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Collingwood Harbour: Sediment Assessment 1995

By:

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NWRI Contribution # 98-275

NATIONAL WATER RESEARCH INSTITUTE

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Environnement Canada

COLLINGWOOD HARBOUR: SEDIMENT ASSESSMENT 1995

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MANAGEMENT PERSPECTIVE

Title	Collingwood Harbour: sediment assessment 1995
Authors	T.B. Reynoldson and K.E. Day
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EC Priority/Issue: The National Water Research Institute received funding from 1991-1994 under the Great Lakes Action Plan to develop methods for the assessment of contaminated sediments. In 1992 and 1993, in collaboration with EP, Ontario Region and the Collingwood Harbour RAP, extensive sampling of the sediments in Collingwood Harbour was conducted by personnel from NWRI. The data collected included samples for invertebrate community structure, sediment toxicity tests and sediment and water chemistry. These samples were collected prior to dredging and were used to identify areas in the Harbour where remediation was required. After samples were collected, EP, Ontario Region, conducted a remedial dredging study to demonstrate innovative sediment removal techniques. In 1995, at the request of the RAP co-ordinator, the same sites were re-sampled by NWRI to determine whether or not the area had responded to the remedial dredging.

Current status: Toxicity tests conducted with sediment collected in 1995 from the same sites indicated an overall worsening in several of the measured endpoints. Using the reference condition approach for the analysis of benthic invertebrate community structure 16 of the re-sampled sites were classified as potentially stressed, 7 as stressed and 2 as severely stressed. Overall, there was a slight trend for most of the sites to be classified as more similar to the reference group than in previous sampling. Examination of the relationship of the environmental variables to the community structure suggests that the invertebrate community is responding to nutrient enrichment as much, or more, than metal contamination. Selected physical and chemical parameters measured in samples of sediment both before and after dredging indicate that dredging did reduce levels of total copper, zinc and lead in the boat slips and some areas of the inner Harbour. The data suggest that there have not been any real improvements in the quality of sediments located in Collingwood Harbour since dredging took place. In fact, there is some suggestion that the quality of the sediments may actually have deteriorated either due to (1) a change in the physical and chemical attributes of the sediment which may (i) affect the bioavailability of contaminants or (ii) change the habitat required by benthic invertebrates for sustainability of populations (2) shifts in the areal extent of contamination throughout the Harbour and exposure of historical contamination; (3) additional toxicity from a continued input of measured or unmeasured contamination due to watershed runoff, point-source inputs or in-place contaminants from inside or outside the Harbour; or (4) continued eutrophication of the Harbour and its subsequent effects on benthic community structure.

Next steps

Recommendations for further work include (1) chemical analyses of archived sediment samples to determine metal speciation and presence of other priority pollutants (2) sediment mapping of the boat slips and inner Harbour to determine the extent of fine-grain deposition (3) re-sampling of sites for benthic invertebrate community structure to determine if communities are returning to reference condition (4) repeat whole sediment toxicity tests with the most sensitive species, *T. tubifex* and include more complete sediment analyses including metal species.

Executive Summary

The National Water Research Institute received funding from 1991-1994 under the Great Lakes Action Plan to develop methods for the assessment of contaminated sediments. In 1992 and 1993, in collaboration with EP, Ontario Region and the Collingwood Harbour RAP, extensive sampling of the sediments in Collingwood Harbour was conducted by personnel from NWRI. The data collected included samples for invertebrate community structure, sediment toxicity tests and sediment and water chemistry. These samples were collected prior to dredging and were used to identify areas in the Harbour where remediation was required. After samples were collected, EP, Ontario Region, conducted a remedial dredging study to demonstrate innovative sediment removal techniques. In 1995, at the request of the RAP co-ordinator, the same sites were re-sampled by NWRI to determine whether or not the area had responded to the remedial dredging.

The data collected from Collingwood Harbour in all three years was compared to a much larger data base which has been assembled from 252 reference sites in Lakes Ontario, Erie, Michigan, Superior and Huron. Using a statistical model, data collected from Collingwood Harbour) were compared with a subset of reference sites with similar environmental attributes. Interpretation of the data was based on how similar or divergent the test sites from Collingwood Harbour were from the reference condition. This 'reference condition' approach (Reynoldson et al., 1997) has been adopted as the basis for numeric biological sediment objectives for the Great Lakes described as the B.E.A.S.T. (Reynoldson et al., 1995). Sites were assigned into the following categories of toxicity based on their similarity or difference to reference sites: unstressed/non-toxic; potentially stressed\toxic; stressed\toxic; severely stressed\toxic.

Toxicity tests conducted in 1992-93 indicated that reproduction (% hatch of cocoons and total young per adult) by *T. tubifex* was severely affected at one site (6705) in the inner Harbour; reproduction was stressed within the east slip (6708) and one other inner Harbour site (6703). Potential stress on reproduction in this species was indicated at several other sites (6704, 6706, 6707,6720, 6723 and 6727) in the boat slips and inner Harbour. Physical and chemical parameters implicated in these reductions included total phosphorus (TP) in the sediment, ferric oxide, and metals (zinc, copper, lead and cobalt).

