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AN ASSESSMENT OF SEDIMENT QUALITY AND BENTHIC INVERTEBRATE COMMUNITY STRUCTURE IN THE ST. LAWRENCE (CORNWALL) AREA OF CONCERN

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MANAGEMENT PERSPECTIVE

Development of sediment guidelines for the Great Lakes (GL2000)

This report describes sediment quality from the Cornwall area of the St. Lawrence River Area of Concern based upon the assessment of invertebrate community structure and sediment toxicity. This assessment has been done using the biological sediment quality criteria developed for nearshore areas of the Laurentian Great Lakes. The biological criteria were derived from methods developed in the United Kingdom that (Wright 1995) establish predictive relationships between the macroinvertebrate fauna and the habitat. The technique involves a multivariate statistical approach using a) data on the structure of benthic invertebrate communities, b) functional responses (survival, growth and reproduction) in four sediment toxicity tests (bioassays) with benthic invertebrates and c) selected environmental variables at 252 reference ('clean') sites in the nearshore areas of all five Great Lakes (Lakes Superior, Huron, Erie, Ontario and Michigan).

Based on data from the 12 sites sampled there is some evidence of mild degradation of invertebrate communities at four sites and possible toxicity at five sites, only one site shows both a degraded community and toxicity. This suggests that factors other than sediment quality are largely responsible for the possible changes in community structure and that sediment contamination is not resulting in toxicity in these tests.

In the absence of other contradictory information a statement regarding the de-listing of the AOC with regard to impaired invertebrate communities would be appropriate.

SOMMAIRE À L'INTENTION DE LA DIRECTION

Élaboration de lignes directrices visant les sédiments pour les Grands Lacs (GL 2000)

Ce rapport décrit la qualité des sédiments de la région de Cornwall du secteur préoccupant du fleuve St-Laurent, d'après l'évaluation de la structure de la communauté des invertébrés et de la toxicité des sédiments. On a effectué cette évaluation d'après les critères de qualité biologique des sédiments élaborés pour les zones littorales des Grands Lacs laurentiens. Ces critères biologiques dérivent de méthodes développées au Royaume-Uni (Wright 1995) qui établissent des rapports prévisionnels entre des espèces fauniques de macroinvertébrés et l'habitat. Cette technique est basée sur une approche statistique multivariable utilisant a) des données sur la structure de communautés d'invertébrés benthiques, b) des réponses fonctionnelles (survie, croissance et reproduction) obtenues avec quatre tests de toxicité des sédiments (épreuves biologiques) utilisant des invertébrés benthiques et c) des variables environnementales sélectionnées pour 252 sites de référence (non contaminés) dans des zones du littoral de chacun des cinq Grands Lacs (lacs Supérieur, Huron, Érié, Ontario et Michigan).

Les données des 12 sites échantillonnés semblent indiquer une légère dégradation des communautés d'invertébrés dans quatre sites et peut-être des cas de toxicité dans cinq sites; toutefois, on n'observe une combinaison de communauté dégradée et de toxicité que dans un seul site. Ces résultats suggèrent que des facteurs autres que la qualité des sédiments sont les principalement responsables des changements possibles de la structure des communautés et que d'après ces tests, la contamination des sédiments n'est pas à l'origine de cas de toxicité.

En l'absence d'autres informations contredisant ces résultats, on devrait annoncer le retrait des SP de la liste des lieux comportant des communautés d'invertébrés dégradées.

Summary

This report describes sediment quality from the Cornwall area of the St. Lawrence River Area of Concern based upon the assessment of invertebrate community structure and sediment toxicity. This assessment has been done using the biological sediment quality criteria developed for nearshore areas of the Laurentian Great Lakes. The biological criteria were derived from methods developed in the United Kingdom that (Wright 1995) establish predictive relationships between the macroinvertebrate fauna and the habitat. The technique involves a multivariate statistical approach using a) data on the structure of benthic invertebrate communities, b) functional responses (survival, growth and reproduction) in four sediment toxicity tests (bioassays) with benthic invertebrates and c) selected environmental variables at 252 reference ('clean') sites in the nearshore areas of all five Great Lakes (Lakes Superior, Huron, Erie, Ontario and Michigan).

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RÉSUMÉ

Ce rapport décrit la qualité des sédiments de la région de Cornwall du secteur préoccupant du fleuve St-Laurent, d'après l'évaluation de la structure de la communauté des invertébrés et la toxicité des sédiments. On a effectué cette évaluation d'après les critères de qualité biologique des sédiments élaborés pour les zones littorales des Grands Lacs laurentiens. Ces critères biologiques dérivent de méthodes développées au Royaume-Uni (Wright 1995) qui établissent des rapports prévisionnels entre des espèces fauniques de macroinvertébrés et l'habitat. Cette technique est basée sur une approche statistique multivariable utilisant a) des données sur la structure de communautés d'invertébrés benthiques, b) des réponses fonctionnelles (survie, croissance et reproduction) obtenues avec quatre tests de toxicité des sédiments (épreuves biologiques) utilisant des invertébrés benthiques et c) des variables environnementales sélectionnées pour 252 sites de référence (non contaminés) dans des zones du littoral de chacun des cinq Grands Lacs (lacs Supérieur, Huron, Érié, Ontario et Michigan).

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Introduction

The Cornwall study area is located within the St. Lawrence River RAP Area of Concern (Dreier et al 1997). The geographic extent of the Area of Concern is from the Cornwall Water Treatment Plant (WTP) to the Glen Walter WTP (Fig.1). However, the study area addressed in this report is restricted to the region in the vicinity of the Cornwall WPCP.

The area described in this report was selected based on results from a 1994 survey (Richman 1996) which provided detailed information on the spatial extent of contaminants along the Cornwall waterfront from Windmill Point (Fig 1) to the west of Pilon Island. Acoustic mapping conducted in July 1997 covered the entire reach of the north channel of the St. Lawrence R. from just downstream of the International Bridge to east of Pilon Island (Rukavina 1997). This mapping confirmed previous depositional areas and also identified other sediment deposits including a major deposit along the north shore of the eastern end of Cornwall Island. Samples collected in July 1997 indicated that the surficial sediments of this deposit were less contaminated than sites along the north shore.

