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A. Locke and S. Courtenay

Science Branch
Fisheries and Oceans
P.O. Box 5030
Moncton, New Brunswick
E1C 9B6

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A. Locke and S. Courtenay

Science Branch,
Dept. of Fisheries and Oceans,
P.O. Box 5030,
Moncton, New Brunswick,
Canada, E1C 9B6

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ABSTRACT

Temperature and salinity profiles, Secchi depth, and total suspended sediment concentration were recorded from May to September 1992 in the Miramichi Estuary, New Brunswick, Canada. Temperature, salinity and Secchi depth in 1992 were similar to those reported by Bousfield (1955) for the summer of 1951, despite major changes in human activities (dredging, pulp mills) in the estuary. Temperatures and salinities were in the range of 2 to 23 _C, and 0 to 28‰, respectively. Secchi depths did not exceed 3 m in the tidal river and Inner Bay, but reached 7 m in the adjacent Gulf of St. Lawrence. Total suspended sediment concentrations ranged from 5 to 70 mg·liter^{-1}.

RÉSUMÉ

Nous avons enregistré des profils de température et de salinité, nous avons mesuré la transparence de l'eau au disque de Secchi et nous avons évalué la concentration globale des sédiments en suspension dans l'estuaire de la Miramichi, au Nouveau-Brunswick, Canada, de mai à septembre 1992. Les données sur la température, la salinité et la transparence (calculeé selon le disque Secchi) de 1992 sont semblables aux données qui avaient été déclarées par Bousfield en 1955, suite à des études menées à l'été de 1951, et ce, malgré d'importants changements dans les activités humaines dans l'estuaire, tels le dragage et l'exploitation des scieries. Les températures et la salinité étaient de l'ordre de 2 à 23 _C et de 0 à 28‰ respectivement. La transparence calculée au disque Secchi n'a pas dépassé trois mètres de profondeur dans le cours

d'eau sujet à marée et dans le fond de la baie, mais elle a atteint sept mètres dans le golfe du Saint-Laurent situé à proximité. Les concentrations globales de sédiments en suspension variaient de 5 à 70 $mg \cdot liter^{-1}$.

1. INTRODUCTION

The Miramichi Estuary, located in the southern Gulf of St. Lawrence, is one of the largest estuaries in Atlantic Canada (surface area, ~300 km2; drainage basin area, ~14,000 km^2). The estuary is used for shipping, wood processing and other industries, and several commercially and recreationally important fisheries (e.g., Atlantic salmon (Salmo salar), striped bass (Morone saxatilis), rainbow smelt (Osmerus mordax), gaspereau (Alosa pseudoharengus and Alosa aestivalis), oyster (Ostrea virginiana) and lobster (Homarus americanus)). Recent changes in human activities in the Miramichi Estuary have prompted concern about possible environmental impacts, particularly on the fisheries resources. Changes in temperature and salinity patterns in the estuary resulting from increased tidal penetration, and increased suspended sediment levels, have been predicted as possible consequences of recent channel dredging activities and changes in industrial use. Our purpose in this paper is to compare temperature, salinity and suspended sediment characteristics of the estuary in summer, 1992, to conditions recorded by Bousfield (1955), to determine whether the predicted changes have occurred.

In recent years, the main physical change in the estuary has been the dredging of a >60-km navigation channel between the barrier islands (Portage and Fox Islands, separating the Inner and Outer Miramichi Bays) and Newcastle (Fig. 1) to a depth of approximately 8 m in 1981 and 1982. Maintenance dredging of this channel has continued since 1983. Industrial use of the estuary has also changed. Up to 1950, about 150,000 tonnes of pulp waste products (bark, wood fibre, biosolids) were estimated lost to the estuary from mills which had been established on the shores of the tidal river for over a century. This estimate accounts for about 1% of the annual sediment discharged into the estuary by the Miramichi River (Buckley, 1990). Between 1950 and 1977, pulp production increased and about 20,000 tonnes·yr^{-1} were discharged. Consequently about 20% of the sediments discharged by the river during that period were composed of wood waste contaminants. In 1978, improvements in industrial waste control were expected to reduce subsequent losses to about 12,000 tonnes·yr^{-1} (Buckley, 1990).