Toxicity tests conducted with sediment collected in 1995 from the same sites indicated an overall decline in several of the measured endpoints. Although reproduction by *T. tubifex* had improved at sites 6703, 6704, 6705 and 6708, percent hatch of cocoons and total young per adult worm was still poor at sites 6707, 6709, 6710 and 6711, and had declined at sites 6714, 6715, 6719 and 6720 to 6727. Again, the physical and chemical parameters implicated in these reductions included TP, lead, zinc, copper and ferric oxide.

Using the reference condition approach for the analysis of benthic invertebrate community structure, the Collingwood Harbour sites were assigned to one of five reference condition community groups found in the Great Lakes based on their environmental attributes. Sites were assigned to one of four categories (above) based on their similarity to the reference group. None of the sites in Collingwood Harbour was found to be equivalent in community structure to those of the reference communities. Of the 25 sites sampled in Collingwood Harbour prior to dredging, 6 were classified as potentially stressed, 6 as stressed and 13 as severely stressed. The sites exhibiting the greatest degree of stress in the 1992 sampling period were located in the east slip. Sites in the west slip and inner Harbour were all potentially stressed.

In 1995, 16 of the re-sampled sites were also classified as potentially stressed, 7 as stressed and 2 as severely stressed. The west slip sites were now classified as stressed rather than potentially stressed as in 1992-93. Overall, there was a slight trend for most of the remaining sites to be classified as more similar to the reference group than previously determined. A description of the taxa responsible for sites in Collingwood Harbour being classified as dissimilar to reference sites included increased abundances of tubificid worms and naidids and the disappearance of more sensitive species such as sponges, fingernail clams, caddisflies and shrimps. Examination of the relationship of the environmental variables to the community structure suggests that the invertebrate community is responding to nutrient enrichment as much, or more, than metal contamination.

Selected physical and chemical parameters measured in samples of sediment both before and after dredging incicate that dredging did reduce levels of total copper, zinc and lead in the boat slips and some areas of the inner Harbour. Dredging did not appear to expose more contaminated sediment which may have been buried deeper in the Harbour (historical) but concentrations of some metals (e.g., copper, zinc, lead) were still above the Province of Ontario's severe effects levels at some sites. Particle size distribution (i.e., % silt, % clay and % sand) shifted slightly in areas which received dredging. For example, in both slips, the % sand decreased whereas the % clay increased by approximately 10%. A similar shift was noted in the inner Harbour sediments especially following dredging activity.

The data suggest that there have not been any real improvements in the quality of sediments located in Collingwood Harbour since dredging took place. In fact, there is some suggestion that the quality of the sediments may actually have deteriorated either due to: (1) a change in the physical and chemical attributes of the sediment which may (i) affect the bioavailability of contaminants or (ii) change the habitat required by benthic invertebrates for sustainability of populations; (2) shifts in the areal extent of contamination throughout the Harbour and exposure of historical contamination; (3) additional toxicity from a continued input of measured or unmeasured contamination due to watershed runoff, point-source inputs or inplace contaminants from inside or outside the Harbour; or (4) continued eutrophication of the Harbour and its subsequent effects on benthic community structure. Each of these possibilities are discussed in detail in the attached report.

Recommendations for further work include: (1) chemical analyses of archived sediment samples to determine metal speciation and presence of other priority pollutants; (2) sediment mapping of the boat slips and inner Harbour to determine the extent of fine-grain deposition; (3) re-sampling of sites for benthic invertebrate community structure to determine if communities are returning to reference condition; (4) repeat whole sediment toxicity tests with the most sensitive species, *T. tubifex* and include more complete sediment analyses including metal species.

Background

The National Water Research Institute received funding from 1991-1994 under the Great Lakes Action Plan (i.e., Cleanup Fund and the Preservation Fund) to develop methods for the assessment of contaminated sediments located in Areas of Concern (AOCs). In 1992 and 1993, in collaboration with EP, Ontario Region and with the support of the Collingwood Harbour RAP team, extensive sampling of the sediments in Collingwood Harbour was conducted by personnel from NWRI. The data collected included samples for invertebrate community structure, sediment toxicity tests and sediment and water chemistry. These samples were collected prior to dredging and were used, in part, to identify those areas in the Harbour where remediation was required (Reynoldson and Day 1994). Six sites (6706, 6707, 6708, 6709, 6710 and 6711) were located within the east and west boat slips where high metal concentrations had been previously noted. The remaining 19 sites (6703, 6704, 6705, 6712-6727) were located in the inner Harbour (Fig. 1). After samples were collected in 1992-93, EP, Ontario Region conducted a remedial dredging study to demonstrate innovative sediment removal techniques. In 1995, at the request of the RAP co-ordinator, the 1992-93 sites were re-sampled to determine whether or not the area had responded to the remedial dredging.

