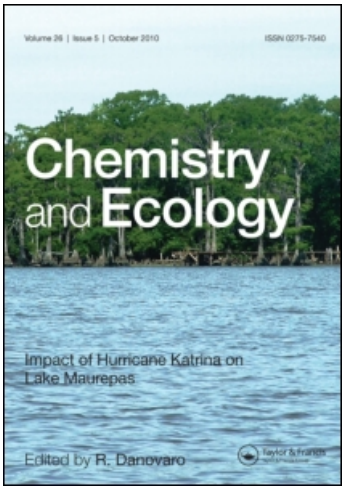

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

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To cite this Article Larsen, Peter F. , Zdanowicz, Vincent , Johnson, Anne C. and Doggett, Lee F.(1983) 'Trace Metals in New England Marine Sediments: Casco Bay, Maine, in relation to Other Sites', Chemistry and Ecology, 1: 3, 191 — 200
To link to this Article: DOI: 10.1080/02757548308070801
URL: http://dx.doi.org/10.1080/02757548308070801

Chemistry in Ecology, 1983, Vol. 1, pp. 191–200
0275–7540/83/0103–0191 $18.50/0

Printed in Great Britain

Trace Metals in New England Marine Sediments: Casco Bay, Maine, in relation to Other Sites

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(*Received June 2, 1982; in final form September 10, 1982*)

The concentrations in surface sediments of the trace metals Cd, Cr, Cu, Ni, Pb and Zn have been determined at 32 stations in the Casco Bay region of the Gulf of Maine. The metals are not distributed homogeneously but exhibit elevated levels around the Portland waterfront and generally low levels at offshore and tidally scoured stations. Comparison of these results to those from both industrialized and non-industrialized sites throughout New England indicates that the sediments in parts of the Casco Bay region are affected by trace metals.

INTRODUCTION

A nearly universal consequence of urbanization and industrialization of estuarine shores is an elevation of environmental levels of various trace metals. Of the three compartments where metals reside in an aquatic environment, the biota, the water and the sediments, the sediments are the major repository (Windom, 1976). Metals anthropogenically introduced to the marine environment are removed from the water column close to the point of entry (Helz *et al.*, 1975; Lyons and Fitzgerald, 1980), and hence metal levels of estuarine and marine sediments can act as sensitive indicators of environmental quality while the sediment record in depositional environments can serve as a historic index of change. Although the distribution of trace metals in the northern New England region has recently received increasing attention in the literature (Armstrong *et al.*, 1976; Lyons and Gaudette, 1979; Mayer and Fink, 1980; Lyons *et al.*, in press) no consideration has been given to Casco Bay, the most developed embayment on the northern New England coast.

Casco Bay, a large, complex bay, located on the south central coast of Maine, is noted for its scenic beauty as well as for its importance to business

and commerce (Figure 1). Within the approximately 400 square kilometers comprising Casco Bay are 300 kilometers of coastline and upwards of 400 islands (U.S. Fish and Wildlife Service, 1980). Included within Casco Bay is the city of Portland, the largest in Maine, which ranks as one of the busiest ports in New England, largely due to heavy petroleum traffic. Portland is also the principal fishing port in Maine. Presently 27% of the coastal population of Maine is situated on Casco Bay and this population should continue to increase in response to continued development of Portland Harbor. At the same time that human and industrial densities are increasing in the Casco Bay region, seals, eagles, black guillemots, and other species indicative of a clean or undisturbed environment, are still found and the area remains heavily utilized for commercial fishing.

This paper presents data on the distribution of the trace metals, Cd, Cr, Cu, Pb, Ni, and Zn in the surficial sediments of Casco Bay with the aim of describing existing conditions and providing a benchmark against which to evaluate future alterations.