This study was designed to collect samples from a range of sediments at different contaminant levels and to investigate the newly described depositional area on the north shore of Cornwall Island.

Methods

Description of the Cornwall study area

Twelve sampling sites were selected to asses the potential biological effects of sediment associated contaminants. Nine sites were located within the depositional areas investigated in 1994, two sites (175, 179) within the deposit north of Cornwall island and one site (167) at the boat launch deposit (Fig 2). In 1977, the Ontario Ministry of the Environment reported to the International Joint Commission (IJC) that Cornwall was listed as an Area of Concern. Included in the restrictions to use by the Remedial Action Plan (RAP) team were possible impaired benthic invertebrate communities and restrictions on dredging because of sediment contamination.

The National Water Research Institute (NWRI) of Environment Canada, with the support of the Cornwall RAP team and Ontario Region of Environment Canada, conducted sampling of the sediments in Cornwall in October 1997. This report presents the results of those investigations and provides a spatial description of the state of the sediments in Cornwall together with an assessment of the degree of contamination.

In this assessment of community structure and sediment contamination we have used the biological sediment guidelines developed by NWRI and Ontario Region of Environment Canada (Reynoldson and Day 1998). This uses a database of 252 reference sites to predict the expected community at any test site and a database of 170 reference sites to assess the toxicity expressed in laboratory bioassays.

Invertebrate Community Structure

Samples for the identification and enumeration of benthic invertebrates were collected with a mini-box corer (40 cm x 40 cm). Each box corer sample was treated as an intact section of sediment that has simply been moved to the surface. It was sampled by completely inserting five 10 cm long Plexiglas tubes (i.d. 6.5 cm, enclosed area 34.2 cm^2) into the sediment in the box corer. Each core tube was considered a replicate sample unit.

The contents of each core tube were removed, placed into a plastic bag and kept cool until sieved through 250 µm mesh. After sieving, the samples were placed in plastic vials (50 ml) and preserved with 4% formalin. After 24 h, the formalin was replaced by ethanol.

Samples were sorted with a low power stereo microscope and identified to species or genus, whenever possible. As required, slide mounts were made for higher power microscopic identification (e.g., Chironomidae and Oligochaeta).

Environmental Variables

Three categories of environmental variables were measured: (1) large spatial scale variables categorised as geographical descriptors; (2) physico-chemical scale variables categorised as geographical descriptors; (2) physico-chemical descriptors of sediment that would relate to small scale interactions between the organisms and their surrounding environment; and, (3) limnological descriptors which relate the sediment to overlying water column processes. The actual variables measured are identified in Table 1. Fourty three environmental variables were measured.

Table 1. Measured environmental variables at reference sites.

Geographic (5 variables)	**Limnological** (8 variables)	**Sediment** (28 variables)
latitude	water depth	Particle Size - 7 variables:
longitude	dissolved oxygen	% gravel, sand, silt clay, mean,
lake basin	pH	75^{th}, 25^{th} percentile
ecodistrict	temperature	Major elements - 12 variables:
date	alkalinity	oxides of Si, Ti, Al, Fe, Mn, Mg,
	total phosphorus	Ca, Na, K, P, and TP, TN
	kjeldahl nitrogen	Nutrients - 2 variables:
	nitrate-nitrite nitrogen	loss on ignition (LOI), TOC
		Metals - 9 variables:
		Totals for V, Cr, Co, Ni, Cu, Zn,
		As, Cd, Pb

The location of each site was established in the field using either Loran C or a hand-held Geographical Positioning System (GPS). Latitude and longitude data were stored as both degree, minute second and decimal degrees.

Sediment was characterized from samples collected from the mini-box corer. Samples of sediment for geochemical analysis were collected from the surface (top 2 cm) of the box corer. Each sample was homogenized in a glass dish with a nalgene spoon and divided as follows:

A sub-sample of sediment for the determination of particle size distribution was placed into a plastic pill jar and stored at ambient temperature in the field. Upon return to the laboratory, samples were lypholysized and analyzed following the method described by Duncan and LaHaie (1979). Large particles (> 63µ) were removed from the sediment sample prior to analysis.

The remaining sediment was stored in a 500 ml plastic container at 4°C in the field and shipped to Bondar Clegg & Co., Ltd., Ottawa, Canada for analyses of major elements, total phosphorous, total organic carbon (TOC), loss on ignition (LOI), and total Kjeldahl nitrogen using standard techniques outlined by the EPA (1981). Concentrations of metals were determined by acid digestion followed by ICP-AES analysis (multi-channel Jarrell-Ash AtomComp 1100) using the methods of McLaren (1981).

Samples of water for chemical analyses were collected using a Van Dorn sampler from 0.5 m above the sediment-water interface. A one litre sample was stored at 4 °C prior to analysis of total phosphorus, Kjeldahl nitrogen, nitrate-nitrite and alkalinity at the National Water Research Laboratory in Burlington, Ontario, Canada. Dissolved oxygen, pH and temperature were measured in the field.

Whole Sediment Toxicity Tests with Reference Sediments

A mini-ponar sampler was used at each site to collect five separate samples of sediment for use in laboratory bioassays with each species of benthic invertebrate. Care was taken at each site during the sampling process to obtain sediment that was not disrupted by a previous sample collection method. The contents of each mini-ponar were placed in a food grade quality plastic bag and the bag was tightly tied with a plastic tie. All samples of sediment were placed in a cooler on ice until they were returned to the laboratory. In the laboratory, the bags of sediment were placed in plastic pails with lids and refrigerated at 4 °C in the dark until bioassays could be conducted using the sediment.