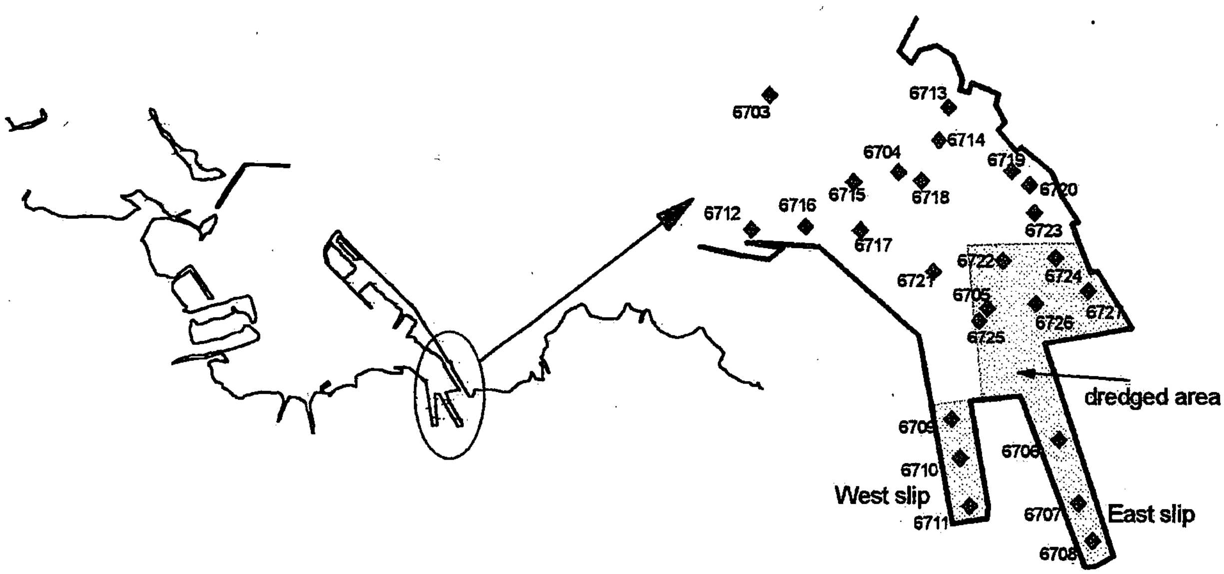

Figure 1. Location of sample sites in slips and inner portion of Collingwood Harbour (dredged area shown in stipple).

The data collected from Collingwood Harbour in all three years was compared to a much larger data base which has been assembled from 252 reference sites in Lakes Ontario, Erie, Michigan, Superior and Huron. This data base includes information on, (1) the structure of the benthic invertebrate communities, (2) measured environmental variables in both the water column and sediment; and (3) the responses of four species of benthic invertebrates, *Hyalella azteca*, *Chironomus riparius*, *Hexagenia* spp. and *Tubifex tubifex*, exposed in the laboratory to whole sediment collected from each site. A statistical technique called multivariate discriminant analysis

(MDA) is used to group reference sites by selected physical, chemical and biological characteristics. Data collected at test sites is compared with the group of reference sites expected to have similar environmental attributes in the absence of human impact and managerial decisions can be made based on how similar or divergent the test site(s) are from the reference condition. This 'reference condition' approach has been adopted as the basis for numeric biological sediment objectives for the Great Lakes described as *B.E.A.S.T.* (Reynoldson et al., 1995).

Results

Sediment toxicity

Ten lethal and sublethal chronic endpoints were measured for four species of benthic invertebrates exposed to whole sediment collected from Collingwood Harbour in 1992, 1993 and 1995. The endpoints measured were percent survival and growth of juvenile amphipods (*H. azteca*), midges (*C. riparius*) and mayflies (*Hexagenia*) as well as percent survival of adult *T. tubifex* worms and reproduction by the worm (percent hatch of cocoons, total cocoons per adult worm and total young per adult worm). All tests were performed by experienced laboratory personnel with Good Laboratory Practice (GLP) and associated QA/QC.