Physical changes predicted to result from these human activities included: increased tidal penetration as a result of dredging deeper channels, possibly resulting in measurably higher salinities and a change in the location of the head of tide; and higher levels of sediment suspension resulting from disturbance of sediments by the dredging and disposal processes (Willis, 1990). Sediment suspension could also be enhanced by increased current velocities, which could result from diversion of currents towards the deeper dredged areas (Willis, 1990). Changes in the sediment supplied by the tidal rivers could result from changes in the type and amount of effluent discharged by the pulp mills.

Recent investigation of the physical environment of the estuary has been limited. Existing published reports on the physical conditions of the Miramichi Estuary relate primarily to conditions prior (1980 and earlier) or immediately after (1981-83) dredging. Among these, the most comprehensive summaries are: Bousfield (1955) on temperature, salinity and water clarity (August 1950 and June-August 1951), Krauel (1975) on temperature and salinity (September-October 1973), Vilks and Krauel (1982) on temperature and salinity (dates between September 1973 and February 1977), Winters (1981) on suspended sediments (May 1976, October 1976 and February 1977), and Kranck and

Milligan (1989) on suspended sediments (September-October 1973 and 1983-84). Recent (1990's) temperature and salinity conditions are described by St-Hilaire et al. (1992), Bettignies and St-Hilaire (1993), St-Hilaire et al. (1995) and LaFleur et al. (1995). However, these researchers studied a more restricted portion of the estuary, did not investigate water transparency or sediment load, and did not compare their findings to pre-1990's conditions to detect possible environmental impacts.

In this paper we report recent data on salinity, temperature, transparency (Secchi depth) and total suspended solids and compare these data with literature values. In particular, we compare data we collected from the head of tide to the seaward extent of the estuary in May-September of 1992 with data collected in a similar manner by Bousfield (1955).

2. STUDY AREA

The Miramichi Estuary is located in the southwestern Gulf of St. Lawrence, in the province of New Brunswick (Figure 1). It is one of the largest estuaries in Atlantic Canada, draining 14,000 km^2, and with a surface area of 300 km^2. Miramichi Bay is 22 km wide near the chain of barrier islands which separates the Inner Bay from the Outer Bay (adjacent to the Gulf of St. Lawrence), and tidal effects extend over 80 km upstream into the Miramichi River and its two major tributaries, the Northwest and Southwest Miramichi rivers. The estuary is stratified by salinity, both vertically and longitudinally, at least during neap tides (Bousfield 1955). The average water depth of the estuary is about 5 m at low tide, although a navigational channel, extending >60 km from just outside the barrier islands to the town of Newcastle, has been dredged to a minimum depth of 7.6 m. The entire system is ice-covered from December to April. Predicted tidal amplitudes at Escuminac, just outside the barrier islands, ranged from 0.5 to 1.4 m during the study period (Canadian Hydrographic Service 1992). Freshwater discharge, measured at Blackville on the Southwest Miramichi River, was 7.5 to 54.0 m^3 sec^{-1} during the study (J.-G. Deveau, Environment Canada, Moncton, NB, personal communication).

3. METHODS

Temperature, salinity, Secchi depth and total suspended sediments were determined at sites in and adjacent to the Miramichi Estuary. Data were collected from May 6, shortly after ice-out, to September 25, 1992. Sampling was conducted from Red Bank on the Northwest Miramichi River, the upper extent of brackish water in this tributary, to the Outer Bay (Fig. 1), a distance of approximately 80 km. Eleven to 24 locations were sampled during each sampling period, with a minimum of two samples collected from each 5-unit (Practical Salinity Scale) salinity interval, when possible. Frequency of sampling varied from twice weekly for stations upstream of Newcastle in May-June and weekly or fortnightly thereafter, to fortnightly for stations from Newcastle to the Inner Bay, to approximately monthly for stations in the Outer Bay.

An SBE-19 Seacat Profiler (Seabird Electronics Inc., Bellevue, WA) was used to record temperature and salinity profiles of the water column from an anchored boat. A water sample (0.5 to 1 liters) for determination of total suspended solid (TSS) concentration was collected using a weighted Tygon tube (inside diameter 2.5 cm) to obtain an integrated sample of the water column from surface to near-bottom (maximum depth 9 m; few stations exceeded 10 m in depth). Upon return to the laboratory, this water sample was frozen, then later thawed and filtered onto a preweighed 0.45-μm cellulose nitrate filter, dried at 60_C for 24 hours, and weighed. Water transparency (Secchi depth) was measured using a 20-cm black-and-white Secchi disk.

