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by

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ABSTRACT

The Yamaska River watershed in Quebec, Canada, is intensely farmed and heavily polluted with poorly treated domestic and industrial wastes. In this study, the responses of several components of the benthic macroinvertebrate community to municipal/industrial versus agricultural pollution in the Yamaska River and its tributaries were investigated, and the performance of eight diversity and biotic indices for assessing these responses was evaluated. Samples of riffle-dwelling, infaunal and colonizing invertebrates were collected from 13 sites representing a wide range of types and degrees of pollution using Surber, scoop and artificial substrate samplers, respectively, during the summer of 1987. The data were summarized using the indices S (number of taxa), N (number of individuals), H' (Shannon-Wiener's diversity index), D (Simpson's index of diversity), BBI (Belgian Biotic Index), TBI (a modification of Hilsenhoff's Biotic Index), %CHIR (percentage of arthropods consisting of chironomids) and %OLIGO (percentage of total organisms consisting of oligochaetes). Different components of the community were found to generate somewhat different assessments and were, therefore, complementary. Most of the indices, with the exception of S and TBI, were found to be unreliable, temporally unstable or otherwise inappropriate for use with certain sampling methods or types of pollution. The results of the study suggest that the impact of agricultural practices on stream ecosystems may be as severe as the impact of municipal and industrial discharges.

RÉSUMÉ

Le bassin de la rivière Yamaska, au Québec (Canada), est trèsagricole et très pollué par des effluents domestiques et industriels mal traités. Dans cette étude, on montre les réponsesde plusieurs espèces de macroinvertébrés benthiques à la pollution municipale et industrielle d'une part et à la pollution agricole d'autre part, et on évalue la valeur de huit indices de diversité et biotiques pour mesurer ces réponses. Des échantillons d'invertébrés des rides sous-aquatiques, de l'endofaune et colonisateurs ont été prélevés à 13 emplacements représentant toute une gamme de types et de degrés de pollution, au moyen d'échantillonneurs de Surber, à godet et à substrat artificiel respectivement, pendant l'été 1987. Les données ont été résumées au moyen des indices S (nombre de taxa), N (Nombre d'individus), H' (indice de diversité de Shannon-Wiener), TBI (modification de l'indice biotique de Hilsenhoff), % CHIR (pourcentage d'arthropodes de la famille des chironomidés) et % OLIGO (pourcentage du total des organismes appartenant aux oligochètes). On a constaté que différents éléments de la communauté donnaient des évaluations quelque peu différentes et qu'ils étaient donc complémentaires. La plupart des indices, à l'exception de S et de TBI, ne sont pas fiables, sont instables dans le temps et inadaptés à certaines méthodes d'échantillonnage ou à la caractérisation de certains types de pollution. Les résultats de l'étude indiquent que les conséquences des pratiques agricoles sur les écosystèmes aquatiques peuvent être aussi gravesque les conséquences des décharges d'eaux usées industrielles et municipales.

MANAGEMENT PERSPECTIVE

Benthic invertebrate community structure has been widely used to assess the impact of municipal and industrial effluents on stream and river ecosystems, but surprisingly little information is available on the responses of aquatic invertebrate communities to one of the most widespread sources of stress to lotic systems, namely, agricultural practices. The objective of this study was to determine whether the environmental stresses imposed on aquatic systems by agricultural practices elicit a response from the benthic community which is characteristic and distinct from the response to sewage pollution. The Yamaska River watershed in Quebec is intensely farmed and heavily polluted by poorly treated domestic and industrial effluents and, therefore, provided a unique opportunity for study.

Because agricultural pollution has been so poorly studied, there are currently no techniques available which have been developed specifically for assessing the impact of agriculture on benthic invertebrates. Therefore, the performance of three commonly used sampling methods and eight summary indices were evaluated in terms of their comparative assessment of municipal/industrial versus agricultural pollution in the Yamaska River and its tributaries. The results of the study showed that no one sampling method gave a satisfactory assessment, and that each was to some extent misleading and was best interpreted in conjunction with the others. With two exceptions, most of the indices were found to be unreliable, temporally unstable or otherwise inappropriate for applications to certain sampling methods or types of pollution. A major finding of the study was that the impact of agricultural practices on stream ecosystems may be as severe as the impact of municipal and industrial discharges. The data set generated by this study will be further scrutinized in order to identify the specific changes in structure and species composition which are characteristic of agricultural pollution, and which may be used to distinguish between agricultural and sewage pollution in the field. Research into the development of an "agricultural biotic index" will follow.