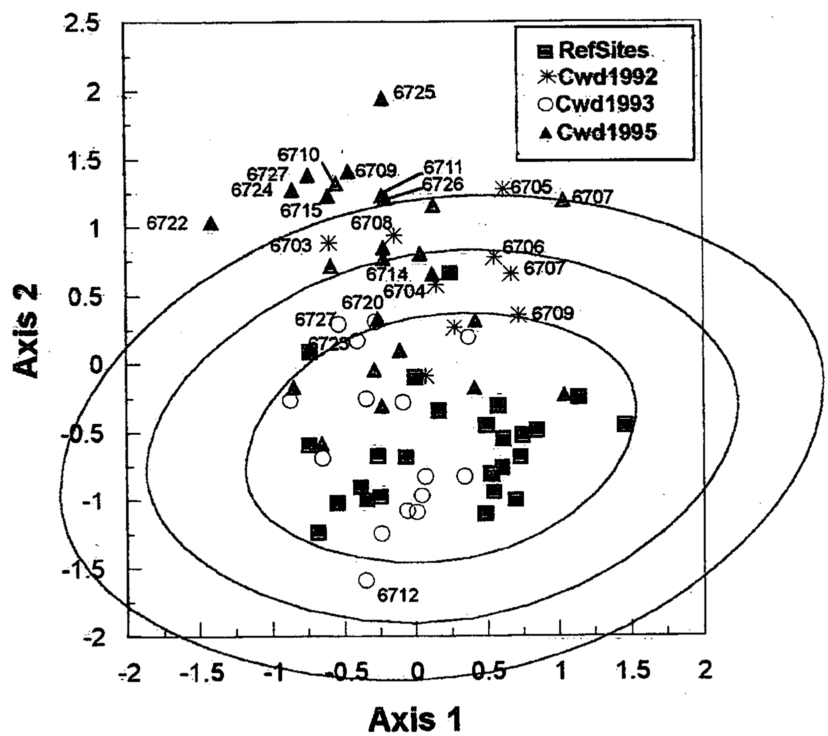

Figure 2. Comparison of reference and Collingwood Harbour sites based on four laboratory tests

The results from the sediment toxicity tests performed with Collingwood Harbour sediment were compared to the results in reference sediment(s) with similar environmental attributes using a multivariate statistical approach and are plotted in ordination space in Figure 2. The location of a test site is a measure of its similarity to the reference condition. Sites are assigned to one of four categories by their proximity to the reference group. The ellipses in Figure 2 are representative of several categories which are probability-based and are as follows:

inside the 90% probability ellipse is equivalent to reference - unstressed/non-toxic;

between the 90 and 99% probability ellipse - potentially stressed/toxic;

between the 99 and 99.9% probability ellipse - stressed/toxic;

outside the 99.9% probability ellipse - severely stressed/toxic.

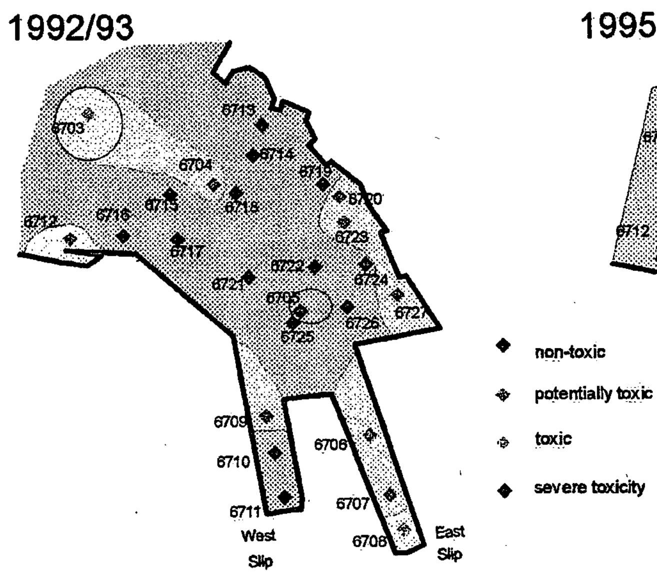

Figure 3. Collingwood Harbour with sites classified by laboratory sediment toxicity tests.

Toxicity tests conducted in 1992-93 indicated that reproduction by *T. tubifex* was severely affected at site 6705 in the inner Harbour. In addition reproduction within the east slip (6708) and the outer Harbour (6703) was stressed . Potential stress on reproduction in this species was indicated at sites 6704, 6706, 6707, 6720, 6723 and 6727 (Figures 2, 3).

Survival and growth of the other three species was good to excellent at all sites with the exception of percent survival of the mayfly, *Hexagenia* spp., at site 6712, and the chironomid *C. riparius* at 6709. Physical and chemical parameters implicated in these reductions included total phosphorus (TP) in the sediment, ferric oxide, and metals (zinc, copper, lead and cobalt). Using a median rank for toxicity test response then none of the sites would be designated as toxic (Figure 4).

Toxicity tests conducted with sediment collected in 1995 from the same sites indicated an overall decline in several of the measured endpoints. Although reproduction by *T. tubifex* had improved at sites 6703, 6704, 6705 and 6708, percent hatch of cocoons and total young per adult worm was still poor at sites 6707, 6709, 6710 and 6711, and had declined at sites 6714, 6715, 6719, 6720, 6721, 6722, 6723, 6724, 6725, 6726 and 6727. Percent survival of the amphipod was reduced at site 6707. Again, the physical and chemical parameters implicated in these reductions included TP, lead, zinc, copper and ferric oxide.