Temperature, salinity and water clarity were expressed graphically with respect to position in the estuary ("distance" on the abscissa of figures refers to seaward distance from Red Bank, the upstream extent of sampling). Mean values of temperature and salinity were calculated for "surface" and "bottom" strata, separated at mid-thermocline and/or mid-halocline (when both were present, their depths corresponded; but some stations had no vertical variation in either temperature or salinity). Pearson's product-moment correlations were calculated in order to examine the relationships between physical variables, using SAS version 6.08 (SAS INSTITUTE 1988) on a VAX 4000 computer.

Detailed printouts of the 1992 data, and additional (but less spatially and temporally comprehensive) physical oceanographic data collected in the ice-free seasons of 1991 and 1993, are published in Locke et al. (1996).

4. RESULTS AND DISCUSSION

4.1. WATER TEMPERATURE

Surface temperatures warmed rapidly from 4 _C in early May to a maximum of 23 _C in August (Table 1), similar to the maximum of 22 _C observed by Bousfield (1955) in July and August, 1951. Likewise, St-Hilaire et al. (1992) found that surface temperatures reached the maximum temperature capacity of their thermographs (23.5 _C) on numerous occasions in July and August, 1991. Bottom waters were only slightly colder than surface waters, ranging from 2 to 22.5 _C (Table 1).

In general, temperatures were higher in the Northwest (0-10 km from Red Bank) and main Miramichi (10-50 km) rivers than in the Inner Bay (>50 km from Red Bank) (Figs. 2, 3). Exceptions to this trend occurred in late August and September, when the Northwest Miramichi River was colder than the Miramichi River.

Patterns of temperature differential between surface and bottom waters changed seasonally. In May and June, there was no vertical difference in temperature in the Northwest Miramichi River, but temperature differential increased with increasing distance from Red Bank (Fig. 4). By July, temperature differences of up to 2 _C were seen in the Northwest Miramichi and vertical differences continued to be greater downriver. Vertical mixing was presumably greater in August and September, as differences in temperature were smaller in these months. Bousfield (1955) documented surface temperatures which were often 2 or 3 _C higher than those at approximately 8 m. We found that differences of 2 to 3 _C were common, and that on occasion surface waters were up to 5 _C warmer than bottom waters. As well, temperature inversions where surface waters were up to 1 _C colder (more commonly, 0.5 _C) than bottom waters were frequently observed. St-Hilaire et al. (1992) noted a 15-day periodicity in the occurrence of temperature inversions which approximated the timing of spring tides. The majority of our sampling was conducted at or near spring tides, which would account for the common occurrence of temperature inversions.

4.2. SALINITY

Surface and bottom salinities ranged from 0 to 26‰, and 0 to 28‰, respectively (Table 1). The upriver sites near Red Bank were essentially freshwater throughout the ice-free season. Surface salinity was 0‰ at Red Bank during the entire sampling period (Fig. 5), and bottom salinity exceeded 0‰ only on August 13-14, when the minimum measured salinity was 2‰ (Fig. 6). The downstream extent of fresh water varied seasonally with discharge. In early May, surface fresh water extended into the main Miramichi River almost to Sheldrake Island. At this time, bottom waters were also fresh as far downstream as Millbank. Two weeks later, freshwater bottom salinities extended only to the mouth of the Northwest Miramichi River. Bettignies and St-Hilaire (1993), sampling stations below Newcastle in mid-May of 1991, likewise found no fresh water near the bottom. By August and September, surface fresh water was also limited to the Northwest Miramichi.

Maximum differences between surface and bottom salinities (Fig. 7) occurred in May (salinity difference of 22‰), followed by July (difference of 16‰), June (difference of 12‰), August (difference of 11‰) and September (difference of 7‰). The location of the maximum differences varied seasonally; in May, the greatest salinity difference was observed near the seaward extent of sampling near Burnt Church, in June and July near the mouth of the Bartibog River, in August near Newcastle and in September near North Esk Boom in the Northwest Miramichi River (Fig. 7). Our results indicate that this zone migrated upstream as the season progressed. In June-August 1951, Bousfield (1955) found the greatest vertical salinity difference (>10‰) near the mouth of the main Miramichi River, similar to our results for June-July. He did not, however, record the upstream movement of this zone in August, perhaps because he sampled in a year of exceptionally high rainfall (Bousfield, 1955). His preliminary sampling in August 1950 indicated much less freshwater influence compared to 1951. Bettignies and St-

Hilaire (1993) noted that, like temperature stratification, the extent of salinity stratification in the Miramichi follows both the diel and monthly tidal cycle, as well as being affected by wind mixing and freshwater runoff.