PERSPECTIVE ADMINISTRATIVE

La structure des communautés d'invertébrés benthiques a été largement utilisée pour évaluer les conséquences des effluents industriels et municipaux sur les écosystèmes aquatiques. Pourtant, il existe peu de renseignements sur les réponses des communautés d'invertébrés aquatiques à l'une des sources les plus communes de stress pour les systèmes lotiques, à savoir les pratiques agricoles. Le but de cette étude était de déterminer sile stress pour les systèmes aquatiques qui résulte des pratiques agricoles provoquait une réponse des communautés benthiques caractéristique de cette pollution et distincte de celle résultantdes déversements d'eaux usées. Le bassin de la rivière Yamaska, au Québec, très agricole et très pollué par des effluents domestiques et industriels mal traités, constituait un terrain d'étude unique.

La pollution agricole ayant été très peu étudiée, il n'existepas de techniques spéciales pour évaluer les conséquences de l'agriculture pour les invertébrés benthiques. C'est pour cela que l'on a étudié la valeur de trois méthodes d'échantillonnage couramment utilisées et de huit indices sommaires pour différencier entre la pollution municipale et industrielle et la pollution agricole dans la rivière Yamaska et ses affluents. Les résultats montrent qu'aucune des méthodes d'échantillonnage ne donne une évaluation satisfaisante et que, dans une certaine mesure, chacune est un peu trompeuse et doit donc être interprétéeavec les autres. A deux exceptions près, la plupart des indices se sont révélés peu fiables, instables dans le temps et inadaptés à certaines méthodes d'échantillonnage ou à la caractérisation de certains types de pollution. Une des principales observations de l'étude, est que les conséquences des pratiques agricoles pour lesécosystèmes aquatiques pourraient être aussi graves que celles desdécharges municipales et industrielles. Les données obtenues seront étudiées plus en détail pour essayer de trouver des changements spécifiques de structure ou de composition des espècesqui pourraient être utilisés pour faire la différence entre la pollution agricole et celle provoquée par les effluents d'égout. On passera ensuite à des recherches sur un "indice biotique agricole".

1. INTRODUCTION

Benthic macroinvertebrate community structure has been widely used to assess the impact of degradable organic pollution, mainly municipal and industrial effluents, on stream and river ecosystems (Metcalfe, 1989). Surprisingly little information is available, however, on the impact of one of the most common and widespread sources of stress to lotic systems, namely, agricultural practices. Agricultural land use imposes a broad range of environmental stresses on aquatic systems, including increases in temperature and loadings of nutrients, salts and suspended sediments, the disruption of normal flow regimes, decreases in allochthonous food sources for shredders and detritivores and inputs of chemical fertilizers and pesticides (Dance and Hynes, 1980). While these stresses can be expected to elicit a response from the benthic invertebrate fauna, it is presently not known whether the resulting changes are distinguishable from those characteristic of sewage pollution.

A variety of sampling techniques has been employed and a wide range of diversity and biotic indices have been developed (e.g., Washington, 1984) to evaluate and quantify the effects of aquatic pollution on benthic invertebrates. Different sampling techniques may generate different assessments because they are selective for specific components of the benthic community. Each component inherently differs in species composition, sensitivity and degree of exposure to polluted water or sediment. Diversity indices are quantitative measures of community structure which include richness, evenness and abundance components. They are non-specific and can presumably be applied to any type of pollution or environmental perturbation.

Biotic indices are based on the indicator organism concept, combining measures of diversity and pollution tolerance for indicator taxa (Tolkamp, 1985). Each is specific to a particular type of pollution, such as nutrient enrichment or heavy metals. To date, no biotic indices have been developed specifically for agricultural pollution.

