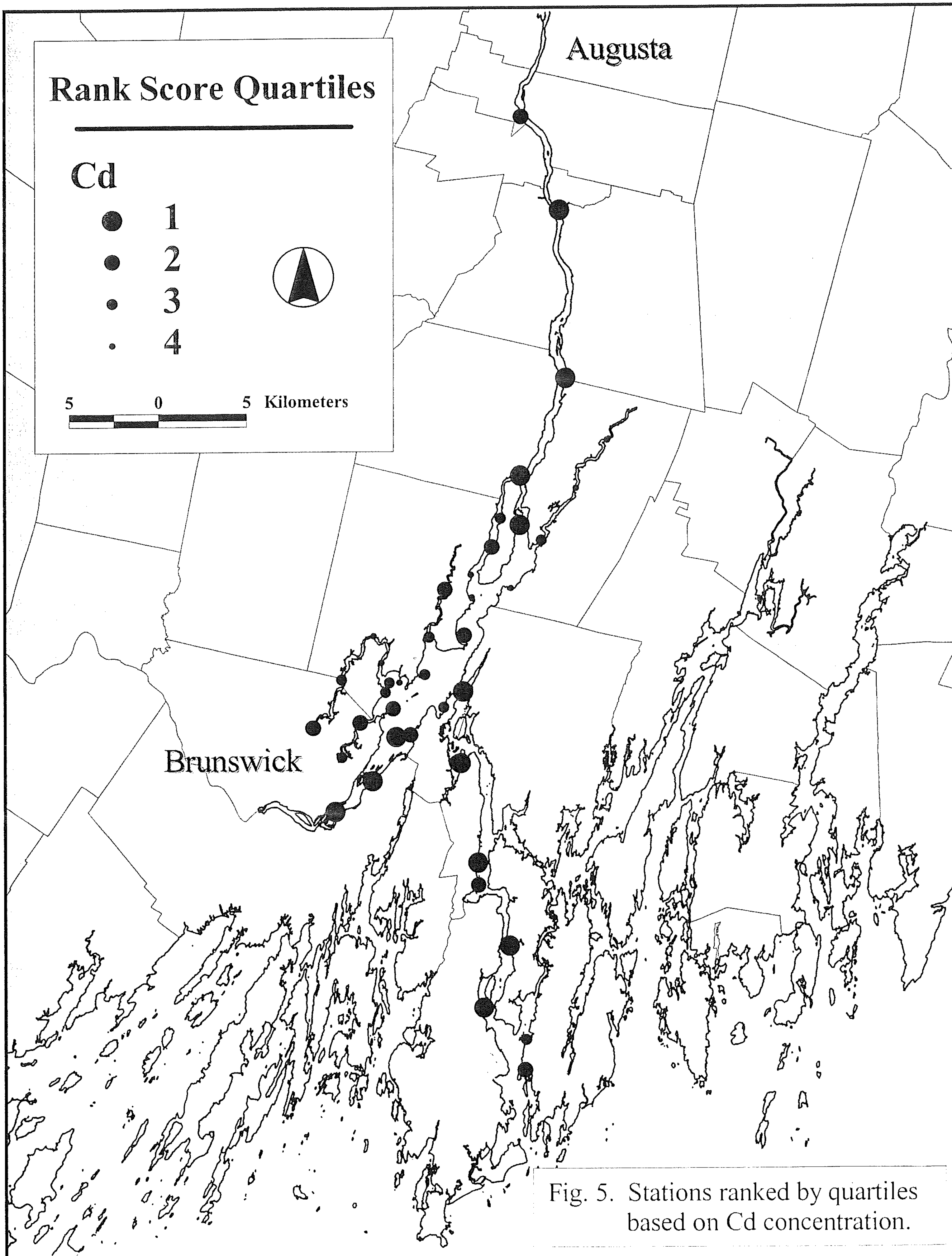

Fig. 5. Stations ranked by quartiles based on Cd concentration.

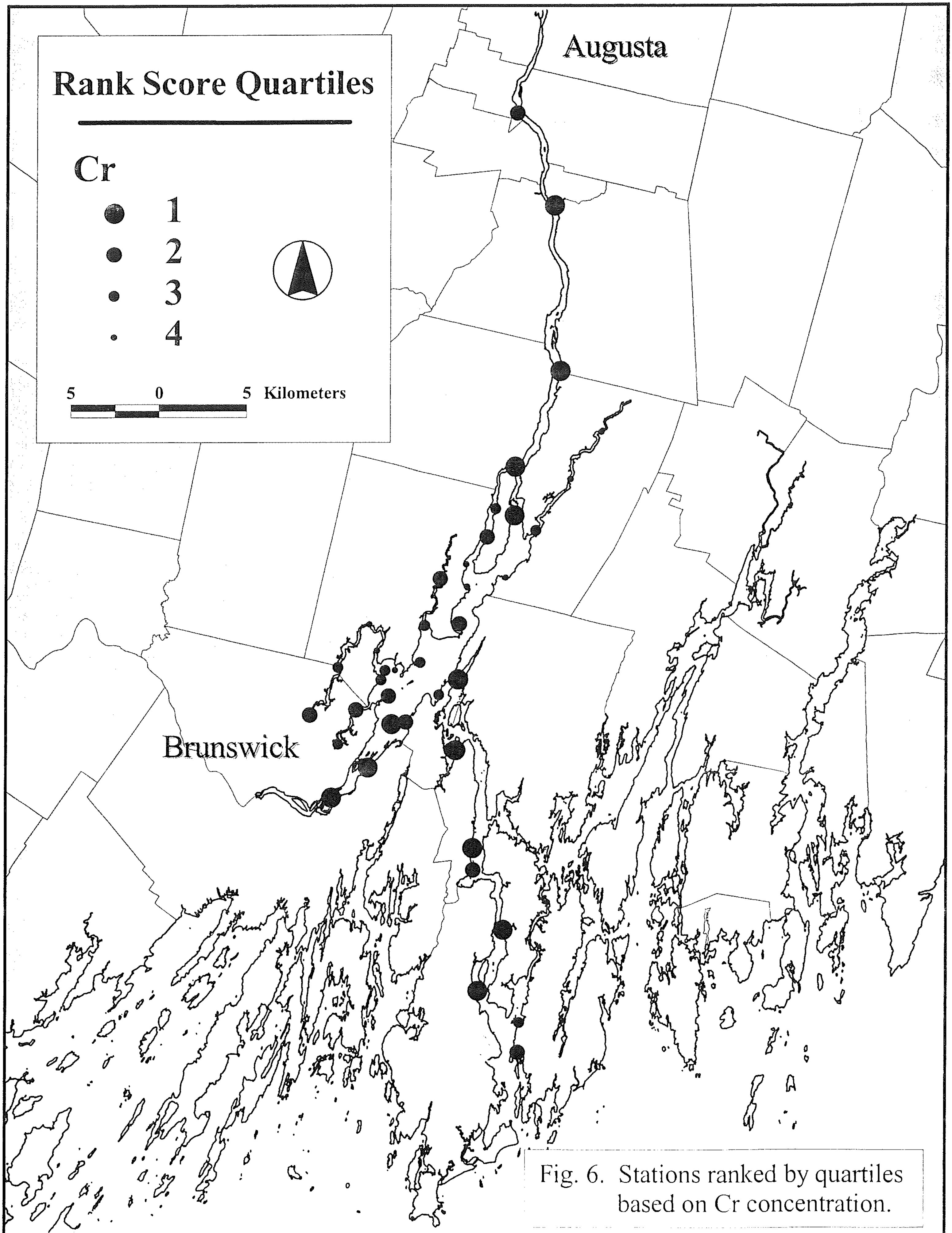

Fig. 6. Stations ranked by quartiles based on Cr concentration.