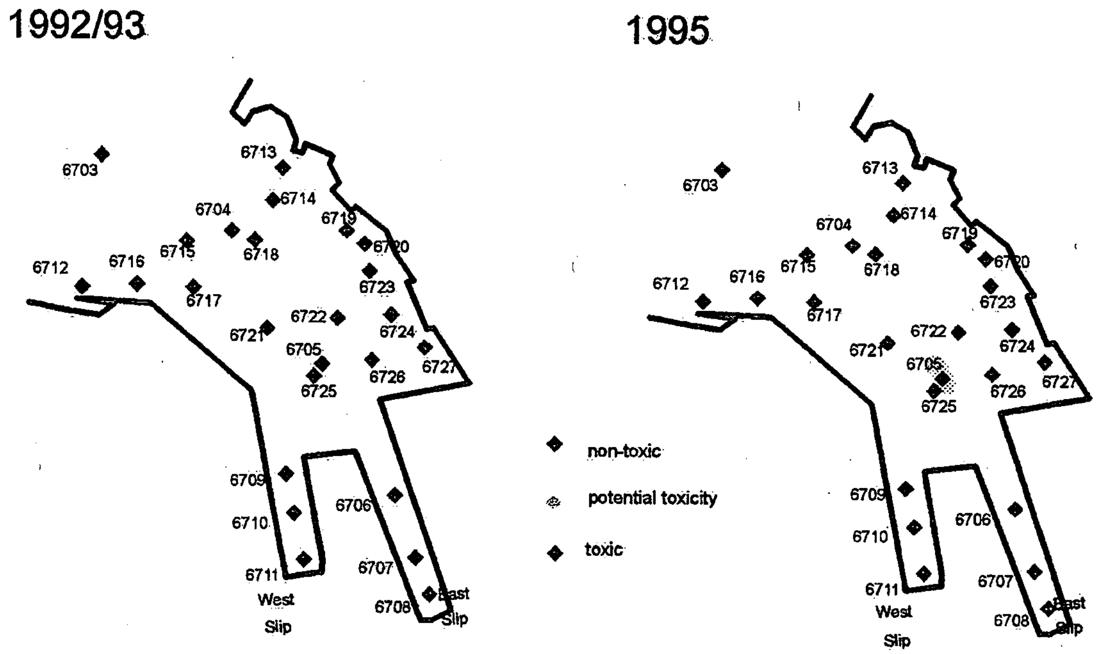

Figure 4 Sediment toxicity based on median rank.

Invertebrate community structure

Using the reference condition approach (Reynoldson *et al.* 1995, in press), the Collingwood Harbour sites were assigned, from their environmental attributes, to one of five reference condition community groups found in the Great Lakes. The condition of the benthic invertebrate community in the Harbour was then assessed by plotting the reference sites and the Collingwood Harbour sites in ordination space (Figure 5). The location of a test site is a measure of its similarity to a group of reference sites. Sites are assigned to one of four categories by their proximity to the reference group. The categories are the same as those described in the toxicity section above.

The analysis of the 1992-93 and 1995 data from Collingwood Harbour show that none of the sites are equivalent to those of the reference group. Of the 25 sites sampled in Collingwood Harbour prior to dredging, 6 were classified as potentially stressed, 6 as stressed and 13 as severely stressed. Examination of the spatial distribution of the sites from Collingwood Harbour (Figure 6) shows that the sites exhibiting the greatest degree of stress in the 1992 sampling period were located in the east slip. Sites in the west slip and inner Harbour were all potentially stressed. The thirteen sites sampled in 1993 prior to dredging were also classified as severely stressed; however, as these samples were collected in the spring whilst all the other samples, including the reference site samples were collected in the fall, this may be a seasonal effect (see below).

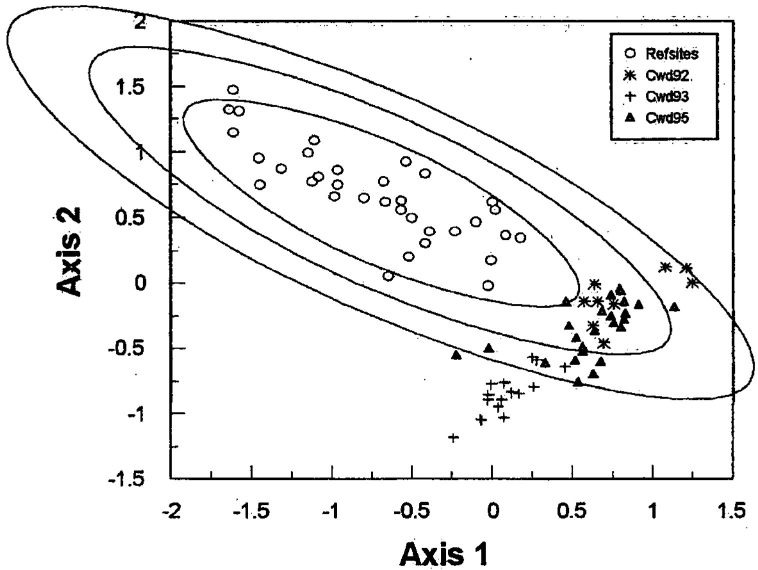

Figure 5 Comparison of reference and Collingwood Harbour sites, showing BEAST stress ellipses.