Sediments were tested within six months of their collection. Storage of sediment for this period has been shown to not have an effect on toxicity data (Defoe and Ankley 1998). A clean control sediment from the Canadian Wildlife Bird Sanctuary, Long Point marsh, Lake Erie, was also run for each species to provide biological quality assurance. The culture of the chironomid, *Chironomus riparius*, and the oligochaete worm, *Tubifex tubifex*, are described in Reynoldson *et al.* (1991), Day *et al.* (1994), and Reynoldson *et al.* (1995). The culture of *H. azteca* was maintained according to the procedure described in Borgmann *et al.* (1989). Eggs of the mayfly, *Hexagenia* spp. (both *H. limbata* and *H. rigida*), were collected during late June and

July in each year of the study (1991-1993) according to the method of Hanes and Ciborowski (1992) and organisms were raised to a suitable age for use in bioassays following a procedure based on Bedard *et al.* (1992) but modified by the addition twice weekly of a diet of a yeast:Cerophyll:NutrafinR (YCT) dissolved in deionized water.

Tests with *H. azteca*, *C. riparius* and *T. tubifex* were conducted in 250 ml glass beakers containing 60 to 100 ml of sieved (500 µm mesh), homogenized sediment with approximately 100 to 140 ml of overlying carbon-filtered, dechlorinated and aerated Lake Ontario water (pH 7.8 to 8.3; conductivity 439 to 578 $\mu s.cm^{-1}$; hardness 119 to 137 mg/L). Tests with the mayfly, *Hexagenia* were conducted in 1 L glass jars with 150 ml of test sediment and 850 ml overlying water. The sediment was allowed to settle for 24 h prior to addition of the test organisms. Tests were initiated with the random addition of 15 organisms per beaker for *H. azteca* (mean dry weight = 0.022 mg) and *C. riparius*, 10 organisms per jar for *Hexagenia* spp. and 4 organisms per beaker for *T. tubifex*. Juvenile *H. azteca* were 3 to 10 d old at test initiation; *C. riparius* larvae were in first instar and within 48h of hatching; *Hexagenia* nymphs were 1.5 to 2 months old (approximately 5 to 8 mg wet weight) and *T. tubifex* adults were 8 to 9 weeks old. Tests were conducted at 23 ± 1° C with a 16L:8D photoperiod except for the test with *T. tubifex* which was conducted in the dark. The test system was static with the periodic addition of distilled water to replace water lost by evaporation. Each beaker was covered with a plastic petri dish with a central hole for aeration using a Pasteur pipette and air line. Dissolved oxygen, temperature, pH and conductivity were measured at the beginning, middle and end of each exposure period. Total ammonia was measured at test termination. Tests were terminated after 10 d for *C. riparius*, 21 d for *Hexagenia* and 28 d for *H. azteca* and *T. tubifex* by sieving the sediment samples through 250 µm mesh. Sediment from the *T. tubifex* test was sieved through 500 µm mesh plus an additional 250 µm mesh at test completion. Endpoints measured in the tests were percent survival and increase in weight (growth measured as dry weight/individual) at test termination for *C. riparius*, *Hexagenia* spp. and *H. azteca*. Initial weights of *Hyalella* and *Chironomus* were considered to be zero. End points measured in the *T.*

ellipses are used for defining degrees of difference from the reference condition using this multivariate approach (Fig. 2). Sites inside the smallest ellipse (90% probability) would be considered *equivalent to reference*; sites between the smallest and next ellipse (99% probability) would be considered *possibly different*; sites between the 99% probability and the largest ellipse (99.9% probability) would be considered *different*, and sites located outside the 99.9% ellipse would be designated as *very different*.

Whole-Sediment Laboratory Toxicity Tests

A similar approach was used to determine if the sediment could be described as toxic using the laboratory tests. The ten test endpoints were plotted in ordination space for the test and 170 reference sites. The degree of difference as described by probability ellipses constructed around the test sites provides information on the degree of difference between the test response and the reference site response. In addition individual test endpoints were compared to criteria established for single endpoints based on the reference site data (Reynoldson and Day 1998).

All analyses were performed using the BEAST software and verified by independent analysis in the source software, PATN, SAS and SYSTAT.

Results

Habitat attributes

A potential limitation of the sediment guidelines as developed so far is there restriction to the Great Lakes, there is therefore some concern over their application to sites sampled outside the area encompassed by the reference sites (Table 2). A comparison of the measured variables shows that the maximum and minimum values of the predictor variables other than longitude are within the range measured at the reference sites. It seems reasonable to assume therefore that the habitat conditions are essentially the same as those encompassed by the Great Lakes reference sites. The major concern therefore is that the geographic ranges of some species may be exceeded at the Cornwall sites. Given that the St. Lawrence R. is directly connected to the Great Lakes and therefor the same organisms could potentially be present it seemed reasonable to at least determine if the reference sites may be applicable.

Actual examination of the species data will provide an assessment of the degree of difference.

Table 2. Range of environmental variables at 252 Great Lakes reference sites and 12 test sites at Cornwall. The predictor variables used in the BEAST model are identified in bold.

	Reference sites		Cornwall sites	
	Minimum	Maximum	Minimum	Maximum
Latitude (decimal °)	41.97	48.90	45.01	45.03
Longitude (decimal °)	-76.62	-88.87	-74.73	-74.67
Water Depth (m)	1	102	5.5	14.5
Gravel (%)	0	36.2	3.8	3.8
Sand (%)	0	99.8	5.6	70.3
Silt (%)	0	95.7	15.6	68.2
Clay (%)	0.1	91.1	10.4	33.2
SiO_2 (%)	19.84	93.30	60.0	61.1
TiO_2 (%)	0.05	1.92	0.56	0.76
Al_2O_3 (%)	2.39	15.02	8.42	11.71
Fe_2O_3 (%)	0.44	21.70	3.29	4.65
MnO (%)	0.01	3.29	0.05	0.08
MgO (%)	0.28	8.35	2.59	3.14
CaO (%)	0.49	32.15	4.63	10.29
Na_2O (%)	0.12	3.53	1.79	2.46
K_2O (%)	0.74	4.18	2.23	2.82
P_2O_5 (%)	0.02	0.56	0.17	0.23
Total Nitrogen (µg/g)	0	12528	1500	4070
Total Phosphorus (µg/g)	20	7180	844	1170
Loss On Ignition (%)	0.59	38.72	10.88	18.62
Total Organic Carbon (%)	0.01	12.85	1.67	4.32
V (µg/g)	4	159	18	34
Cr (µg/g)	4	123	14	40
Co (µg/g)	1	49	5	10
Ni (µg/g)	1	348	9	27
Cu (µg/g)	0	91	21	69
Zn (µg/g)	5	482	100	823
As (µg/g)	3	115	2.5	2.5
Cd (µg/g)	0	4	0.5	0.5
Pb (µg/g)	1	153	22	179
Water pH	6.3	11.9	8.38	8.46
Dissolved Oxygen (mg/l)	4.9	15.0		
Alkalinity (mg/l)	38.1	118.0	86.2	93.2
Total Phosphorus (mg/l)	0.0014	0.1094	0.01	0.32
Total Kjeldahl Nitrogen (mg/l)	0.031	1.480	0.20	1.64
Nitrate-nitrite (mg/l)	0.001	0.416	0.24	0.30