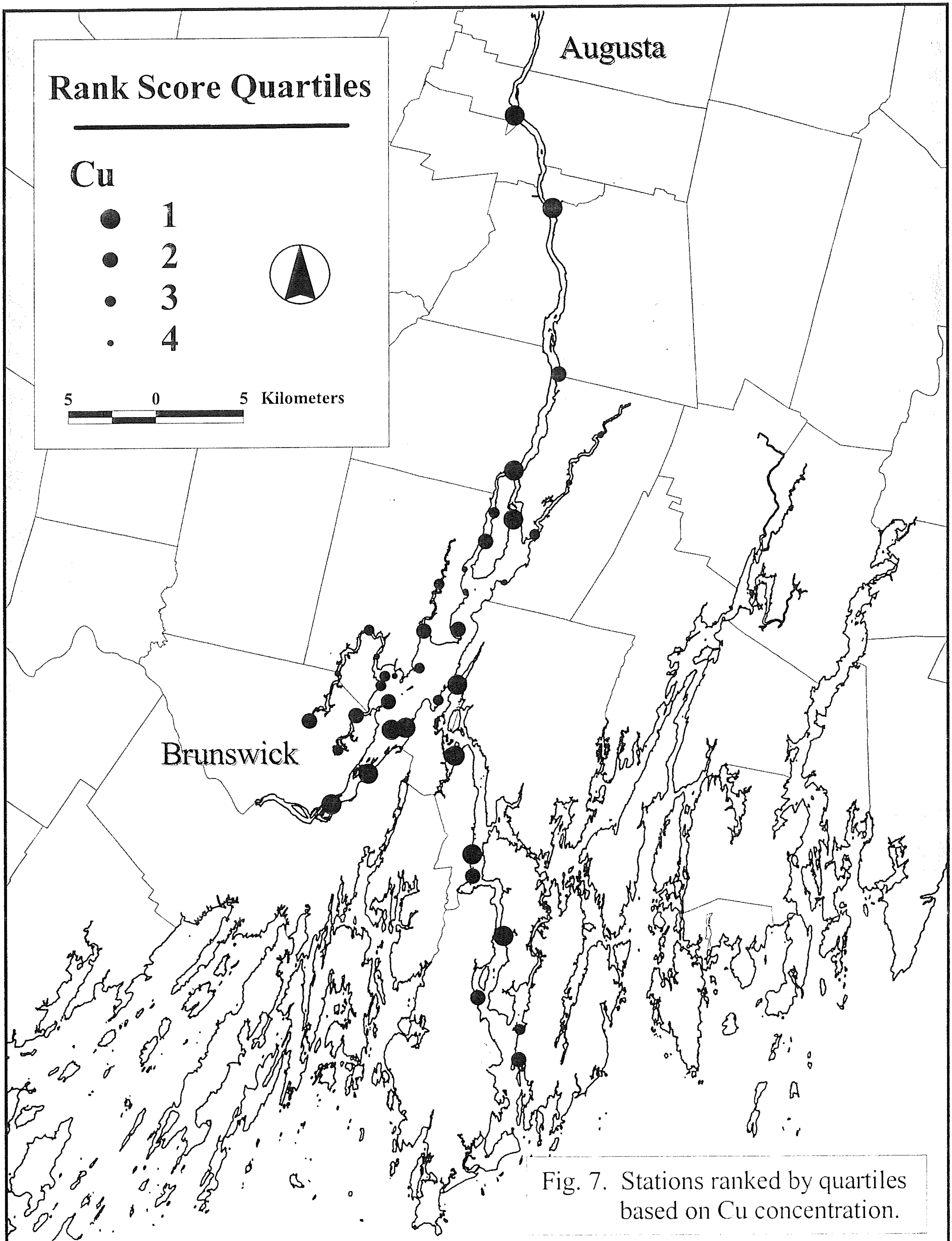

Fig. 7. Stations ranked by quartiles based on Cu concentration.

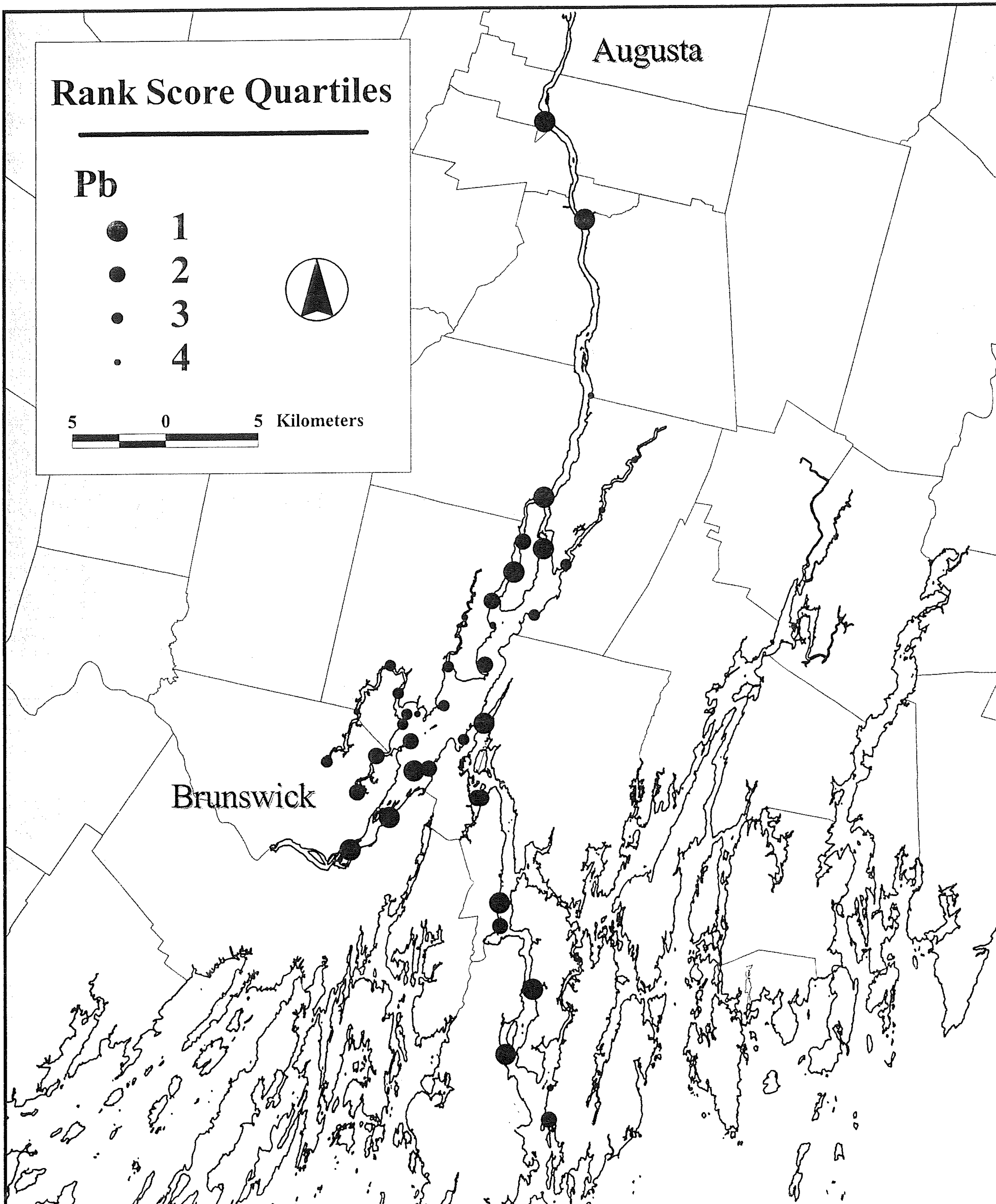

Fig. 8. Stations ranked by quartiles based on Pb concentration.