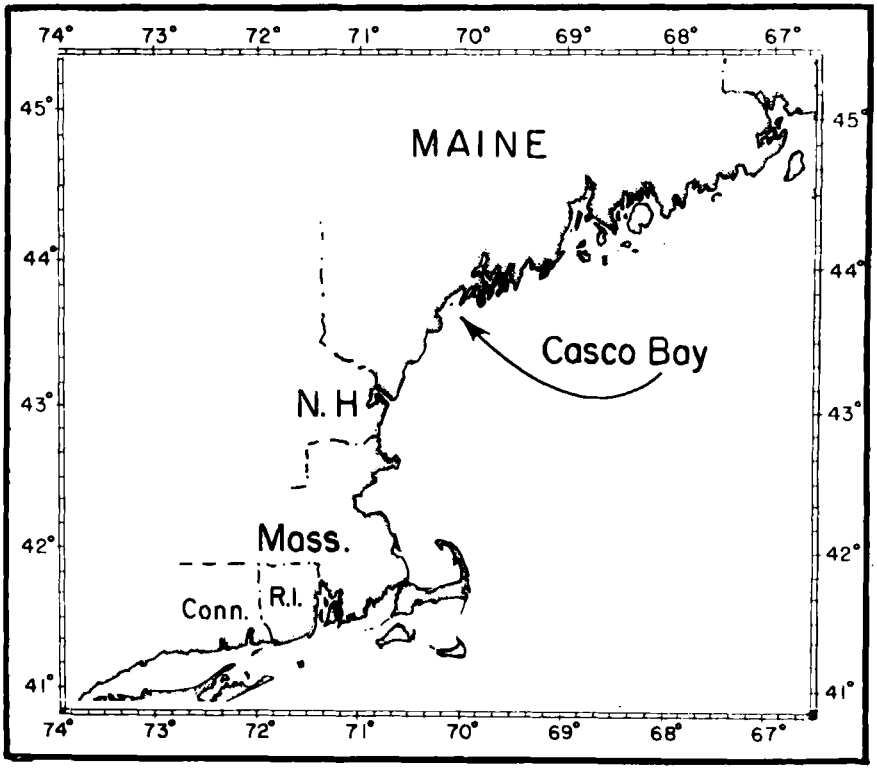

FIGURE 1 The location of Casco Bay.

METHODS

Sample collection and preparations

Sediments were obtained with a 0.1 m^2 Smith-McIntyre grab. Sediment subsamples were taken from the center of the grab using an acid-cleaned plastic scoop. Subsamples were placed in individual acid-washed polyethylene bottles and stored frozen until analysis. A separate subsample was taken for grain size and organic carbon analyses. The 32 sampling locations are presented in Figure 2.