Invertebrate Community Structure

All 12 sites were predicted to reference Group 2 based on the habitat attributes,

Table 3. Taxa characterising reference Group 2 and their occurrence at 12 Cornwall test sites.

Taxa	Occurrence at Gp 2 reference sites (%)	Number of Cornwall sites species present
Procladius spp	84.6	11
Tanytarsus spp	82.1	9
Pisidium casertanum	79.5	6
Spirosperma ferox	56.4	5
Chironomus spp	53.8	12
Cladotanytarsus spp	51.3	6
Cryptochironomus spp	51.3	11
Potamothrix vejdovskyi	51.3	0

Reference Group 2 is characterised by the fingernail clam *Pisidium casertanum* and the amphipod , *Diporeia hoyi*; and the group represented more oligotrophic conditions (Reynoldson and Day 1998). Group 2 is also more diverse than the other community groups but is the least spatially defined. While the majority of sites in this Group are located in Georgian Bay, the Group also includes sites from Lakes Erie (eastern basin), Ontario, Huron, Michigan and the North Channel. Nine taxa were common (>50% occurrence) at the reference sites (Table 3). Of these all but one, the tubificid worm *Potamothrix vejdovskyi*, was found at the Cornwall sites.

The BEAST ordination assessment was conducted at the generic level, individuals of several taxa found in the Cornwall samples were too small to be identified to species. The occurrence of 120 genera at the 39 reference sites comprising Group 2 was compared with the 12 test sites sampled in Cornwall. Two very simple descriptors of community structure are taxa richness and total abundance. The range observed at the reference sites is shown in Table 4 together with the results from the Cornwall sites. These data show the overall diversity and abundance to be well within the range observed at reference sites and a general trend to greater diversity and abundance. The results of the multivariate analysis are summarised in Figure 3 for two of the three ordination axes used to describe the data (stress = 0.1910). Four sites

(127, 164, 175, 179) are outside the 90% probability ellipse, none are outside the 99% ellipse, the 90% ellipse is defined as an area where they may be considered as different to the reference sites, with a Type 1 error of 10%. The sites showing possible stress all have high diversity and abundance. Also shown (Fig. 3) are the taxa contributing most significantly ($P < 0.01$) to the ordination analysis, these are *Procladius, Chironomus, Paralauterborniella, Pisidium* and *Piona*. The sites that are outside the 90% ellipse have increased abundance of the chironomid midges *Chironomus, Procladius* and *Paralauterborniella*, and the mite *Piona* which was not present at the reference sites. The fingernail clam *Pisidium* is reduced at several of the sites and absent from three of the four sites assessed as possibly stressed.

Table 4. Summary of taxonomic composition of benthic invertebrates at Group2 reference sites and 12 Cornwall test sites. (occurrence at reference sites is based on percentage of those sites at which a taxon was present; abundance is expressed in terms of numbers per 34.2cm²)

Site	taxa richness No of genera mean (SD)	total abundance No. per 34.2 cm² mean (SD)	Abundance and (Occurrence) of: Procladius	Pisidium	Piona	BEAST assessment Community
Reference (n=39)	20.5 (9.8)	60.6 (46.1)	1.94 (84.6%)	6.24 (82.1%)	0.0 (0.0)	
105	19	38.25	5.2	4.6	1.0	unstressed
109	19	35.20	7.2	4.2	0.2	unstressed
117	20	32.40	6.8	4.4	0.8	unstressed
127	24	98.60	3.8	0.6	1.2	possibly stressed
128	37	106.40	2.6	12.6	0.6	unstressed
131	20	51.80	5.8	10.0	0.8	unstressed
132	25	48.00	4.4	8.0	0.0	unstressed
156	26	49.80	2.2	3.6	0.0	unstressed
164	17	30.00	3.6	0.0	1.2	possibly stressed
167	28	74.00	4.8	9.4	0.8	unstressed
175	24	81.60	11.0	0.0	0.4	possibly stressed
179	26	97.80	14.4	0.0	0.6	possibly stressed

The relationship between the community responses and habitat variables has been examined by correlation of the results from the ordination of the taxonomic data with the habitat information. Seven habitat variables are significantly ($P < 0.01$) correlated with the three ordination axes scores (Figure 3), these are: sample depth, (sediment). Those oriented with the position of the Cornwall sites are illustrated in Figure 3. The fact that the test sites are shallower than most of the reference sites is indicated by the orientation of the depth axis. However, most notable is that there may be some effect of metals as the sites do appear to be associated with a metal vector, as opposed to the geographic vector. However, as noted earlier the community occurring at these sites cannot be described as degraded.

Table 5. Comparison of individual bioassay endpoints from 12 Cornwall sites with warning level values derived from Great Lakes reference sites (Reynoldson and Day 1998).