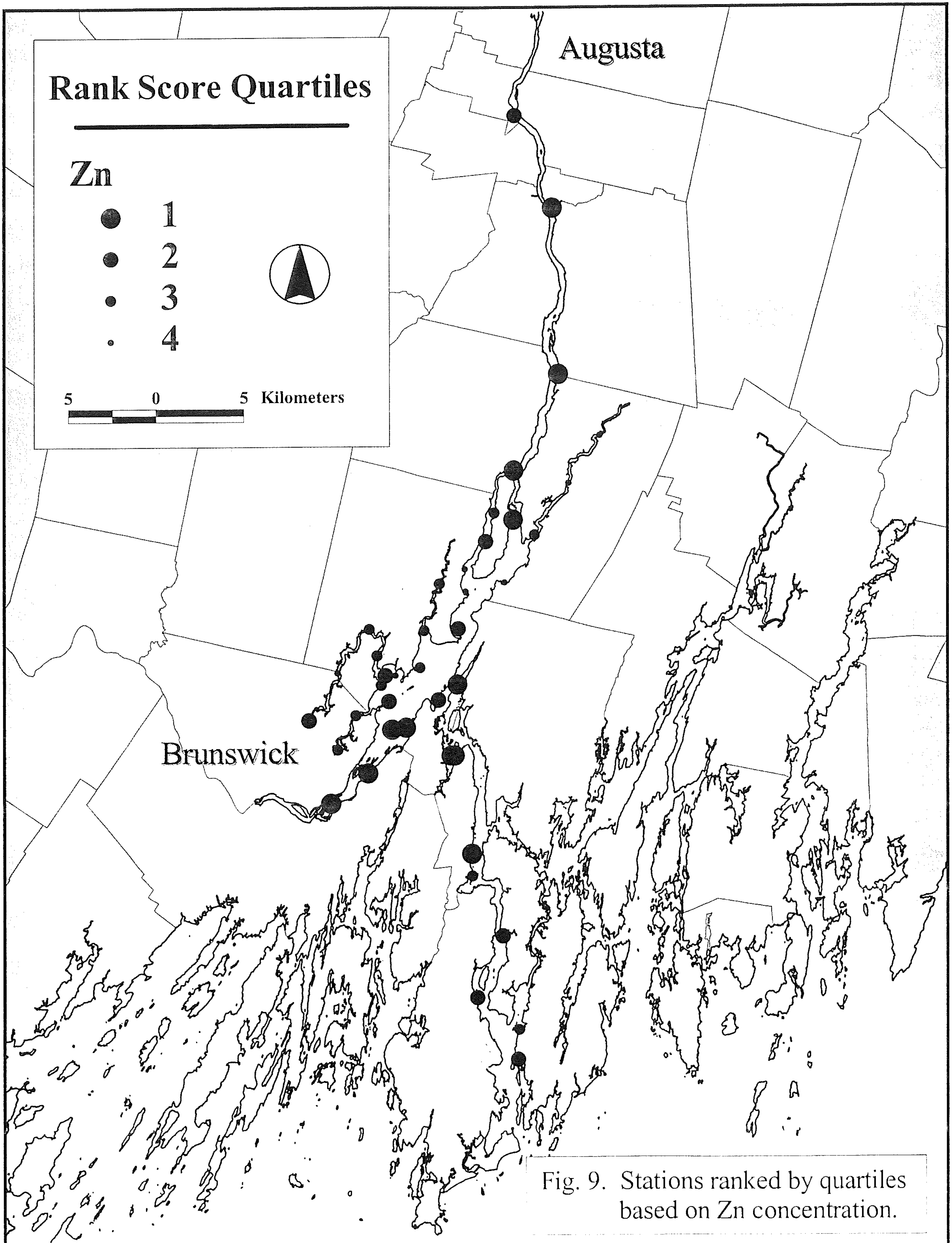

Fig. 9. Stations ranked by quartiles based on Zn concentration.

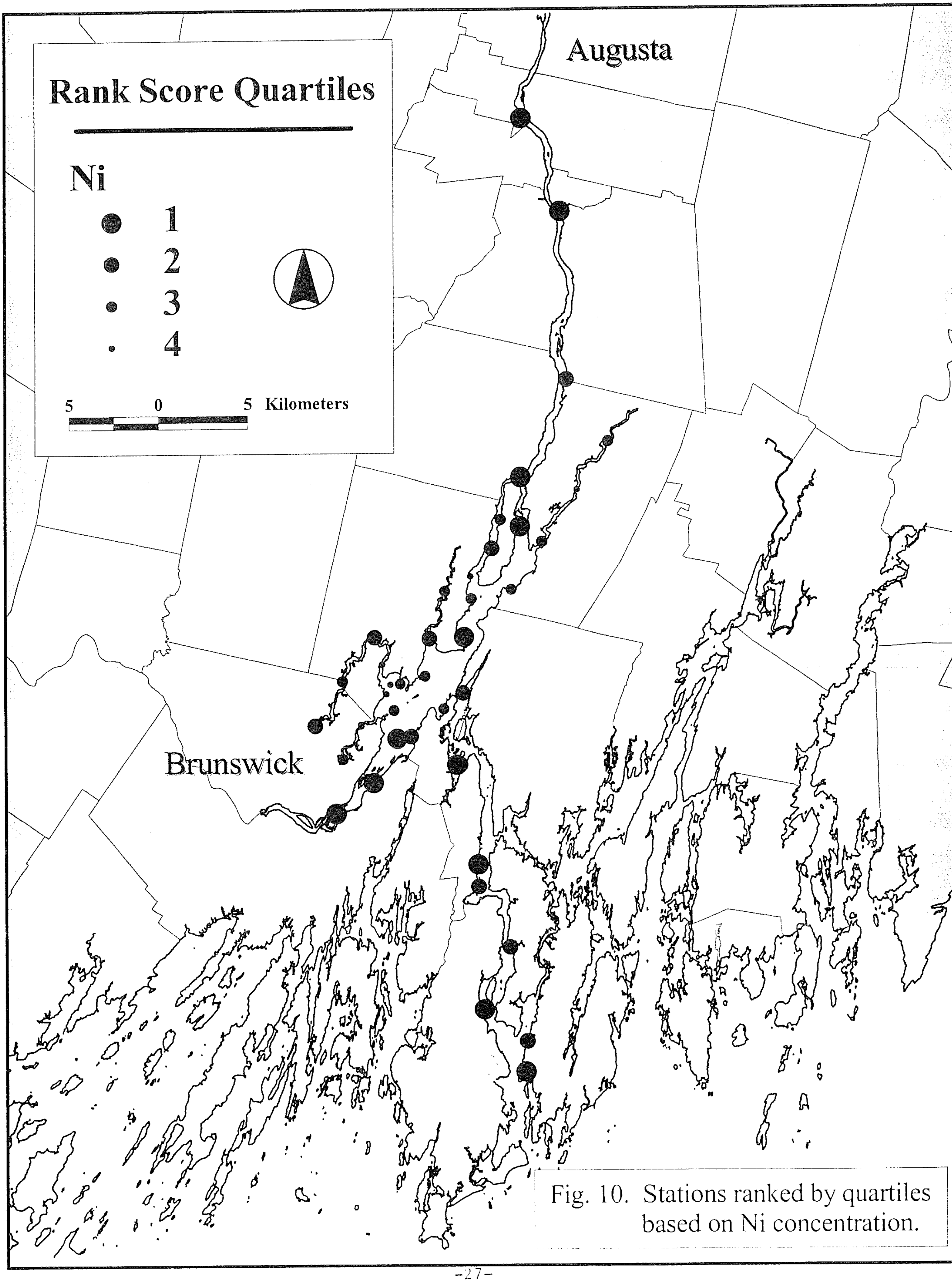

Fig. 10. Stations ranked by quartiles based on Ni concentration.