In 1995, 16 of the re-sampled sites were classified as potentially stressed, 7 as stressed and 2 as severely stressed. The west slip sites were now classified as stressed rather than potentially stressed as in 1992-93. Two of the three sites in the east slip were more similar to the reference sites than previuosly. Overall, there was a slight trend for most of the remaining sites to be classified as more similar to the reference group than in 1992/93. In the inner Harbour, 7 of 19 sites were unchanged, 5 sites improved by one category and 7 sites improved by two categories. Those sites in the dredged area all showed some improvement.

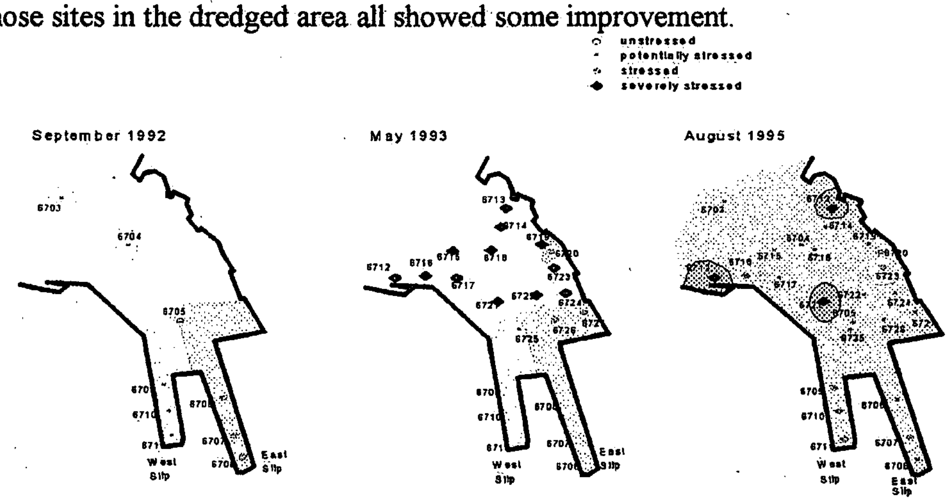

Figure 6. Comparison of selected invertebrate families at reference sites an Collingwood Harbour.

Examination of the taxa responsible for sites in Collingwood Harbour being classified as dissimilar to reference sites can be useful in identifying the type of stress at a site. This can be done by identifying which taxa are responsible for the position of site(s) in ordination space and are shown in Figure 6, together with those environmental variables that are related to the community structure. Eight families show a relationship with the ordination structure. The tubificid worms (Tub) are indicators of sediment enrichment; sites with high numbers of tubificid worms are located toward the bottom left of the lefthand plot. In 1992-93, they had highest numbers in the west slip and inner Harbour and were reduced in the east slip. In 1995, their numbers were above reference in the east and west slips (7.2 per sample for reference vs. 9.8 and 52.8 per sample, respectively in the slips) and in the inner Harbour (39.8 per sample). The increase in naidid worms was only observed at sites sampled in the spring of 1993. These were all inner Harbour sites and the increased abundance resulted in these sites being positioned outside the stress ellipses but this result is likely a seasonal effect related to spring reproduction. Five families showed reduced numbers relative to the reference condition. These were the Spongillidae (sponges), Sphaeridae (fingernail clams), Gammaridae (shrimps), Leptoceridae (caddis fly) and Hydrobiidae (mites). All these families were absent from almost all sites, both before and after the dredging, and sites with low numbers of these families are located toward the bottom right of the ordination plot.

In summary, diversity was lower in the Harbour (3.0 - 4.7 families) than at the reference sites (10.5 families), although there was an increase in the number of families collected after dredging in both the slips and inner Harbour (5.3 - 5.8 families). It was also noteworthy that the Tubificidae remained the most abundant family and occurred in numbers in Collingwood Harbour sites that were much higher than at reference sites even though reproduction of this species in laboratory tests was reduced. However, there is continued absence of more sensitive species. This community response is indicative of organic enrichment.