4.3. SECCHI DEPTH

In all months sampled, Secchi depths were greater in the Northwest Miramichi River (at and above North Esk Boom) and in Miramichi Bay than in the main Miramichi River (Fig. 8). Seasonal variation in Secchi depth was very limited. Typical values for the Northwest Miramichi River and Inner Bay were 3 m, and for the main Miramichi River, 1 m or less. Several km outside the barrier islands, Secchi depths increased to 7 m. These results are consistent with those reported by Bousfield (1955) for Miramichi Bay (1.8 m in the upper end and south side of the Inner Bay, 2.5 m along the north side of the Inner Bay, and the Outer Bay) and offshore Gulf of St. Lawrence (typically 6.1 m, maximum value 7.7 m).

Our observations of reduced water clarity in the Miramichi River relative to the Inner Bay were consistent with turbidity studies by Kranck and Milligan (1989), who reported a well developed maximum turbidity zone (MTZ) with its seaward end east of Point aux Carr. We did not, however, observe the strong trends in landward extent of this MTZ as described by Kranck and Milligan (1989), where the seasonal effects of freshwater discharge shifted the upper end of the MTZ between the mouth of the Northwest Miramichi River (October) and Millbank (May).

4.4. SUSPENDED SOLIDS

Typical suspended solid concentrations in June-August 1992 were in the range of 5 to 30 mg·liter^{-1} (Fig. 9). Occasionally samples were collected with suspended solids of 70 mg·liter-1. There was no strong trend with location or seasonal variation, probably due to limitations in the method of collection. Because the water samples used for analysis were collected with a weighted 9-m hose, the proportion of the water column sampled in each case was variable. Furthermore, in strong currents the hose was carried on an angle and sampled less than the top 9 m of the water column. This limits the comparability between sites because one of the major sources of solids is resuspension from the bottom of the river. As well, these data were collected at different tidal stages, which also affects the degree of current and consequently of both sediment resuspension and the effectiveness of our sampling method. The data are presented here mainly to indicate the minimum range of variation in the system.

The range of suspended sediment concentrations we recorded is consistent with the observations of Winters (1981). Suspended sediment concentrations in May 1976 ranged from 0.5 to 90 mg·liter^{1}, and in February 1977 from 0.1 to 80 mg·liter^{-1}. Maxima of suspended particulate material occurred at regular intervals during tidal cycles, and the magnitude of maxima varied with tidal energy. The most consistent maxima occurred near bottom, mainly during tidal current peak velocities leading to resuspension. Occasionally surface maxima occurred, generally near the end of ebb tides (Winters, 1981).

Compared to October-November 1970 (Stasko, 1976), the abundance of suspended wood fibre in the water column near Newcastle has markedly improved. In sampling suspended particulate material with plankton nets near Newcastle, Stasko rarely found anything but wood fibre (2-5 mm long) in his nets. Occasionally plankton, bark and wood chips were collected. In extensive sampling in this area we did not collect any wood fibre in plankton nets towed through the water column. We did, however, find large quantities of wood chips in nets that hit bottom, upriver from Newcastle as far as McKay's Cove and downriver at least to Millbank, but as far as we could determine this material was not suspended in the water column to any great extent.

4.5. RELATIONSHIPS BETWEEN PHYSICAL VARIABLES

Physical variables were not independent of one another. In general, waters of the lower estuary were more saline, colder and more transparent than those of the upper estuary. Correlations of surface with bottom temperatures, surface with bottom salinities, and surface and bottom salinities with distance from Red Bank were consistently positive and significant at $P<0.05$ (Table 2). Significant negative correlations of Secchi depth with bottom temperature, surface temperature with surface and bottom salinities, bottom temperature with bottom salinity, and surface and bottom temperatures with distance from Red Bank were seen in at least half of the sampling periods (Table 2).