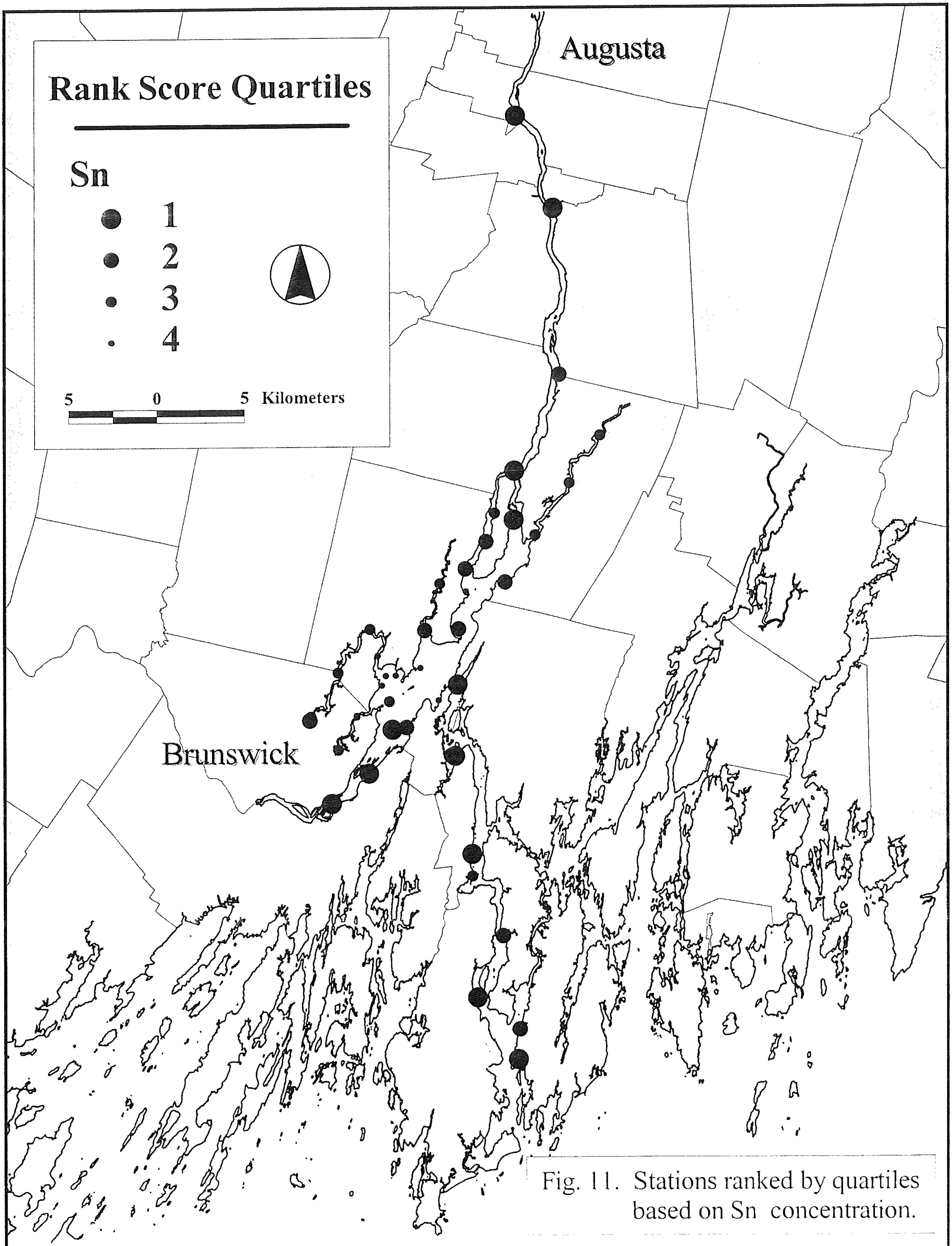

Fig. 11. Stations ranked by quartiles based on Sn concentration.

Table 13. Stations inversely ranked by their cumulative rank scores.

Total Rank	Station	Cd Rank	Cr Rank	Cu Rank	Pb Rank	Zn Rank	Sn Rank	Ni Rank	Rank Sum	Quartile
1	UKR-8	1	1	1	3	1	1	1	9	1
2	MB-6	3	5	6	5	5	6	3	33	1
3	LKR-4	4	4	4	10	6	2	4	34	1
4	MB-5	2	6	5	6	4	4	12	39	1
5	MB-3	5	3	3	7	2	10	10	40	1
6	UKR-4	10	8	10	1	8	3	2	42	1
7	UKR-2	30	2	2	4	3	5	7	53	1
8	UKR-1	9	15	7	2	13	12	6	64	1
9	LKR-1	7	9	9	12	9	7	14	67	1
10	LKR-6	11	12	8	8	15	14	13	81	1
11	LKR-2	8	16	14	14	11	13	9	85	1
12	LKR-9	13	13	13	16	14	9	8	86	1
13	MB-4	6	14	12	13	7	19	19	90	2
14	LKR-3	19	11	11	17	10	11	17	96	2
15	LKR-7	29	7	15	11	22	8	5	97	2
16	UKR-9	23	17	17	9	16	17	21	120	2
17	UKR-13	18	20	20	19	17	15	11	120	2
18	UKR-10	25	19	18	15	18	16	15	126	2
19	UKR-3	24	10	16	41	12	21	24	148	2
20	MB-2	15	21	22	18	21	30	36	163	2
21	AR-2	27	25	24	29	29	22	16	172	2
22	LKR-5	31	23	19	20	27	33	23	176	2
23	MR-1	17	26	25	21	30	29	30	178	2
24	CR-5	14	37	30	26	28	26	20	181	2
25	LKR-8	20	27	27	42	31	18	18	183	3
26	AR-1	28	18	26	39	26	25	29	191	3
27	MR-2	22	24	23	23	25	39	45	201	3
28	CR-1	46	22	21	27	19	24	43	202	3
29	MB-7	26	28	33	25	23	41	32	208	3
30	CR-7	12	29	28	31	20	46	46	212	3
31	MR-4	16	31	29	28	24	43	44	215	3
32	UKR-7	33	36	35	24	35	37	27	227	3
33	ER-4	35	33	36	36	34	34	25	233	3
34	UKR-6	21	30	31	32	47	35	40	236	3
35	AR-3	38	35	34	33	32	40	33	245	3
36	UKR-5	39	32	32	30	33	42	37	245	3
37	ER-5	34	39	40	34	41	23	35	246	4
38	UKR-11	47	40	39	22	44	20	38	250	4
39	CR-2	45	41	38	43	37	27	22	253	4
40	CR-3	32	34	41	40	39	36	34	256	4
41	ER-1	43	44	45	44	38	31	26	271	4
42	ER-2	37	42	42	37	40	32	42	272	4
43	ER-3	40	43	44	38	42	28	41	276	4
44	CR-6	41	38	37	35	36	45	47	279	4
45	MR-3	36	45	43	45	43	38	39	289	4
46	UKR-12	44	46	46	46	46	44	28	300	4
47	CR-8	42	47	47	47	45	47	31	306	4

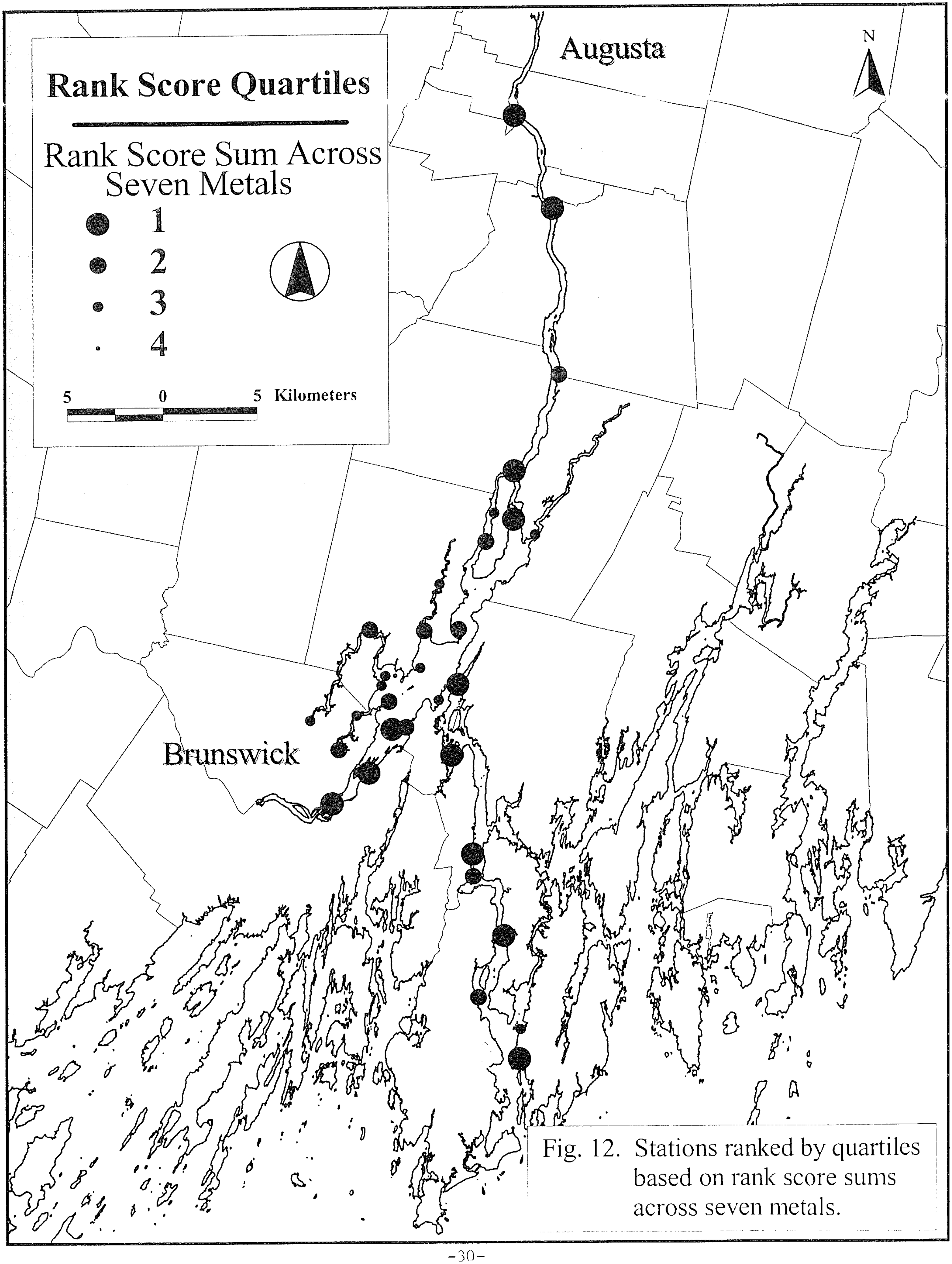

Fig. 12. Stations ranked by quartiles based on rank score sums across seven metals.