The purpose of the present study was to compare the responses of different components of the benthic invertebrate community to municipal/industrial vs. agricultural impacts in a watershed receiving both types of pollution, and to evaluate the performance of eight commonly used summary indices for assessing these responses.

2. MATERIALS AND METHODS

2.1 Location of Study

The study was conducted in the Yamaska River watershed, which is located southeast of Montreal in the Eastern Townships of Quebec. Agriculture is the primary land use in the basin. Fifty-three percent of the 4843 km^2 drainage basin is farmed (Desmeules and Gelinas, 1977) and approximately 26% of all agricultural pesticides used in the province are applied in this relatively small basin (Reiss et al., 1984). According to Statistics Canada's 1986 Census of Agriculture (Statistics Canada, 1987a), corn is the principal grain crop grown and hay accounts for the majority of the remaining area under crop. The main pesticide classes used in the Yamaska River basin in 1982 were triazines and triazoles (38% of total, excluding oils), amides (18%), carbamates (16%) and organophosphates (7%) (Reiss et al., 1984). Maguire et al. (1989) detected 4 organchlorine insecticides, 22 organophosphate insecticides, 2 triazine herbicides and one triazine fungicide in centrifuged water collected on five occasions between July 16 and August 6, 1987 at the mouth of the Yamaska River. Atrazine, a triazine herbicide used on corn, was found consistently in the samples at concentrations approaching 100 times that of any other pesticide.

The Yamaska River basin is also the location of most of Canada's textile industry. Twelve mills with a total of 2000 employees operate in the towns of Acton Vale, Cowansville, Farnham, Granby and Saint-Hyacinthe (Marc Sinotte, Environnement Québec, personal communication). Other industries include pulp and paper, foundries, inorganic and organic chemical manufacturing and secondary industries, metallurgy and surface finishing. Twenty-three of these industries, which have a workforce of 4000, have been recently targeted for effluent reductions (Entraco, 1989).

The population of the Yamaska basin is approximately 300,000, with about one-quarter of the population living in the towns of Granby and Saint-Hyacinthe (Statistics Canada, 1987b). Sewage treatment at the time of this study was restricted to primary treatment facilities in these two towns.

2.2 Site Selection and Classification

Thirteen sites on the Yamaska River and its tributaries were selected for study (Figure 1). Six sites were located 5-10 km downstream of major urban areas, and were chosen to represent municipal and/or industrial impacts (sites 4, 5, 8, 9, 12 & 37). Four sites were located in tributaries known to drain agricultural land (Muir et al., 1978), and were therefore expected to represent the impacts of agricultural practices (sites 30, 31, 32 & 33). The remaining 3 sites, which were located in relatively undisturbed subbasins, served as controls (sites 3, 35 & 36). These classifications were verified and refined on the basis of 1986 census data on population (Statistics Canada, 1987b) and agricultural activities (Statistics Canada, 1987a), which were released in 1988 (Table I).

Percent farmed area sprayed with herbicides in the watershed upstream of each site was selected as the indicator of agricultural intensity, as this parameter was highly correlated with area under grain crops, the application of fertilizers and area under tile drainage (r = .96 -.99). Area under hay was not highly correlated with the use of herbicides or fertilizers or with tile drainage (r = .23 -.57), indicating that hay crops are not heavily cultivated. Insecticide use was not highly correlated with either grain or hay crops (r = .55 -.66) nor with fertilizer or herbicide use r = .54 -.62), suggesting that insecticide use may be mainly restricted to other crops which were not specifically considered such as orchards or vegetables. Braun and Frank (1980) reported that insecticides were applied to all fruit crops in eleven southern Ontario watersheds, while only 7.2% of the area under corn received treatments. Although the application rate for insecticides in the Yamaska River basin was very low in comparison with herbicides, it was significant at site 30.

2.3 Field Methods

The study design called for a comparison of three sampling techniques at each site. A Surber sampler (600 µm aperture Nitex mesh; sampling area = 0.093m^2) was used to collect resident riffle-dwellingorganisms, an enclosed shovel or "scoop" sampler (500 µ Nitex mesh; sampling volume = 0.003m^3; Prater et al., 1977) to collect resident infaunal invertebrates, and artificial substrate samplers of a round multiple plate design (effective surface area = 0.130 m^2) to collect the colonizing fauna. As depth and proximity to the shore are major placement factors influencing the types and numbers of benthic organisms colonizing artificial substrates (De Pauw et al., 1986), these factors were standardized to 25 cm (stream bed to bottom of sampler) and mid-stream, respectively. The deployment apparatus for the artificial substrates is pictured in Figure 2.