	C. riparius growth	*C. riparius* survival	*H. azteca* growth	*H. azteca* survival	*H. limbata* growth	*H. limbata* survival	*T. tubifex* CC/ad	*T. tubifex* hatch	*T. tubifex* survival	*T. tubifex* yg/ad
Warning level	<0.21	< 67.8	<0.23	< 67.0	<0.9	< 85.5	< 7.2	<38.1	<89.0	< 9.9
CS10597	0.21	93.33	0.34	100.00	4.81	100.00	11.04	**35.41**	100.00	**6.62**
CS10997	0.26	70.67	0.31	96.00	4.88	100.00	11.05	48.29	100.00	25.40
CS11797	0.30	78.67	0.29	97.33	4.31	100.00	11.20	39.61	100.00	**1.10**
CS12797	0.34	86.67	0.42	90.67	4.06	100.00	9.80	**24.38**	100.00	**1.90**
CS12897	0.32	81.33	0.48	82.67	3.26	100.00	9.45	48.51	100.00	**8.55**
CS13197	0.29	93.33	0.33	92.00	1.76	100.00	10.30	48.33	100.00	10.60
CS13297	0.28	76.00	0.32	94.67	1.45	100.00	10.20	45.15	100.00	13.65
CS15697	0.25	92.00	0.49	97.33	4.43	100.00	11.05	**27.85**	100.00	**3.55**
CS16497	0.25	88.00	0.23	93.33	3.87	98.00	11.25	**35.87**	100.00	**5.05**
CS16797	0.27	96.00	0.44	96.00	4.22	100.00	10.86	**31.89**	95.00	**4.65**
CS17597	0.30	69.33	0.25	91.67	4.10	100.00	10.65	50.51	100.00	18.15
CS17997	0.30	73.33	0.23	86.67	5.08	98.00	11.00	47.77	100.00	13.00

Sediment Toxicity

The results from the 10 test endpoints are summarised in Table 5, only two endpoints are below the warning levels derived from the reference sites, these are both related to reproduction in the tubificid oligochaete *Tubifex tubifex*. Five sites (105, 127, 156, 164, 167) have a reduced rate of cocoon hatching, suggestive of impairment in the embryogenesis of the worm eggs. All five sites not unexpectedly have reduced young also, however, a further two sites (117 and 128) have reduced young per adult. The other three species show no evidence of sediment toxicity. *Tubifex* survival is normal and gametogenesis in the adult worms is unaffected, *i.e.* the ability to produce cocoons by the adult worms. The rate of cocoon hatching, which is stimulated by the development of the eggs in the cocoons into young worms, is reduced at five sites, which has the effect of causing reduced young at those same sites, at two additional sites the number or survival of young is also reduced, this could be due to either an effect on embryogenesis, that is the eggs do not develop or there is a toxic effect on small rapidly growing individuals.

The approach being recommended at a recent Canada/Ontario workshop for assessing multiple toxicity endpoints is to use the same ordination approach for comparing reference to test sites as used to assess effects on community structure, this has the advantages that it reduces redundancy between endpoints, downweights those species (e.g. *Tubifex*), where more endpoints are measured and provides the same Type 1 error as the community assessment. Three ordination axes were sufficient to describe the relationship for the 10 endpoints (stress = 0.1268), results for two axes are shown in Figure 4, together with the 90, 99 and 99.9% probability ellipses constructed around the reference sites only. From Figure 3 no sites can be seen to be outside the 99% ellipse (middle ellipse), The 99% ellipse is taken as the boundary for sediments we would consider toxic, based on test response. Sites inside the smaller ellipse we would consider equivalent to reference, i.e. no evidence of toxicity. Four sites (105, 127, 156, 167) are between the 90% (smallest) and 99% ellipse suggesting there is evidence of mild toxicity. The four endpoints contributing most to the ordination structure (r values > 0.881) were *Tubifex* young per adult (Ttyg), *Hyalella* survival (Hasu) and *Chironomus* survival (Crsu). The response of the four Cornwall sites with some potential toxicity show that this is related to the reduced reproduction of *Tubifex* (Ttyg) as these sites are oriented along the vector associated with that endpoint. Examination of the relationship of the other two axes showed no Cornwall sites to be outside the 99% ellipse, but site 117 was outside the 90% ellipse on Axis 1 v Axis 2 and sites 127, 156 and 167 were outside the 90% ellipse on Axis I v Axis 3. In summary, five sites: 105, 117, 127, 156, and 167; show evidence of potential toxicity, largely due to reduced reproduction in *T. tubifex*, none of the other species appear to be affected.

The relationship between toxicity and sediment attributes and contaminants has been looked at for 30 variables including, physical attributes (particle size), major elements, and metals. This has been done by relating the observed patterns in ordination space with the habitat attributes. Six variables show a statistically significant relationship ($P < 0.01$) with the ordination axes. These are, in descending order: %silt, %SiO2, Zn, %CaO, Particle size (75th percentile) and % loss on ignition, their orientation relative to the sites is shown in Figure 4. From Figure 4 the two variables that appear associated with the movement of the Cornwall sites outside the reference group are elevated levels of zinc and a high silt content.

Table 6. Summary of sediment quality based on invertebrate community structure, sediment toxicity and sediment chemistry.

Site	BEAST assessment		Variables exceeding OMOE sediment criteria		Variables > 2 SD than reference
	Community	Toxicity	low	severe	
105	unstressed	possibly toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb		Zn
109	unstressed	non toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb	Zn	Cu, Zn, Pb
117	unstressed	possibly toxic	TP, TOC, Cu, Zn, Pb		Zn
127	possibly stressed	possibly toxic	TP, TOC, Cu, Zn		Gravel, 25%PS
128	unstressed	non toxic	TP, TOC, Cu, Zn		
131	unstressed	non toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb		Cu Zn
132	unstressed	non toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb		
156	unstressed	possibly toxic	TP, TOC, Cu, Zn		
164	possibly stressed	non toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb		Cu Zn
167	unstressed	possibly toxic	TP, TOC, Ni, Cu, Zn		
175	possibly stressed	non toxic	TP, TOC, Cr, Ni, Cu, Zn		
179	possibly stressed	non toxic	TP, TOC, Cr, Ni, Cu, Zn		

Comparison of community and toxicity data

The assessments of community and toxicity effects are summarised in Table 6, in addition the habitat attributes that either exceed Ontario sediment criteria (Persaud et al 1992) or are outside the range observed at the reference sites are also identified. Again it should be emphasised that no site showed definite evidence of an impaired community or toxic sediment. Those sites outside the normal range of variability of reference sites were only outside the 90% probability ellipse. Of the total of eight sites showing some deviation from reference, only one (Site 127) showed evidence of modified communities associated with sediment toxicity. However, at Site 127 the levels of the measured contaminants did not exceed the normal range observed at reference sites (mean + 2SD), the main difference at this site is the high proportion of gravel and sand, and the generally larger particle size.