5. CONCLUSIONS

In general, our observations of temperature, salinity and Secchi depth resembled the conditions reported by Bousfield (1955) for the summer of 1951 and by St-Hilaire et al. (1992) and Bettignies and St-Hilaire (1993) for the summer of 1991. There was no detectable effect of changes in pulp mill effluents on Secchi disc transparency in the upper estuary compared to that observed by Bousfield (1955), although the particulate material released by the mills was evidently much less than that recorded by Stasko (1976). We also did not detect long-term or consistent differences in salinity or suspended sediment load that could be attributed to dredging or changes in the shipping channel. It should be noted, however, that no dredging took place inside the barrier islands in 1992. On one occasion in the summer of 1993, we noted a large amount of suspended clay sediment on a plankton net towed for 10 min, about 0.5 km from maintenance dredging in the Inner Bay. Several km from the dredging, we detected much less sediment on the net, suggesting that sediment resuspension was relatively local and probably of limited duration. However, if the timing and location of this short-term acute sediment load coincided with usage of the estuary by susceptible organisms, such as larval fishes, it is possible that high mortality of a cohort could occur.

Some aspects of the physical conditions of the Miramichi bear further study. Concentration and resuspension of sediments in the maximum turbidity zone of the Miramichi River and upper portion of the Inner Bay (Kranck and Milligan, 1989) allow this area to act as a sink for sediment-borne contaminants of industrial or municipal origin. Our analyses of suspended sediments do not provide a complete picture of longitudinal or tidal effects on sediment load in the estuary. We recommend analysis of total suspended solids at a consistent tidal stage (and at regular intervals during complete tidal cycles) and horizontal transects of vertical turbidity profiles.

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7. REFERENCES

Bettignies, C., and A. St-Hilaire. 1993. Variations mensuelles de la salinité et de la stratification dans l'estuaire de la Miramichi - influence des marées, des débits et du vent. Proceedings of the Canadian Society of Civil Engineering Annual Conference, Fredericton, NB, Canada **1993**: 495-504.

Bousfield, E.L. 1955. Some physical features of the Miramichi estuary. J. Fish. Res. Bd. Canada **12**: 342-361.

Buckley, D.E. 1990. Sedimentary geology of the Miramichi estuary system in relation to dredging and dumping activities: a review. Review of impacts of channel dredging on biological resources of the Miramichi system. Acadia Centre for Estuarine Research, Acadia University, Wolfville, NS, Canada. 10 pp., unnumbered.

Canadian Hydrographic Service. 1992. Canadian tide and current tables, 1992. Volume 2. Gulf of St. Lawrence. Department of Fisheries and Oceans, Ottawa, ON, Canada.

Kranck, K. and T.G. Milligan. 1989. Effects of a major dredging program on the sedimentary environment of Miramichi Bay, New Brunswick. Canadian Technical Report of Hydrography and Ocean Sciences **112**: 1-61.

Krauel, D.P. 1975. The physical oceanography of the Miramichi River estuary, September-October, 1973. Environment Canada Fisheries and Marine Service Technical Report **571**: 1-184.

LaFleur, C., B. Pettigrew, A. St-Hilaire, D.A. Booth and E.M.P. Chadwick. 1995. Seasonal and short-term variations in the estuarine structure of the Miramichi. In: E.M.P. Chadwick (ed.). Water, science and the public: the Miramichi ecosystem. Canadian Special Publication of Fisheries and Aquatic Sciences **123**: 45-72.

Locke, A., S.C. Courtenay, K. Robichaud-LeBlanc and A. St-Hilaire. 1996. Physical oceanographic data from the Miramichi Estuary, 1991-1993. Can. Data Rep. Fish. Aquat. Sci. 1000: iv + 44 p.

St-Hilaire, A., C. Bettignies, D. Booth and E.M.P. Chadwick. 1992. Tidal influence on the stratification of the Miramichi estuary. In: M. Jennings and M.G. Bhowmick (eds.). Proceedings of the American Society of Chemical Engineering, Water Forum '92: Hydraulic Engineering: 953-958.

St-Hilaire, A., D. Booth, C. Bettignies, E.M.P. Chadwick and S.C. Courtenay. 1995. Is the Miramichi a stratified estuary?. In: E.M.P. Chadwick (ed.). Water, science and the public: the Miramichi ecosystem. Canadian Special Publication of Fisheries and Aquatic Sciences **123**: 73-82.