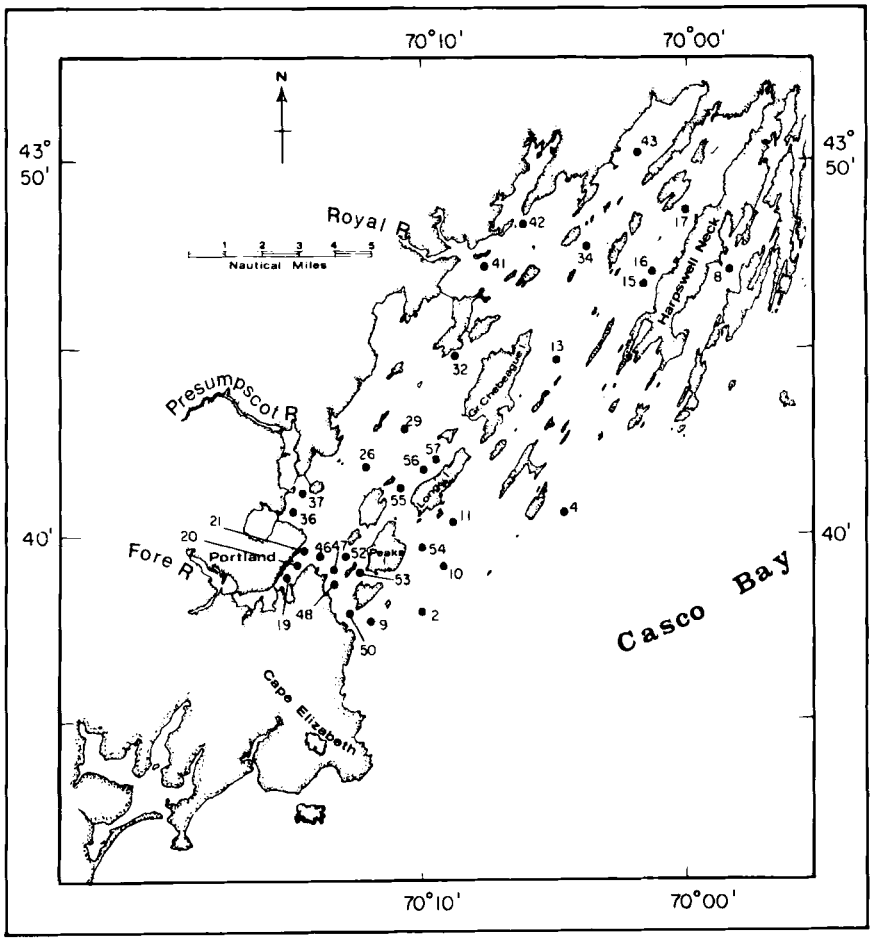

FIGURE 2 Locations of trace metal stations in Casco Bay.

Laboratory analysis

Organic carbon content was determined by chromic acid digestion (Buchanan and Kain, 1971). Grain size distributions were analyzed by standard sieve and pipette techniques (Ingram, 1971; Galehouse, 1971).

Metal analyses were accomplished using modifications of the methodology described by the U.S. Environmental Protection Agency (1969). Three to ten g of dried (60°C, 16–20 h) sediment were weighed into a 100 ml glass beaker. Ten ml of concentrated HNO_3 were added, and the samples evaporated to dryness. When cool, each received 5 ml of 8% NH_4Cl (w/v), 5 ml of 0.02 M Ca $(NO_3)_2$· 4 ml H_2O, and 15 ml of an acid mixture (80 ml concentrated HNO_3 plus 20 ml HCL diluted to 1 L with DIH_2O (deionized water)) and the volumes were reduced to 10 to 15 ml. Cooled samples were filtered using DIH_2O. Sediment trapped on the filter paper was washed two to three times with DIH_2O and the filtrate was brought to a final volume of 25.0 ml. The filtrates were aspirated into an air-acetylene flame in an atomic absorption spectrophotometer. U.S. National Bureau of Standards No. 1654 river sediment was analyzed by the same method to determine recovery rate. Average recoveries were Cd 92%, Cr 109%, Cu 102%, Ni 81%, Pb 104% and Zn 107%.

RESULTS AND DISCUSSION

Results of the sediment metals analyses are presented in Table I. Mean values (and ranges) in ppm dry weight for the six elements are: Cd 0.48 (0.20—0.90), Cr 34.5 (5.85–55.0), Cu 15.5 (2.40—44.5), Ni 17.6 (4.53—32.0), Pb 26.8 (9.00—61.4) and Zn 65.4 (20.8—100.5). Examination of the distribution of these metals in the Casco Bay region indicates that the considerable variation around the mean has a distinct geographic pattern in five of the six metals. The distributions of Cd, Cr, Cu, Pb and Zn are characterized by the relatively high values in the Portland vicinity, especially in Portland Harbor, low values in the sandy sediments of the tidally scoured main channel entering Casco Bay, low values at the deeper offshore stations and generally moderate values close to the mean in the central and upper Bay areas.

Nickel does not completely manifest the pattern described above. Stations in the shipping channel and some of the offshore stations do have levels below the mean, but markedly elevated concentrations are scattered throughout the Bay and not found only in Portland Harbor.

Four of the metals, Cd, Cr, Cu and Pb, display a gradient of decreasing concentrations down the axis of the Fore River, which constitutes Portland

TABLE I

Concentration of metals (ppm dry weight) in surface sediments of Casco Bay, Maine with corresponding percent of sediment < 63 μm and organic carbon contents (mg/g dry weight).