In general there is no strong evidence for either impaired invertebrate communities or any associated sediment toxicity. While several variables exceed the OMOE low effect level criteria, this also occurs at reference sites, at only one site did any measured value exceed the severe effect criteria, Zn at Site 109, this site showed no indication of either toxicity or impaired community structure. There is some effect on reproduction of the worm *Tubifex*, this may account for the absence of the worm *P. vejdovski*, a species present at many (53%) of the reference sites. However, immature worms were found at all but one site (164) and the apparent absence of *Potamothrix* is likely due to the absence of identifiable mature animals. In conclusion, these data do not indicate a sediment contamination problem associated with the samples taken form the Cornwall area.

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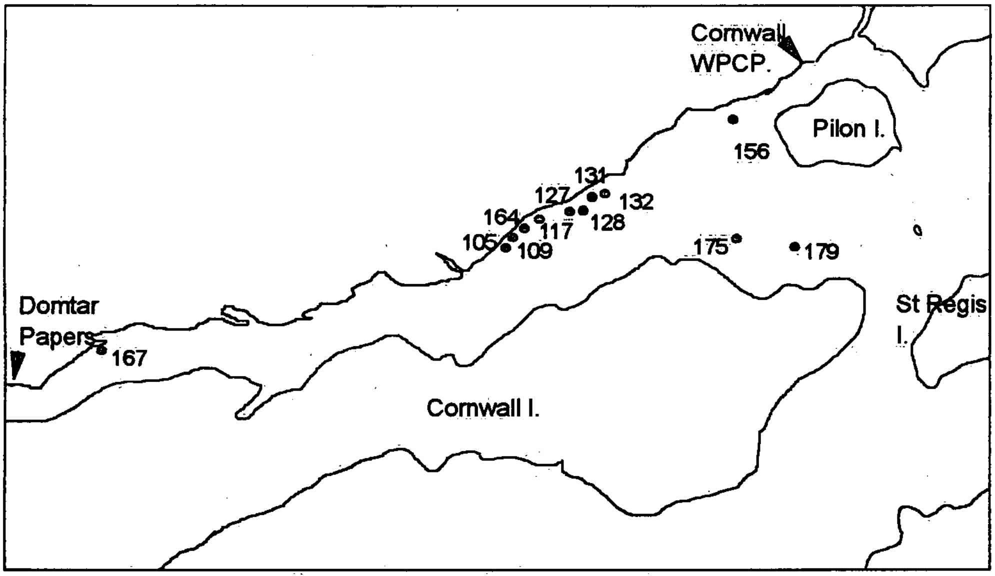

Figure 1. Location of 12 sediment sampling stations in the Cornwall area of the St. Lawrence AOC, with major discharges (from Dreier et al 1997).

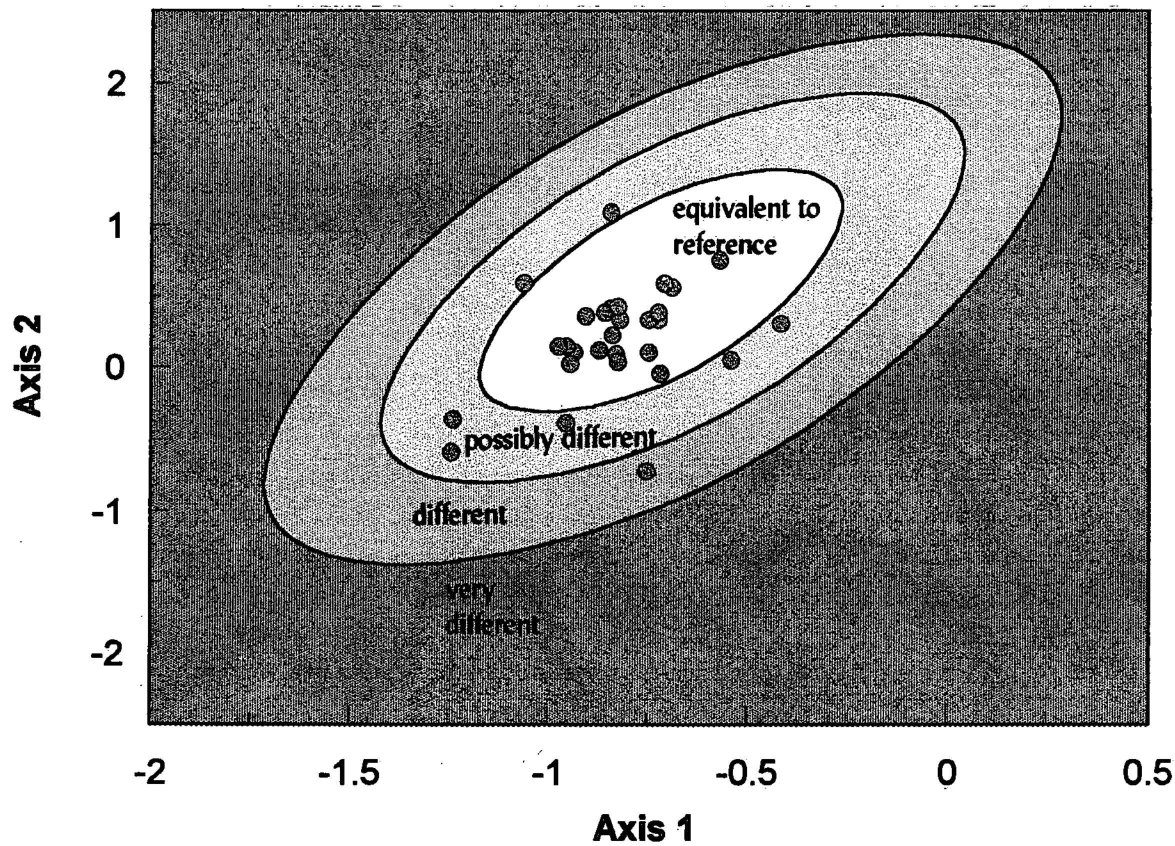

Figure 2. Impairment stress levels derived for reference sites in HMDS ordination space. Bands, based on 90, 99 and 99.9% probability ellipses, are identified as A (equivalent to reference), B (possibly different), C (different) and D (very different).