COMPARISON WITH OTHER STUDIES

Comparisons between studies are often difficult due to differences in sampling techniques, analytical methodology and documentation. Nevertheless, even with the limitations, valuable insights can be discovered and the effort is usually rewarding. In the present case, there are a small number of recent studies that can be utilized. An initial observation is that, since the studies are all relatively recent, temporal comparisons would have little meaning.

The results, or selected results, of five studies are summarized in Table 14. Most of the included numbers represent means. The reader is reminded that there are variances around these mean values. The first three studies listed employ very comparable methodologies.

The first data set presented in Table 14 includes the mean concentrations of seven metals in the seven subregions of the present study. The previously noted concentration differences between the four smaller tributaries and the main stem regions are obvious. The results of Getchell (2002) from the nearby Boothbay region are included as a baseline. Her Gulf of Maine stations were taken 2-8 kilometers off Cape Newagen. Although no sites downwind of a continent are unimpacted by contaminants, these sites are isolated from direct inputs and may be considered to represent regional background contaminant levels. Her Boothbay and Inner Boothbay Harbor stations represent sites along a gradient of presumed increasing contaminant input. Comparison of the present results with Getchell's reveals that, with one exception, samples for the Kennebec/Androscoggin system contains elevated levels of metals. Zn appears to be especially elevated. The one exception is Pb that exhibits concentrations in the four small Merrymeeting Bay tributaries that are below our chosen Gulf of Maine background level.

There is good correspondence between the present results and those of Larsen and Gaudette (1995). Stations 23-25 of Larsen and Gaudette (1995) are located in the lower Kennebec River and in each case the range of values reported for these stations bracket the mean values reported for the LKR grouping in the present study. These authors had reported that metal levels in the region, especially in the main stem of the Kennebec estuary, were elevated above pre-industrial levels.

Results from the FOMB/DEP study are in general agreement with the present study for the two metals that were analyzed in common. Pb levels are near or below the Gulf of Maine baseline and Zn levels are in agreement for similar areas; for instance, in the Muddy River 127.9 vs. 116.2 and in the Abagadasset River 114.4 vs. 121.3. The FOMB/DEP study is still in production. Once it is complete with detailed methodology and specific sampling sites, it would be productive to do more thorough comparisons of these and other parameters.

Chilcote and Waterfield (1995) sampled 14 stations in the Merrymeeting Bay area. Because of the extremely sandy nature of their samples, and basic differences in methodology, we are not able to compare results.

Table 14. Comparisons of various recent trace metal studies in the Merrymeeting Bay Region

This Study - normalized data, means of several samples

	Cd	Cr	Cu	Pb	Zn	Sn	Ni
Muddy River	0.64	50.8	27.6	24.7	116.2	10.8	28.5
Cathance River	0.46	45.5	24.8	20.8	110.4	10.9	29.4
Abagadasset River	0.53	59.2	28.9	23.6	121.3	13.6	33.0
Eastern River	0.40	43.2	21.5	20.6	96.8	13.5	31.3
Upper Kennebec River	0.67	84.4	42.7	63.5	183.8	25.5	65.0
Merrymeeting Bay	1.03	93.2	50.8	49.5	272.7	23.7	56.6
Lower Kennebec River	0.82	86.5	46.8	39.0	186.9	28.5	57.7

Getchell (2002) - normalized data, means of several samples

	Cd	Cr	Cu	Pb	Zn	Sn	Ni
Gulf of Maine	0.43	-	14	29	55	-	-
Booth Bay	1.4	-	19	42	72	-	-
Inner Boothbay Harbor	2.7	-	76	102	143	-	-

Larsen and Gaudette (1995) - normalized data

	Cd	Cr	Cu	Pb	Zn	Sn	Ni
Station 23 - Below Bath	0.77	62.5	37.0	35.2	137.7	25.2	42.7
Station 24 - Sasonoa R.	0.71	71.0	58.6	55.9	173.3	32.7	32.8
Station 25 - Whiskeag Creek	1.32	97.0	52.2	32.6	286.8	56.8	71.4
Station 26 - Merrymeeting Bay	0.71	54.1	36.0	42.6	139.8	26.4	27.1

FOMB/DEP (1999) - normalization unknown, means of three samples

	Cd	Cr	Cu	Pb	Zn	Sn	Ni
Abagadasset River	-	-	-	26.5	114.4	-	-
Androscoggin River	-	-	-	21.2	110.1	-	-
Kennebec River	-	-	-	21.8	94.8	-	-
Muddy River	-	-	-	31.9	127.9	-	-
Swans Island	-	-	-	21.2	95.7	-	-
Whiskeag Creek	-	-	-	31.8	129.6	-	-

Chilcote and Waterfield (1995) - unnormalized data, means of 3-6 samples

	Cd	Cr	Cu	Pb	Zn	Sn	Ni
Androscoggin River	0.07	11.8	4.7	8.3	38.7	-	-
Merrymeeting Bay	0.16	18.8	6.7	9.9	48	-	-
Kennebec River	0.14	28.7	8.7	15.7	59.8	-	-

DISCUSSION

The results of this study reveal a coherent explanation of the distribution and movement of trace metals into and through the Kennebec/Androscoggin River system. The major points are as follows. Metal levels are generally elevated above pre-industrial levels (Lyons *et al.*, 1978; Larsen *et al.*, 1983a) and above a Gulf of Maine baseline (Getchell, 2002) indicating that metals are presently entering the system (Table 14). There are statistically significant differences in metal levels between our seven defined subregions that show that the greatest concentration elevations are limited to the main stem of the system, i.e. the Kennebec River and estuary and Merrymeeting Bay that, in our groupings, includes the lower Androscoggin River (Table 4). The four small tidal rivers that enter Merrymeeting Bay, the Muddy, Cathance, Abagadasset and Eastern Rivers, have watersheds limited to the Merrymeeting Bay vicinity and exhibit less elevated metal levels. In the case of Pb, sediment concentrations are actually below the Gulf of Maine baseline (Getchell, 2002). We, therefore, may conclude that the major portion of the observed trace metals is from outside of our immediate study area, i.e. from upstream sources in the Kennebec River and Androscoggin River watersheds.

The conclusion that the Kennebec and Androscoggin watersheds are the principal sources of metals in the system is reinforced by the distribution of the stations that ranked the highest in terms of metal concentrations (Table 13, Fig.12). For instance, Stations MB –6, MB-5 and MB-3 are situated where the Androscoggin River broadens into Merrymeeting Bay. It is here where the currents would slow and the river would drop part of its suspended load. Likewise, highly ranked stations in the upper Kennebec are located where the river first meets the two-way tidal flow below the (former) dam in Augusta (Stations UKR-1 and UKR-2) or where the river first broadens out into upper Merrymeeting Bay (Stations UKR-4 and UKR-8).

Four stations in the upper reach of the lower Kennebec River estuary, the Sagadahoc estuary, also were highly ranked (Stations LKR-1,2,3&4). Whereas we cannot dismiss potential inputs from the population/industrial center of Bath, there is a hydrodynamic explanation why these stations would exhibit higher metal burdens than stations immediately upstream in Merrymeeting Bay. When fresh, river water collides with seawater to form an estuary, unique physical and chemical processes result. Seawater is denser than fresh water. As a result, in a constricted tidal estuary, it sinks and produces a bottom current with a net upstream movement. Conversely, the fresh water floats upon seawater and produces a surface current with a net downstream movement. Hence, as sediment particles carried by the downstream flowing river water sink, as they tend to do, they become entrained in the upstream moving bottom current. Further upestuary, the particles will be mixed back into the downstream surface current to sink again into the bottom current. Many particles become captured in this cyclic estuarine circulation. At the same time, when the fine river borne sediment and organic particles, with which the contaminants are associated, come into contact with the salts in the seawater, chemical and electrostatic changes occur. This causes changes in the solubility of many contaminant complexes and, very dramatically, it causes the small contaminant laden particles to floccolate, i.e. bind together, and become less buoyant. The result of these processes is that the upper reaches of estuaries are often characterized by a region of increased suspended loads and underlain by muddy deposits. This region is called the turbidity maximum and it is here where higher levels of contaminants would be expected. Hydrographic conditions in the Kennebec estuary allow for the formation of a turbidity maximum during periods of low or moderate flows which occur about three-quarters of the time (Kistner and Pettigrew, 2001). The location of the Kennebec turbidity maximum is most often in the upper reach where we encountered metal levels higher than at stations both upstream and downstream.