Sta.	Depth (m)	Cd	Cr	Cu	Ni	Pb	Zn	% < 63 μm	Organic carbon
2	30.5	< 0.25	27.0	9.45	11.0	13.5	39.0	46.3	8.6
4	33.6	0.40	26.0	8.38	18.5	18.5	49.4	36.0	15.7
8	15.3	0.30	23.0	8.70	13.0	12.0	43.0	36.7	13.3
9	16.8	0.20	8.50	2.40	4.53	10.5	20.8	0.9	4.7
10	38.1	0.35	39.1	14.0	22.8	29.7	70.8	79.2	21.1
11	24.4	0.25	31.0	11.4	18.5	24.0	59.5	65.4	19.1
13	14.6	0.50	36.5	11.8	19.5	21.5	65.5	65.0	21.6
15	17.1	0.55	38.0	20.0	20.0	33.5	73.5	79.6	23.9
16	15.3	0.55	54.0	16.4	27.5	25.0	30.5	95.1	38.2
17	11.3	0.60	47.5	16.6	32.0	19.5	84.5	98.6	35.6
19	13.7	0.87	49.2	44.5	23.6	61.4	81.9	78.2	26.2
20	10.4	0.80	46.5	32.0	18.5	51.0	100.0	83.4	26.6
21	7.6	0.59	36.6	25.5	22.8	45.0	90.1	89.5	33.2
26	9.2	0.60	55.0	19.7	22.5	35.0	89.0	96.8	37.2
29	13.7	0.50	50.0	16.3	20.0	29.5	74.5	77.1	24.1
32	7.6	0.65	40.0	15.8	22.0	21.5	66.0	95.6	41.3
34	10.7	0.50	49.4	15.8	23.7	20.2	71.6	97.0	34.0
36	7.9	0.90	10.8	13.8	6.60	59.0	80.0	84.8	233.0
37	2.1	0.75	34.5	19.2	14.0	35.5	83.5	54.3	44.5
41	7.3	0.40	31.0	13.1	21.0	16.5	61.0	79.3	2.31
42	6.1	0.55	43.0	14.8	23.0	20.5	68.0	92.8	25.4
43	7.6	0.55	50.4	16.1	24.4	19.0	73.8	97.6	30.7
46	7.6	0.45	26.0	15.0	14.0	30.5	70.5	42.9	15.2
47	16.8	< 0.25	21.5	9.90	12.0	9.0	36.0	34.5	5.5
48	9.2	0.30	18.0	10.2	9.35	22.5	44.5	26.3	11.2
50	21.4	0.45	5.85	4.45	5.75	16.5	21.0	2.7	1.5
52	15.3	0.60	34.5	20.2	20.5	35.5	80.5	80.3	26.1
53	15.3	0.80	44.0	22.6	9.05	—	87.0	30.4	37.8
54	32.0	< 0.25	23.5	7.95	12.5	18.0	41.0	33.6	10.8
55	25.6	0.30	20.5	8.70	11.0	17.5	40.5	26.5	10.9
56	13.7	0.55	43.0	17.0	23.0	32.0	81.0	72.1	28.5
57	14.3	0.45	41.5	14.6	16.0	28.0	64.0	90.7	23.4

Harbor, suggesting that there is an addition of metals upstream of the uppermost station (19). Whereas upland drainage may be an important source of metals deposited in coastal sediments, it does not seem to explain the elevated levels in the Fore River (called the Stroudwater River in its non-tidal portion). The Fore River has a small drainage area (28 sq. miles) relative to the two other principal rivers entering Casco Bay, the Presumpscot (590 sq. miles) and the Royal (142 sq. miles), which show little or no elevation of metal levels near their mouths. In addition, above Portland, the Fore River is largely surrounded by tidal marshes and

residential developments serviced by municipal sewers which discharge elsewhere. It seems likely, therefore, that the elevated metal levels in Portland Harbor sediments result from anthropogenic introductions within the harbor and the industrialized lower Fore River estuary. Additional sampling above Portland will be required to prove this hypothesis.

Linear correlations were computed for the six metals as well as percent organic carbon and percent sediment < 63 μm (Table 2). This analysis shows that, as demonstrated elsewhere (i.e. de Groot *et al.*, 1976), metal levels in Casco Bay surficial sediments are highly correlated with fine grained sediment and levels of organic carbon. That these factors are significant is a reflection of the large reactive surface area of fine-grained sediments and the sorptive capacity of many organic compounds (Stern and Grant, 1981). These relationships help to explain the areal distribution of the metals as, for example, the uniformly low levels encountered in the coarse sediments in the main entrance to Casco Bay. The six metals are also highly correlated to each other in terms of their distribution and concentration (Table II). The only exceptions to this generalization are the correlations of nickel with cadmium and lead with chromium.