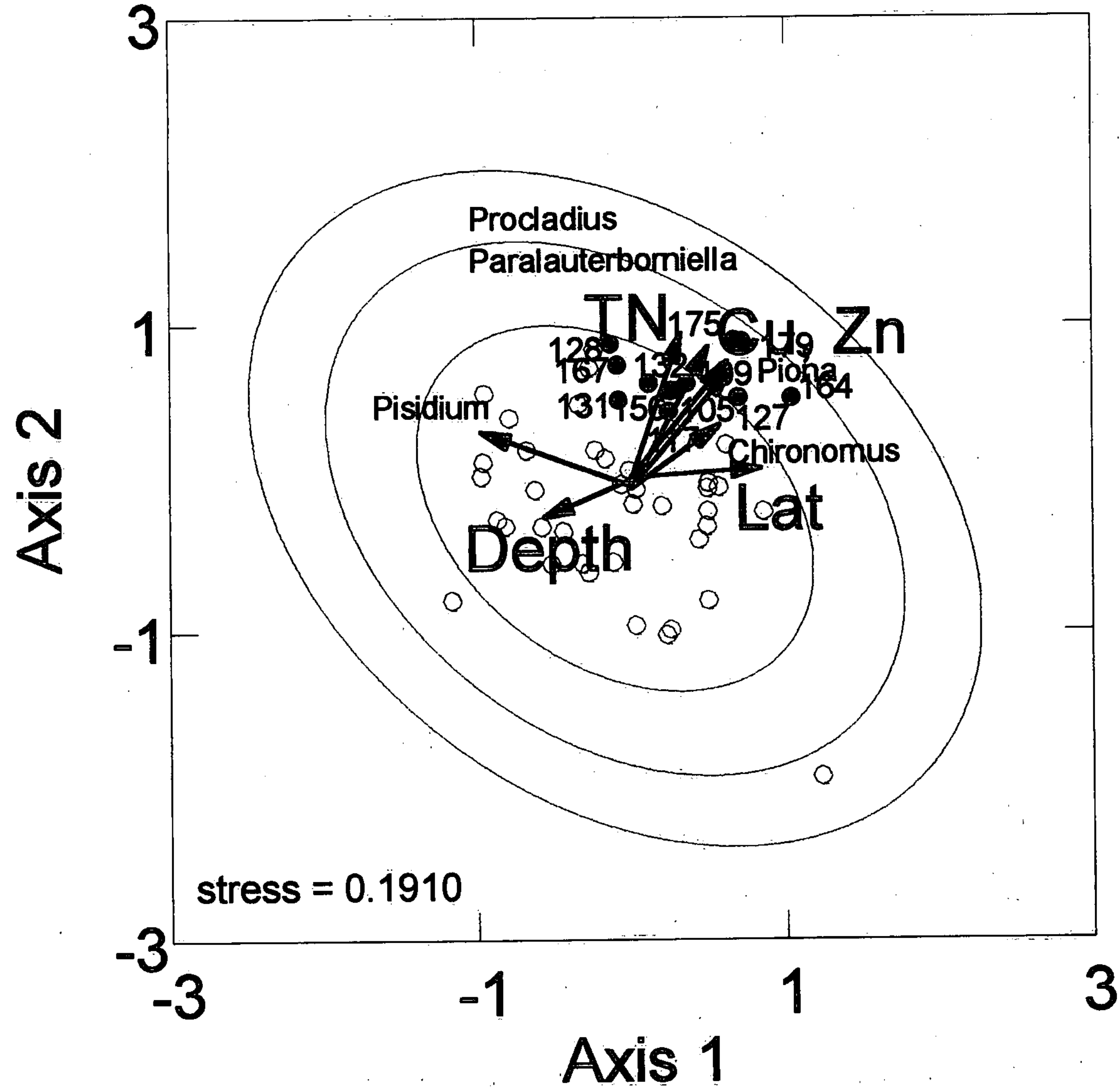

Figure 3. Assessment of Cornwall sites using HMDS ordination at the genus level, showing 90, 99 and 99.9% ellipses around reference sites (open circles) and 12 test sites (solid circles) sampled at Cornwall. The contribution of the taxa and environmental variables are shown by arrows.