The fact that metals are entering the Kennebec/Androscoggin system from upstream does not mean that they are accumulating in the tidal portions of the system that we sampled. Olsen, *et al.* (1993) investigated a range of US east coast estuaries in an effort to explain patterns observed in estuarine particle retention or export. The Kennebec/Androscoggin system fits into their Type I where "sediment and contaminant accumulation are negligible". Like our study area, Type I areas have noncohesive sediments strongly influenced by physical or biological mixing. They are in "a state of dynamic equilibrium with respect to sea level, river discharge, tidal currents and wave activity" and have "apparently obtained an equilibrium depth above which net particle and contaminant deposition is negligible, despite an excess of both." They say further that the entire suspended sediment and contaminant load bypasses these areas. Any deposition that occurs is temporary due to resuspension by currents and waves.

The findings that the metals are being introduced into the lower Kennebec/Androscoggin system from upstream and are not accumulating in Merrymeeting Bay or the lower estuary supports the hypothesis of Larsen and Gaudette (1995) that the large Kennebec/Androscoggin watershed (27,700 km2) is the source for much of the contamination observed in the nearshore Gulf of Maine. Although we have emphasized trace metals in this research, the distribution of organic contaminants such as PAHs and dioxin should mirror the metal distribution because of similar affinities for fine-grained sediments and organic particles.

SUMMARY AND CONCLUSIONS

Metal levels in the Kennebec/Androscoggin study area sediments are generally elevated relative to background

Highest metal levels are found in the main stem of the system

Principal sources of the metals are the watersheds of the Kennebec and Androscoggin Rivers

The smaller tributaries with watersheds in the immediate Merrymeeting Bay area have statistically significant lower metal levels

Higher metal levels in the upper reach of the lower Kennebec estuary may be explained by the location of the Kennebec turbidity maximum

The system is in dynamic equilibrium in regards to particle and contaminant deposition. Accumulation of metals and, by inference, other contaminants in the system is negligible

These finding are further evidence that contaminants from the Kennebec/Androscoggin watershed are transported to the nearshore Gulf of Maine

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Appendix 1. Latitude and longitude of trace metal staations.

LOCATION	STATION	LATITUDE	LONGITUDE
Muddy River	MR-1	43.94763	-69.91065
	MR-2	43.96516	-69.89798
	MR-3	43.96445	-69.89790
	MR-4	43.98057	-69.88038
Cathance River	CR-1	43.96231	-69.93104
	CR-2	43.96414	-69.93029
	CR-3	43.98670	-69.91131
	CR-5	44.00901	-69.88922
	CR-6	43.99558	-69.88360
	CR-7	43.98547	-69.87772
	CR-8	43.98575	-69.87063
Abagadasset River	AR-1	44.03248	-69.83944
	AR-2	44.00856	-69.85013
	AR-3	43.98967	-69.85286
Eastern River	ER-1	44.10876	-69.72576
	ER-2	44.08449	-69.74737
	ER-3	44.08449	-69.74737
	ER-4	44.05791	-69.77155
	ER-5	44.03362	-69.79274
Upper Kennebec River	UKR-1	44.27163	-69.78857
	UKR-2	44.22442	-69.76104
	UKR-3	44.13960	-69.75560
	UKR-4	44.09042	-69.78693
	UKR-5	44.06890	-69.80069
	UKR-6	44.06890	-69.80069
	UKR-7	44.06890	-69.80069
	UKR-8	44.06556	-69.78703
	UKR-9	44.05424	-69.80663
	UKR-10	44.05424	-69.80663
	UKR-11	44.04018	-69.82125
	UKR-12	44.02882	-69.82053
	UKR-13	44.00950	-69.82550
Merrymeeting Bay	MB-2	43.97240	-69.87504
	MB-3	43.95817	-69.87269
	MB-4	43.95931	-69.86270
	MB-5	43.93580	-69.88906
	MB-6	43.92006	-69.91502
	MB-7	43.97337	-69.83943
Lower Kennebec River	LKR-1	43.98136	-69.82592
	LKR-2	43.94522	-69.82992
	LKR-3	43.94526	-69.82723
	LKR-4	43.89507	-69.81430
	LKR-5	43.88377	-69.81381
	LKR-6	43.85340	-69.79177
	LKR-7	43.82179	-69.80946
	LKR-8	43.80567	-69.77923
	LKR-9	43.79026	-69.78010

Appendix 2. Normalized concentrations of major metals (ppm dry wt.) in surface sediments with percentage of sediment <63 μm.

River		Normalized Mn	Normalized Fe	% Fines
Muddy River	MR-1	125.7	12150.9	46.7
	MR-2	143.9	14514.5	49.4
	MR-3	78.8	8864.0	72.8
	MR-4	122.8	10637.3	77.2
Cathance River	CR-1	229.9	22346.9	17.2
	CR-2	186.3	13969.1	47.6
	CR-3	94.1	8405.3	77.8
	CR-5	117.9	11565.3	75.4
	CR-6	102.6	11044.9	60.8
	CR-7	127.2	16537.0	33.6
	CR-8	37.8	6053.2	48.1
Abagadasset River	AR-1	104.1	16647.0	39.3
	AR-2	127.6	12839.7	66.8
	AR-3	101.3	9584.5	79.9
Eastern River	ER-1	135.4	13813.2	49.8
	ER-2	144.4	12166.3	71.3
	ER-3	137.3	11956.2	71.6
	ER-4	157.5	13158.4	66.2
	ER-5	116.3	12418.4	54.1
Upper Kennebec River	UKR-1	257.7	24110.3	33.7
	UKR-2	657.7	48967.9	12.8
	UKR-3	366.2	27029.0	22.5
	UKR-4	458.0	37214.5	20.1
	UKR-5	118.1	11597.9	48.6
	UKR-6	145.7	11764.1	59.5
	UKR-7	105.4	10023.0	59.5
	UKR-8	583.3	72132.0	8.9
	UKR-9	244.8	21052.9	41.2
	UKR-10	201.2	20530.5	39.9
	UKR-11	134.5	14248.6	59.9
	UKR-12	76.0	10802.2	61.0
	UKR-13	153.3	17387.0	37.8
Merrymeeting Bay	MB-2	136.8	12811.6	33.6
	MB-3	406.1	46427.9	11.5
	MB-4	224.6	23039.4	21.1
	MB-5	159.7	32214.5	17.8
	MB-6	344.9	27869.9	13.3
	MB-7	81.8	13454.7	38.0
Lower Kennebec River	LKR-1	217.8	32386.1	19.7
	LKR-2	170.8	23333.9	31.9
	LKR-3	242.2	28630.4	22.5
	LKR-4	176.9	39313.1	12.7
	LKR-5	88.4	14437.1	40.6
	LKR-6	138.6	26261.3	19.5
	LKR-7	115.8	21963.6	30.7
	LKR-8	63.7	14924.3	49.4
	LKR-9	118.8	24452.2	29.5

Appendix 3. Concentrations of metals (ppm dry wt.) in surface sediments before normalization.