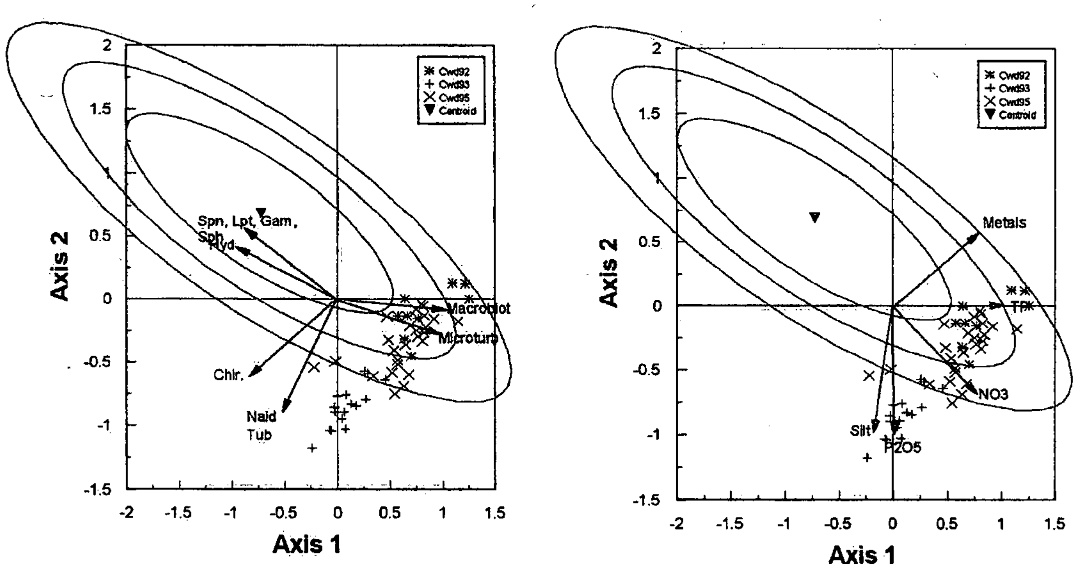

Figure 7. Taxa and environmental gradients at reference and Collingwood Harbour sites.

Examination of the relationship of the environmental variables to the community structure (Figure 7) supports the interpretation that the invertebrate community is responding to nutrient enrichment as much, or more, than metal contamination. The data show that sites with high metal levels would be located to the top right side of the ordination plot and sites with high nutrient levels would be located to the bottom and left of the ordination plot

Sediment chemistry

Selected physical and chemical parameters were also measured in sediment collected both before and after dredging and are presented in Table 1. The values are averages for sites located in each of the slips and for areas within the inner Harbour which were either dredged or left undisturbed. Both the east and west boat slips of Collingwood Harbour had been known previously to be heavily contaminated with metals and our samples indicated that concentrations of copper, zinc and lead were very high in sediments collected from these areas in 1992. Some areas in the inner Harbour also had elevated levels of these contaminants. The data show that dredging did reduce levels of total copper, zinc and lead in the slips. Concentrations of metals in the area of the inner Harbour which was dredged were not significantly different from areas which were left undisturbed following dredging with the exception of zinc which was still higher in the dredged sites than the undredged areas. Dredging did not appear to expose more contaminanted sediment which may have been buried deeper in the Harbour (historical) but concentrations of some metals (e.g., copper, zinc, lead) were still above the Province of Ontario's severe effects levels at some sites.

Table 1. Concentration of selected variables before and after remedial dredging in Collingwood Harbour

Variable (OMEE severe effect concentration)	Reference	East Slip		West Slip		Inner Harbour undisturbed		Inner Harbour dredged	
		1992	1995	1992	1995	1992/3	1995	1992/3	1995
Cu ppm (110)	21.5	3042	1804	401	115	41	50	63	49
Zn ppm (820)	99.3	10750	2967	1401	370	161	138	264	163
Pb ppm (250)	39.1	802	651	260	322	78	51	154	75
Fe_2O_3 ppm	4.0	17.4	8.5	5.6	4.2	3.2	3.2	3.7	3.2
Sand %	19.7	37.5	21.8	15.3	4.2	11.7	7.9	17.0	9.1
Silt %	51.8	44.1	48.0	66.0	66.7	68.0	64.6	59.0	59.4
Clay %	27.4	17.2	29.6	18.6	29.0	20.3	23.8	27.4	30.9
TP ppm	650	1085	779	1425	934	937	928	939	892
P_2O_5 ppm	0.2	0.02	0.26	0.34	0.34	0.28	0.28	0.27	0.27

Particle size distribution (i.e., % silt, % clay and % sand) shifted slightly in areas which received dredging. For example, in both slips, the % sand decreased whereas the clay increased by approximately 10%. A similar shift was noted in the inner Harbour sediments especially following dredging activity. The presence of a relatively high silt content in both boat slips following dredging is suggestive of a continuing source of fine-grained material. Both the change in % clay and % silt content as well as a change in ferric oxide may affect the bioavailability of contaminants such as metals. In addition, an elevated level of lead in the west slip following dredging may indicate a continued source of contaminants.