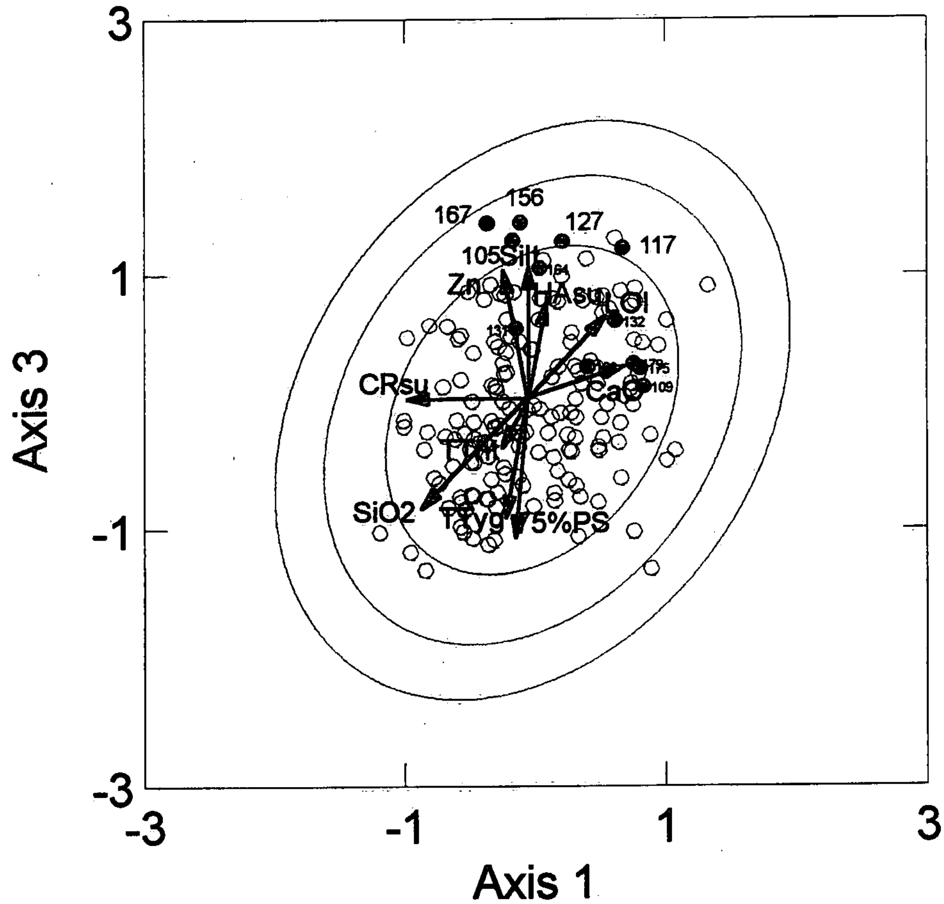

Figure 4. Assessment of Cornwall sites using HMDS ordination of 10 sediment toxicity endpoints, showing 90, 99 and 99.9% ellipses around reference sites (open circles) and 12 test sites (solid circles) sampled at Cornwall. The contribution of the endpoints and environmental variables are shown by arrows.

Appendix 1. Summary of sediment variables for 12 Cornwall sites.

	Average +2SD	OMOE low	OMOE severe	105	109	117	127	128	131	132	156	164	167	175	179
% Gravel	2.54			0	0	0	3.81	0	0	0	0	0	0	0	0
% Sand	108.84			14.57	5.57	50.27	70.28	45.9	14.03	22.71	46.64	16.77	26.98	26.58	17.32
% Silt	83.67			64.48	68.23	31.99	15.55	33.64	52.8	49.76	29.42	56.7	45.22	48.05	53.98
% Clay	72.72			20.95	23.2	17.74	10.37	20.46	33.17	27.53	23.94	26.53	27.8	25.37	28.7
Mean Particle Size	237.38			17.33	15.77	41.49	195.67	31.68	8.12	13.01	28.75	13.97	16.81	15.66	13.07
25% Particle Size	388.21			35.57	35.43	148.37	658.23	108.49	21.77	37.14	102.19	37.12	65.44	66.11	39.47
75% Particle Size	158.44			5.37	4.53	7.5	30.24	5.75	2.26	3.25	4.37	3.46	3.02	3.8	2.97
Sio2 (%)	85.79			53.92	54.51	59.25	61.08	55.78	50.96	54.75	59.47	54.41	58.32	53.12	54.88
Tio2 (%)	0.92			0.67	0.65	0.59	0.56	0.76	0.56	0.63	0.56	0.59	0.64	0.66	0.65
Al2o3 (%)	15.75			10.65	10.85	9.52	8.42	9.78	9.68	9.64	10.31	10.68	11.02	11.71	11.65
Fe2O3 (%)	8.23			4.24	4.05	3.47	3.45	4.17	3.38	3.46	3.29	3.73	3.51	4.65	4.51
MnO (%)	0.40			0.06	0.06	0.06	0.07	0.08	0.06	0.06	0.06	0.06	0.05	0.08	0.08
MgO (%)	5.81			3.06	3.11	2.78	3.14	2.96	2.59	2.61	2.66	2.79	2.74	3.01	3.04
CaO (%)	17.84			6.71	6.62	6.58	7.73	7.29	10.29	8.83	5.72	7.32	4.63	5.59	6.08
Na2O (%)	2.90			1.93	2.03	2.11	1.87	2.12	1.79	1.88	2.46	2.17	2.26	1.91	2.02
K2O (%)	3.45			2.55	2.59	2.32	2.34	2.31	2.23	2.42	2.64	2.64	2.57	2.82	2.82
P2O5 (%)	0.35			0.19	0.2	0.18	0.17	0.19	0.23	0.21	0.19	0.21	0.2	0.21	0.2
Total Nitrogen (ppm)	6501			3850	3650	2000	1500	2140	2910	2530	1890	2790	2820	4070	3570
Total Phosphorus (ppm)	1456	600	2000	952	1170	913	910	924	1110	1020	844	942	980	980	1090
Loss On Ignition (%)	26.21			14.63	14.48	12.14	10.88	13.91	18.62	15.84	11.02	14.17	13.15	14.31	13.82
Total Organic Carbon (%)	6.59	1	10	3.71	3.97	3.22	1.67	3.69	4.22	3.46	2.52	3.48	4.32	3.42	3.08
V (ppm)	91			29	28	24	18	26	26	26	19	25	24	34	33
Cr (ppm)	95	26	110	37	40	26	14	20	29	27	19	36	25	35	33
Co (ppm)	24			7	7	6	6	8	7	7	5	9	6	10	8
Ni (ppm)	119	16	75	22	23	15	9	13	20	18	13	19	20	27	23
Cu (ppm)	56	16	110	56	69	55	21	27	56	45	22	61	35	40	36
Zn (ppm)	276	120	820	676	823	554	100	121	363	238	140	580	111	130	124
As (ppm)	40	6	33	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Cd (ppm)	2.3	0.6	10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Pb (ppm)	97	31	250	69	179	85	22	28	50	47	25	131	31	28	26

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