Stasko, A.B. 1976. Suspended particulate matter in Miramichi estuary at Newcastle, N.B. Fisheries Research Board of Canada Manuscript Report Series **1402**: 1-14.

Vilks, G. and D.P. Krauel. 1982. Environmental geology of the Miramichi estuary: physical oceanography. Geological Survey of Canada Paper **81-24**: 1-53.

Willis, D.H. 1990. Miramichi estuary - physical oceanography. Review of impacts of channel dredging on biological resources of the Miramichi system. Acadia Centre for Estuarine Research, Acadia University, Wolfville, NS, Canada. 10 pp., unnumbered.

Winters, G.V. 1981. Environmental geology of the Miramichi estuary: suspended sediment transport. Geological Survey of Canada Paper **81-16,** 1-12.

Table 1. Ranges of environmental variables in the Miramichi Estuary during fortnightly sampling in 1992.

Date	N	Secchi depth (m)	Distance from Red Bank (km)	Surface salinity (‰)	Bottom salinity (‰)	Surface temperature (_C)	Bottom temperature (_C)
May 6-8	13	0.5-1.0	22-64	0-14	0-28	4-6	2-4
May 19-20	12	0.9-2.5	0-48	0-12	0-27	12-13	7-13
June 3-4	14	0.8-2.5	0-48	0-19	0-24	14-16.5	12.5-16.5
June 16-18	20	1.0-2.8	0-62	0-23	0-26	15.5-20.5	14-20.5
July 2-3	15	0.5-1.8	0-48	0-14	0-21	16-17.5	16-17.5
July 15-17	14	0.7-2.0	0-48	0-13	0-24	15.5-18.5	15.5-18.5
July 21-27	24	1.0-7.0	0-72	0-26	0-27	16.5-21.5	15-21.5
Aug. 13-14	13	1.1-2.8	0-51	0-22	2-28	18-21	17.5-21
Aug. 25-27	11	0.7-3.0	0-42	0-18	0-21	19.5-23	19-22.5
Sept. 24-25	12	0.8-3.0	0-48	0-23	0-26	13-18	13-17.5

Table 2 (a) Pearson correlation coefficients of physico-chemical variables in Miramichi Estuary, for all 1992 dates combined. Values in bold type are significant at P<0.05.

	Temperature Surface	Bottom	Salinity Surface	Bottom	Susp. Sed.	Distance from Red Bank
Secchi depth	**0.21**	**0.18**	**0.41**	**0.19**	**-0.22**	**0.19**
Surface temperature	--	**0.96**	0.12	0.001	**-0.31**	**-0.27**
Bottom temperature	--	--	-0.0003	**-0.18**	-0.11	**-0.43**
Surface salinity --	--	--	**0.87**	-0.09	**0.80**	
Bottom salinity --	--	--	--	-0.18	**0.88**	
Suspended sediment	--	--	--	--	--	-0.08

(b) Occurrence of significant (P<0.05) positive and negative correlations between physico-chemical variables, by date of sampling. Dates are designated by numbers (0=May 6-8, 1=May 19-20, 2=June 3-4, 3=June 16-18, 4=July 2-3, 5=July 15-17, 6=July 21-23 and 27, 7=Aug. 13-14, 8=July 25 and 27, 9=Sept. 24-25), and the sign of the correlation coefficient is indicated by by + (positive) or - (negative).

	Temperature Surface	Bottom	Salinity Surface	Bottom	Susp. Sediment	Distance from Red Bank
Secchi depth	+:8 -:4679	+:8 -:34579	+:36 -:28	+:3 -:28	+:no correlation -:3	+:6 -:128
Surface temperature	--	+:123456789 -:0	+:0 -:123689	+:0 -:12368	+:3 -:6	+:04 -:12368
Bottom temperature	--	--	+:no correlation -:1267	+:no correlation -:01268	+:no correlation -:6	+:no correlation -:012678
Surface salinity	--	--	--	+:0123456789 -:no correlation	+:68 -:3	+:0123456789 -:no correlation
Bottom salinity	--	--	--	--	+:6 -:3	+:0123456789 -:no correlation
Suspended sediment	--	--	--	--	--	+:no correlation -:36

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