LOCATION	SITE	Cd	Cr	Cu	Pb	Zn	Sn	Ni
Muddy River	MR-1	0.345	26.89	13.85	13.92	55.74	6.27	14.04
	MR-2	0.320	28.80	15.49	14.24	63.58	5.21	16.25
	MR-3	0.315	27.45	14.81	10.48	64.22	7.78	18.09
	MR-4	0.580	38.55	22.32	19.86	99.36	6.74	20.22
Cathance River	CR-1	0.034	10.36	5.49	4.53	24.87	2.75	7.08
	CR-2	0.095	20.26	11.25	7.83	47.94	6.68	15.99
	CR-3	0.393	36.94	17.46	15.60	75.01	8.67	18.84
	CR-5	0.595	35.08	21.56	20.11	91.88	11.24	20.22
	CR-6	0.223	27.56	14.99	13.54	61.80	4.57	18.92
	CR-7	0.290	17.04	9.78	8.26	48.38	2.26	10.01
	CR-8	0.158	12.32	6.47	4.59	30.77	2.94	9.04
Abagadasset River	AR-1	0.226	28.55	11.63	8.24	50.14	6.02	15.69
	AR-2	0.393	38.61	20.45	17.01	80.85	10.86	21.96
	AR-3	0.334	37.59	21.22	19.41	92.11	7.42	20.99
Eastern River	ER-1	0.120	20.03	9.58	7.85	48.45	6.51	14.70
	ER-2	0.300	30.04	15.09	15.11	67.58	9.14	22.47
	ER-3	0.264	28.93	14.16	15.17	65.32	9.95	21.52
	ER-4	0.308	31.86	16.42	14.41	71.02	7.74	22.33
	ER-5	0.260	24.41	12.20	12.46	50.40	8.75	17.13
Upper Kennebec River	UKR-1	0.329	28.50	19.78	37.49	62.61	9.72	22.47
	UKR-2	0.068	22.41	10.02	10.30	51.26	4.43	18.56
	UKR-3	0.140	20.38	9.34	4.47	44.74	4.00	17.73
	UKR-4	0.192	20.61	10.02	57.22	49.94	7.31	15.95
	UKR-5	0.192	24.25	13.32	12.34	55.59	4.39	17.03
	UKR-6	0.388	30.02	16.36	14.62	23.66	6.91	18.90
	UKR-7	0.288	27.73	15.55	16.23	60.84	6.40	17.46
	UKR-8	0.162	19.45	8.76	8.39	42.24	8.20	16.39
	UKR-9	0.262	30.16	16.87	19.20	71.24	8.43	21.72
	UKR-10	0.248	26.57	14.02	15.50	61.61	8.47	18.22
	UKR-11	0.113	26.47	14.00	17.80	52.09	11.28	19.94
	UKR-12	0.126	18.91	9.64	6.17	34.46	4.68	14.33
	UKR-13	0.255	24.07	12.35	12.21	58.70	8.61	14.92
Merrymeeting Bay	MB-2	0.254	20.27	10.63	11.48	47.82	4.49	11.57
	MB-3	0.130	16.69	8.18	7.04	50.66	3.57	10.27
	MB-4	0.238	18.07	9.87	8.55	54.21	4.09	11.24
	MB-5	0.233	18.87	11.46	11.82	61.18	6.21	10.47
	MB-6	0.168	14.44	8.51	9.03	42.58	4.60	9.81
	MB-7	0.224	20.36	10.27	10.27	50.31	3.48	11.47
Lower Kennebec River	LKR-1	0.204	19.18	10.11	8.06	46.66	6.80	13.62
	LKR-2	0.316	23.81	14.40	12.63	66.82	8.71	16.23
	LKR-3	0.151	20.34	11.00	7.96	48.43	6.76	14.56
	LKR-4	0.157	15.38	8.86	5.87	35.15	5.25	12.11
	LKR-5	0.206	24.02	13.61	12.81	51.41	4.85	15.24
	LKR-6	0.174	17.23	10.87	11.16	35.00	5.24	11.71
	LKR-7	0.167	32.13	13.09	13.78	43.15	9.61	15.96
	LKR-8	0.325	27.64	14.52	9.03	57.58	10.07	16.64
	LKR-9	0.243	25.53	13.33	11.00	53.36	9.41	16.49

Appendix 4. Grain size calculations and data.

	SITE#	Wt. Sed. (g)	Wt. Sand (g)	Wt. Fines * 50 less Calgon Wt. (g)	Comb. Wt. (g)	Total Sed. less Comb. Sed. (g)	% Error	Wt. Clay *50 less Calgon Wt. (g)	Wt. Silt (g)	% Sand	% Silt	% Clay	% Fines
Muddy River	MR-1	15.436	7.865	6.890	14.755	0.681	4.4	2.170	4.720	53.3	32.0	14.7	46.7
	MR-2	15.586	7.660	7.470	15.130	0.456	2.9	1.940	5.530	50.6	36.6	12.8	49.4
	MR-3	15.170	4.017	10.730	14.747	0.423	2.8	2.505	8.225	27.2	55.8	17.0	72.8
	MR-4	15.220	3.339	11.300	14.639	0.581	3.8	2.210	9.090	22.8	62.1	15.1	77.2
Cathance River	CR-1	15.918	13.021	2.700	15.721	0.197	1.2	1.155	1.545	82.8	9.8	7.3	17.2
	CR-2	17.207	8.809	7.990	16.799	0.408	2.4	2.250	5.740	52.4	34.2	13.4	47.6
	CR-3	15.040	3.200	11.240	14.440	0.600	4.0	2.410	8.830	22.2	61.2	16.7	77.8
	CR-5	15.012	3.481	10.685	0.140	0.846	5.6	2.445	8.240	24.6	58.2	17.3	75.4
	CR-6	16.865	6.393	9.920	16.313	0.552	3.3	1.520	8.400	39.2	51.5	9.3	60.8
	CR-7	15.957	10.477	5.305	15.782	0.174	1.1	0.990	4.315	66.4	27.3	6.3	33.6
	CR-8	15.365	7.763	7.185	14.948	0.418	2.7	0.460	6.725	51.9	45.0	3.1	48.1
Abagadasset River	AR-1	15.617	9.312	6.030	15.342	0.276	1.8	1.355	4.675	60.7	30.5	8.8	39.3
	AR-2	11.566	3.682	7.420	11.102	0.464	4.0	1.885	5.535	33.2	49.9	17.0	66.8
	AR-3	15.182	2.919	11.610	14.529	0.652	4.3	2.145	9.465	20.1	65.1	14.8	79.9
Eastern River	ER-1	15.047	7.391	7.335	14.726	0.321	2.1	1.400	5.935	50.2	40.3	9.5	49.8
	ER-2	15.525	4.319	10.750	15.069	0.455	2.9	2.520	8.230	28.7	54.6	16.7	71.3
	ER-3	15.049	4.143	10.440	14.583	0.466	3.1	2.245	8.195	28.4	56.2	15.4	71.6
	ER-4	15.085	4.955	9.705	14.660	0.425	2.8	2.170	7.535	33.8	51.4	14.8	66.2
	ER-5	15.146	6.774	7.970	14.744	0.402	2.7	1.420	6.550	45.9	44.4	9.6	54.1
Upper Kennebec River	UKR-1	16.129	10.386	5.275	15.661	0.467	2.9	1.025	4.250	66.3	27.1	6.5	33.7
	UKR-2	16.967	14.680	2.160	16.840	0.127	0.7	0.800	1.360	87.2	8.1	4.8	12.8
	UKR-3	15.370	11.811	3.425	15.236	0.134	0.9	0.745	2.680	77.5	17.6	4.9	22.5
	UKR-4	15.064	11.915	2.995	14.910	0.154	1.0	0.855	2.140	79.9	14.4	5.7	20.1
	UKR-5	15.878	7.995	7.555	15.550	0.328	2.1	1.215	6.340	51.4	40.8	7.8	48.6
	UKR-6	15.035	5.858	8.620	14.478	0.557	3.7	1.800	6.820	40.5	47.1	12.4	59.5
	UKR-7	15.981	6.297	9.270	15.567	0.414	2.6	1.630	7.640	40.5	49.1	10.5	59.5
	UKR-8	15.453	13.985	1.370	15.355	0.098	0.6	0.330	1.040	91.1	6.8	2.1	8.9
	UKR-9	15.082	8.561	6.005	14.566	0.517	3.4	1.390	4.615	58.8	31.7	9.5	41.2
	UKR-10	15.584	9.120	6.045	15.165	0.419	2.7	1.325	4.720	60.1	31.1	8.7	39.9
	UKR-11	15.139	5.940	8.865	14.805	0.334	2.2	1.975	6.890	40.1	46.5	13.3	59.9
	UKR-12	15.104	5.715	9.090	14.805	0.300	2.0	1.410	7.680	38.6	51.9	9.5	61.4
	UKR-13	15.244	9.266	5.625	14.891	0.353	2.3	1.035	4.590	62.2	30.8	7.0	37.8
Merrymeeting Bay	MB-2	19.340	12.558	6.345	18.903	0.437	2.3	1.230	5.115	66.4	27.1	6.5	33.6
	MB-3	15.094	13.308	1.735	15.043	0.051	0.3	0.395	1.340	88.5	8.9	2.6	11.5
	MB-4	15.107	11.847	3.165	15.012	0.095	0.6	0.860	2.305	78.9	15.4	5.7	21.1
	MB-5	14.961	12.136	2.625	14.761	0.200	1.3	0.770	1.855	82.2	12.6	5.2	17.8
	MB-6	15.363	13.156	2.025	15.181	0.182	1.2	0.435	1.590	86.7	10.5	2.9	13.3
	MB-7	15.731	9.552	5.850	15.402	0.329	2.1	1.245	4.605	62.0	29.9	8.1	38.0
Lower Kennebec River	LKR-1	15.038	11.815	2.900	14.715	0.322	2.1	0.720	2.180	80.3	14.8	4.9	19.7
	LKR-2	15.115	10.080	4.730	14.810	0.305	2.0	1.095	3.635	68.1	24.5	7.4	31.9
	LKR-3	15.237	11.673	3.395	15.068	0.168	1.1	0.820	2.575	77.5	17.1	5.4	22.5
	LKR-4	15.307	13.252	1.925	15.177	0.130	0.8	0.445	1.480	87.3	9.8	2.9	12.7
	LKR-5	15.164	8.861	6.045	14.906	0.258	1.7	1.450	4.595	59.4	30.8	9.7	40.6
	LKR-6	15.094	11.983	2.910	14.893	0.201	1.3	0.800	2.110	80.5	14.2	5.4	19.5
	LKR-7	15.096	10.313	4.570	14.883	0.212	1.4	0.810	3.760	69.3	25.3	5.4	30.7
	LKR-8	15.269	7.474	7.297	14.771	0.498	3.3	1.532	5.765	50.6	39.0	10.4	49.4
	LKR-9	15.110	10.476	4.385	14.861	0.249	1.6	1.265	3.120	70.5	21.0	8.5	29.5