Examination of plots of the concentrations of each metal against organic carbon levels revealed that Cd, Cu, Pb and Zn had concentrations well above the regression line only at stations 19 and/or 20. Removal of these stations from the correlation analysis increased the correlation coefficients between the metals and organic carbon to 0.817, 0.826, 0.578 and 0.883, respectively (compare Table II). This is taken as further evidence, especially in the cases of Cu and Pb, that the elevated metal levels observed in Portland Harbor are anthropogenically derived.

TABLE II

Correlation matrix for Casco Bay trace metal samples[1]

	Org. C	Cd	Cr	Cu	Pb	Ni	Zn	% < 63 μm
Organic carbon	1.000							
Cadmium	0.762	1.000						
Chromium	0.822	0.461	1.000					
Copper	0.578	0.705	0.635	1.000				
Lead	0.476	0.775	0.287	0.802	1.000			
Nickel	0.675	0.319	0.826	0.466	0.175	1.000		
Zinc	0.853	0.786	0.766	0.775	0.724	0.625	1.000	
% < 63 μm	0.7428	0.504	0.776	0.4652	0.8239	0.813	0.773	1.000

[1] $n = 32$ except for lead and organic carbon where $n = 31$. Significant at 99% confidence interval of $r \geqq 0.449$ for $n = 32$ and $r \geqq 0.456$ for $n = 31$.

COMPARISON WITH OTHER STUDIES

Comparison of trace metal levels in Casco Bay sediments with levels found in other recent New England investigations will help to put these results into perspective. Five studies utilizing comparable methodology are available for comparison. Lyons *et al.*, (in press) examined trace metal levels in five northern New England estuaries. They concluded from sediment profiles that three of them, Machias Bay, Cape Rosier and the Seabrook River estuary show little increase in trace metal concentrations over the past century and are probably representative of pre-industrial levels. Two other estuaries, the Saco and Kennebec, exhibit recent anthropogenic enrichment due to industrial and/or sewage inputs. Armstrong *et al.*, (1976) determined trace metal values of the sediments of the Great Bay estuary which has been historically subjected to industrial discharges. Lyons and Gaudette (1979) investigated concentrations in Jeffreys Basin, a fine-grained depositional area off the coast of southern Maine and New Hampshire. They concluded that the relatively high levels found there are the result of fine-grained sediment export from estuaries. Two southern new England estuaries, the non-industrialized Mystic River estuary and the affected Branford Harbor, were contrasted by Lyons and Fitzgerald (1980). Finally Greig *et al.*, (1977) analyzed a large number of sediment samples from Long Island Sound, a large, highly "urbanized" estuary. For purposes of comparison we have used only their results from the eastern half of the Sound, stations 72–143, to avoid the overbearing influence of inputs from the New York City area.

Trace metal levels at the 11 New England sites are contrasted in Table III. It is important to remember that trace metal distributions in Casco Bay are very heterogenous and the mean values are only a gross representation of the conditions in a given subarea. Cadmium levels in Casco Bay compare favourably with the three other sites having reported values. The mean value is close to that of the unaffected Mystic River estuary and considerably lower than the values reported for Branford Harbor and eastern Long Island Sound. Casco Bay sediments appear to be only moderately enriched in terms of chromium. The mean concentration is nearly twice that of the pre-industrial levels of northern New England estuaries, but an order of magnitude lower than the Saco and Great Bay estuaries, both of which are highly enriched with chromium due to tannery operations (Armstrong *et al.*, 1976; Mayer and Fink, 1980; Lyons *et al.*, in press).

Copper levels in Casco Bay are also elevated relative to the non-industrialized estuaries and are comparable to the other impacted sites with the exceptions of the Kennebec River estuary, Maine and Branford Harbor, Connecticut. Long Island Sound is the only other site from which nickel