Interpretation of Results

The data suggest that there have not been any real improvements in the quality of sediments located in Collingwood Harbour since dredging took place. In fact, there is some suggestion that the quality of the sediments may actually have deteriorated either due to (1) a change in the physical and chemical attributes of the sediment which may (i) affect the bioavailability of contaminants or (ii) change the habitat required by benthic invertebrates for sustainability of populations (2) shifts in the areal extent of contamination throughout the Harbour and exposure of historical contamination; (3) additional toxicity from a continued input of measured or unmeasured contamination due to watershed runoff, point-source inputs or in-place contaminants from inside or outside the Harbour; or (4) continued eutrophication of the Harbour and its subsequent effects on benthic community structure. Each of these possibilities are discussed in detail below.

(1) Change in the physical and/or chemical attributes of the sediment.

(i) Multivariate analysis did indicate that metals such as copper, zinc and lead were responsible for some of the decline in tubificid reproduction in laboratory bioassays. Chemical analyses for these metals did not indicate an increase in their concentrations at any sites within Collingwood Harbour; in addition, in areas of heavy contamination such as the boat slips, concentrations of copper and zinc declined. However, these measurements are for total metals which do not give a true indication of the speciation of the metal ions present nor their bioavailability. A change in particle size distribution, especially an increase in % clay, could affect the speciation of these metals and their bioavailability. Further investigation would be required to determine if metal toxicity is the reason for any increased toxicity in sediments of Collingwood Harbour.

(ii) The removal of fine-grained sediment from areas of Collingwood Harbour during dredging could result in a change in the particle size distributions of the sediment. Such a shift was shown in the measurements of % sand and % clay in areas of the Harbour which were dredged (Table 1). Benthic invertebrate communities have specific habitat requirements and are known to respond to grain size differences both in field studies and in laboratory toxicity tests. An increase in % clay could have a detrimental effect on the reproductive effort of tubificid worms and other benthic invertebrates due to difficulties in burrowing activity and in the nutrients obtained from ingestion of sediment particles as food.

The possibility that a change in the sediment matrix is responsible for the poorer reproduction is supported by the fact that the effect occurred in the areas that were dredged , the undisturbed areas showing little change in response.

(2) Shifts in the areal extent of contamination throughout the Harbour and/or exposure of historical contamination

Removal of material during dredging may have resulted in a resuspension of fine-grained suspended particles throughout the water column within the inner Harbour during dredging. This material and its associated contaminant load would then be re-deposited at other areas within the Harbour. Chemical measurements after dredging did not indicate an increase in any concentrations of metals. However, many contaminants which may be toxic to benthic invertebrates were not measured in this study due to fiscal restraints and therefore we have no data from which to determine if toxicity from other contaminants re-distributed during dredging is causing detrimental effects. Further chemical analyses of a list of priority pollutants would be beneficial in archived sediments from throughout the Harbour.

If this explanation were likely one would expect the change in response to be more widespread or to occur in sites that were not dredged.

(3) Toxicity from outside sources

Dredging of the east and west slips as well as some areas of the inner Harbour in 1993 resulted in all fine-grained material being removed at these sites to the glacial clay (I. Orchard, personal communication). However, when re-sampling was conducted in both east and west slips as well as the inner Harbour in 1995, fine-grained sediments were present at all sites. This indicates that deposition of fine-grained sediments is occurring on an ongoing basis in the Harbour. The deposition of fine-grained sediments has not been recently studied in this Harbour to determine if they are an additional source of contamination. Also, during the dredging process, several abandoned vehicles (cars) were encountered by the dredging apparatus (I. Orchard, personal communication). It is possible that these vehicles (which were not removed) are leaking gasoline, oil and other contaminants which may be causing toxicity. Finally, the watershed surrounding Collingwood Harbour is agricultural and runoff from this area on an ongoing basis as well as input from the town of Collingwood could be impacting the Harbour. Such inputs from the watershed could serve as a possible explanation for (4) below.

(4) Effects of eutrophication on the benthic community structure

Both laboratory toxicity tests and benthic invertebrate community structure suggest that eutrophication may have a potential impact on the sediment in Collingwood Harbour. Multivariate statistical analysis implicated total phosphorus (TP) in the sediment as a possible factor causing reduced tubificid reproduction. Interpretation of the species composition of the benthic invertebrate communities present in the inner Harbour suggest communities which are responding to added nutrients. The Harbour is known to be in an area with large inputs of agricultural runoff.

Recommendations

We would suggest a number of actions to be taken to clarify these data and provide some resolution, to the factors responsible:

1. Archived samples of sediment have been maintained from all sites sampled both in 1992/3 and 1995. Analyses of some or all of these samples can be performed to determine if

there has been a change in metal speciation that will correlate with reproduction in the worm, and or identify unmeasured contaminants that may be responsible.

2. More detailed sediment mapping of the slips and dredged Harbour area will identify the nature of fine grained material present and whether or not all the contaminated sediment was removed, and/or whether new deposition of contaminated material has occurred.

3. Further sampling of both invertebrate communities and sediment toxicity, using only *T. tubifex* should be conducted to confirm these data. In addition more complete chemical analyses, including metal species, is essential.

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