Appendix 5. Loss on ignition calculations and data.

LOCATION	SITE #	WT. PAN(g)	WT. PAN & SED. (g)	WT. SED. (g)	WT. PAN & SED. (g) AFTER HEATING 105C	WT. SED. (g)	WT. PAN & SED. (g) AFTER HEATING 540C	WT. SED. (g)	L.O.I.(g)	L.O.I. (o/o)
Muddy River	MR-1	1.5295	22.0398	20.5103	21.8431	20.3130	19.6795	18.1500	2.1636	10.0510
	MR-2	1.5530	22.1656	20.6026	21.9538	20.4008	20.7700	19.2170	1.1838	5.8027
	MR-3	1.5382	23.3815	21.8433	23.1655	21.6273	21.6422	20.1040	1.5233	7.0434
	MR-4	1.5396	22.1757	20.6301	21.9788	20.4392	20.1679	18.8283	1.8109	8.8599
Cathance River	CR-1	1.5012	26.3593	24.7981	26.2510	24.6898	25.2674	23.7062	0.9836	3.9838
	CR-2	1.5349	22.0383	20.5034	21.8980	20.3631	21.0149	19.4800	0.8831	4.3368
	CR-3	1.5677	23.6497	22.0820	23.4649	21.8972	21.9194	20.3517	1.5455	7.0580
	CR-4	1.6405	22.2570	20.7165	21.9852	20.4447	19.4104	17.8899	2.5748	12.5940
	CR-5	1.5644	23.2124	21.6480	22.9007	21.3363	20.9626	19.3982	1.9381	9.0836
	CR-6	1.5413	22.9997	21.4584	22.8689	21.3276	21.9812	20.4399	0.8877	4.1622
	CR-7	1.5543	22.8063	21.2520	22.7460	21.1917	22.2092	20.6549	0.5308	2.5331
	CR-8	1.5530	23.7089	22.1559	23.6437	22.0907	23.2743	21.7213	0.3694	1.6722
Abagadasset River	AR-1	1.5528	23.2394	21.6806	23.0781	21.5253	22.1868	20.6340	0.8913	4.1407
	AR-2	1.5548	23.1550	21.6002	22.8560	21.3012	21.1845	19.6297	1.6715	7.8470
	AR-3	1.5531	22.4267	20.8736	22.2392	20.6861	20.8943	19.3412	1.3449	6.5015
Eastern River	ER-1	1.5503	23.6064	22.0581	23.4501	21.8998	22.6974	21.1471	0.7527	3.4370
	ER-2	1.5596	22.1370	20.5774	21.8938	20.3342	20.7032	19.1436	1.1908	5.8552
	ER-3	1.5562	21.1712	19.8150	20.9818	19.4256	20.0396	18.4834	0.9422	4.8503
	ER-4	1.5673	21.6045	20.0372	21.3960	19.8287	20.0784	18.5111	1.3176	6.6449
	ER-5	1.5548	20.9617	19.4069	20.8279	19.2731	20.0549	18.5001	0.7730	4.0108
Upper Kennebec River	UKR-1	1.5560	22.7564	21.2004	22.5964	21.0404	21.8781	20.3221	0.7183	3.4139
	UKR-2	1.5543	24.4499	22.8956	24.3314	22.7771	23.6212	22.0669	0.7102	3.1180
	UKR-3	1.5410	23.5873	22.0463	23.5057	21.9647	22.9811	21.4201	0.5446	2.4794
	UKR-4	1.5622	26.3520	24.7904	26.2354	24.6732	25.5245	23.9823	0.7109	2.8813
	UKR-5	1.5499	22.5280	20.9781	22.4244	20.8745	21.6104	20.0605	0.8140	3.8995
	UKR-6	1.5434	22.1774	20.6340	22.0227	20.4793	20.9416	19.3982	1.0811	5.2790
	UKR-7	1.5345	21.9518	20.4173	21.8088	20.2743	20.8097	19.2752	0.9991	4.9279
	UKR-8	1.5663	21.0687	19.5024	20.9929	19.4266	20.5557	18.9894	0.4372	2.2505
	UKR-9	1.5638	23.4042	21.8404	23.2308	21.6070	22.1841	20.6203	1.0467	4.8308
	UKR-10	1.5460	22.4386	20.8926	22.2985	20.7525	21.3347	19.7887	0.9638	4.0443
	UKR-11	1.5630	22.6488	21.0858	22.5028	20.9398	21.5904	20.0274	0.9124	4.3573
	UKR-12	1.5562	23.1153	21.5591	22.9713	21.4151	22.3038	20.8076	0.6075	2.8368
	UKR-13	1.5592	21.9676	20.4084	21.8754	20.3162	21.1876	19.6284	0.6878	3.3855

Merrymeeting Bay	MB-2	1.5314	22.0897	20.5583	21.9870	20.4556	21.2840	19.7532	0.7024	3.4338
	MB-3	1.5492	22.7967	21.2475	22.7063	21.1571	22.1679	20.6187	0.5384	2.5448
	MB-4	1.5559	21.9889	20.4330	21.8890	20.3331	21.1682	19.6123	0.7208	3.5450
	MB-5	1.5437	22.6987	21.1550	22.8169	21.0732	21.8978	20.3541	0.7191	3.4124
	MB-6	1.5537	23.3280	21.7743	23.2591	21.7054	22.8639	21.3102	0.3952	1.8207
	MB-7	1.5517	23.8700	22.1189	23.5573	22.0056	22.9057	21.3540	0.6510	2.9611
Lower Kennebec River	LKR-1	1.5346	21.7677	20.2331	21.6843	20.1497	20.9821	19.4475	0.7022	3.4849
	LKR-2	1.5776	23.0257	21.4481	22.9118	21.3342	22.1109	20.5333	0.8009	3.7541
	LKR-3	1.5564	21.0351	19.4787	20.9255	19.3691	20.3638	18.8074	0.5617	2.9000
	LKR-4	1.5822	22.2230	20.6608	22.1465	20.5843	21.7319	20.1697	0.4146	2.0142
	LKR-5	1.5400	23.3274	21.7874	23.1907	21.6507	22.1033	20.5633	1.0874	5.0225
	LKR-6	1.5548	21.4525	19.8977	21.3495	19.7947	20.7285	19.1737	0.0210	3.1372
	LKR-7	1.5761	22.0957	20.5196	21.9544	20.3783	20.9636	19.3875	0.9908	4.8620
	LKR-8	1.5673	22.1382	20.5709	21.9977	20.4304	21.0723	19.5050	0.9254	4.5295
	LKR-9	1.5700	20.9539	19.3839	20.7972	19.2272	19.9918	18.4218	0.8054	4.1889