TABLE III

Comparison of trace metal levels at several New England locations

Site	Cd $\bar{x}$	Cd range	Cd S.D.	Cr $\bar{x}$	Cr range	Cr S.D.	Cu $\bar{x}$	Cu range	Cu S.D.	Ni $\bar{x}$	Ni range	Ni S.D.	Pb $\bar{x}$	Pb range	Pb S.D.	Zn $\bar{x}$	Zn range	Zn S.D.
Casco Bay (this study)	0.47	0–0.90	0.23	34.5	5.8–55.0	13.4	15.5	2.4–44.5	8.0	17.6	4.5–32.0	6.7	26.8	9.0–61.4	13.1	65.4	20.8–100.5	20.5
Kennebec River Estuary, ME[1] (Lyons *et al.*, in press)				29	—	—	33	—	—				33	—	—	64	—	—
Saco River Estuary, ME[1] (Lyons *et al.*, in press)				274	—	—	15	—	—				36	—	—	47	—	—
Penobscot Bay, ME[1] (Lyons *et al.*, in press)				18	—	—	9	—	—				12	—	—	32	—	—
Machias Bay, ME[1] (Lyons *et al.*, in press)				16	—	—	9	—	—				13	—	—	35	—	—
Seabrook River Estuary, NH[1] (Lyons *et al.*, in press)				19	—	—	7	—	—				9	—	—	29	—	—
Great Bay Estuary, NH (Armstrong *et al.*, 1976)				142	9.6–594	112	16.4	2.9–129	14.8				40.7	0.80–145	22.1	60.6	13.4–212	28.5
Jeffreys Basin (Lyons and Gaudette, 1979)				56.3	20.1–83.7	—	16.4	2.4–35.1					31.2	9.5–58.6	—	75.4	30.7–102.4	—
Mystic River Estuary, CT[1] (Lyons and Fitzgerald, 1980)	0.41	—	—				4.4	—	—				14.5	—	—	56.5	—	—
Branford Harbor, CT[1] (Lyons and Fitzgerald, 1980)	1.16	—	—				34.5	—	—				265	—	—	54.5	—	—
Eastern Long Island Sound[2] (Greig *et al.*, 1977)	2.7	—	1.0	57.7	—	56.7	20.0	—	26.4	7.6	—	6.6	16.2	—	14.5	48.0	—	43.7

[1] Comparisons limited to surface sediments
[2] Stations 72–143

data are available and the mean value is much lower than that of Casco Bay.

The mean value of lead in Casco Bay sediments is higher than that of the four non-industrialized sites and Long Island Sound, but generally lower than the other industralized estuaries. Mean zinc concentration, on the other hand, is only exceeded by that reported for Jeffreys Basin.

SUMMARY AND CONCLUSION

These results show that trace metals are not distributed homogenously in the Casco Bay region. Whereas a strong correlation exists between metal concentrations and both mean grain size and organic carbon concentrations, there is also a strong geographic pattern not completely explained by these relationships or the location of freshwater inputs. In general, high trace metal levels are found in the Portland area, which includes the lower Fore River estuary, low levels are found in scour channels, relatively low concentrations are encountered at the offshore sites and moderate levels occur in the very fine sediments of central and upper Casco Bay. In addition, four metals exhibit a concentration gradient down the lower Fore River estuary. Since the small drainage basin of the Fore (Stroudwater) River is not industrialized above Portland an anthropogenic source(s) within the lower estuary is suggested.

Comparisons with other New England sites indicate, with the exception of cadmium, that trace metal concentrations in Casco Bay are elevated well above presumed pre-industrial levels. Mean values of each of the other metals examined are comparable to levels reported from other industrialized New England areas.

Realizing that trace metal concentrations from stations in the Portland area are generally much higher than the mean, and that the mean is reduced by low concentrations elsewhere in the Bay, it is concluded that surficial sediments in Portland Harbor and the lower Fore River estuary are affected by trace metals. Sediment profile studies are needed to put the present levels into a historical context.

Acknowledgements

Field sampling was facilitated by the excellent support of Paul DeRocher and Mike Dunton aboard the Maine Department of Marine Resources vessel R/V *Explorer*. Henri E. Gaudette and W. Berry Lyons of the University of New Hampshire provided advice on data interpretation and read the manuscript. Grain size and sediment organic carbon analyses were performed by GEOMET Technologies, Inc., Melville, New York. This work was supported by NOAA-NMFS contract NA-80-FA-C-0008 and by Maine Department of Marine Resources contract 2-81 with funds provided by the Coastal Energy Impact Program of the Office of Coastal Zone Management. Contribution number 82020 of the Bigelow Laboratory for Ocean Sciences.

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