Triplicate Surber samples and one scoop sample were collected at each site July 7-9, 1987, and three artificial substrate samplers were installed. Surber and scoop sampling were repeated seven weeks later on August 25-27, 1989, and the artificial substrate samplers were retrieved. Physical conditions precluded the use of some techniques at some sites. For example, sites 4, 30 and 33 did not have riffle areas and could not be sampled with the Surber sampler. Furthermore, sites 31 and 35 could not be sampled in August due to low water levels. The scoop sampler could not be used at sites 12 and 31, because the substrate was mainly bedrock. Although artificial substrate samplers were set at all 13 sites, the sampler at site 12 could not be relocated due to heavy weed growth, and the sampler at site 35 was partially dry.

All samples of invertebrates were concentrated through a 200 µm aperture sieve and immediately preserved in 10% formalin. They were later transferred to 70% alcohol with 2% glycerin prior to sorting. Organisms were sorted with the aid of a dissecting microscope and identified to the lowest practical taxonomic level. A complete list of taxa is available upon request.

2.4 Summary Indices

The data were summarized using eight indices which have been successfully applied to water quality assessment in other studies, or which have been suggested to be potentially informative in specific situations. These included the number of taxa per sample (S), number of individuals per sample (N), Shannon-Wiener's diversity index (H'), Simpson's index of diversity (D), the Belgian Biotic Index (BBI), a modification of Hilsenhoff's Biotic Index (TBI), the percentage of arthropods in each sample consisting of chironomids (%CHIR) and the percentage of total organisms in each sample consisting of oligochaetes (%OLIGO). Index values were calculated as "site totals", that is, the data for triplicate Surber and artificial substrate samples were combined before the index for each method was calculated and compared with the value for the single scoop sample.

S is a simple measure of the richness of the community, and its value would be expected to decrease with increasing pollution or environmental stress. N is a measure of abundance which should increase in response to nutrient enrichment but decrease in response to toxic pollution (Mason et al., 1985). The mathematical formulae for the diversity indices, H' and D, are given in Washington (1984). The value of H' decreases while the value of D increases with increasing pollution or stress.

The Belgian Biotic Index (De Pauw and Vanhooren, 1983) has been successfully used for the assessment of organic and nutrient pollution in Europe, and has been applied to both handnet and artificial substrate (De Pauw _et al_., 1986) samples. It was modified slightly for use with North American fauna, as follows: Heptageniidae were not separated from other Ephemeroptera and _Physella_ was given the same entry value as Sphaeriidae. BBI values range from 0 (very heavily polluted) to 10 (unpolluted). Hilsenhoff's Biotic Index (Hilsenhoff, 1987) was developed for use in Wisconsin with kicknet samples of riffle-dwelling arthropods, each taxon of which has an assigned tolerance value for organic and nutrient pollution. As Yamaska River samples frequently contained few arthropods, Hilsenhoff's (1987) taxa list was expanded to include non-arthropods for which tolerance values were assigned based on a review of the literature (e.g., Lauritsen _et al_., 1985) and personal experience. This modification is referred to as the "total biotic index" or TBI. Index values for the TBI range from 0 (excellent) to 10 (very heavily polluted), on a reverse scale to the BBI.

Winner _et al_. (1980) observed a good correlation between the degree of metal contamination and the numerical dominance of chironomids in the riffle-dwelling insect communities of Ohio streams, and suggested that this ratio be pursued as an index of metal pollution. As a general guideline, sites which are heavily contaminated with metals should have a %CHIR value of 75% or greater, while unpolluted sites should have values not exceeding 20%. The percentage of total organisms consisting of oligochaetes was recommended by Hynes (1966) as a good indicator of sewage pollution, as these organisms are generally tolerant of low oxygen levels and flourish under conditions of nutrient enrichment.

2.5 Data Analysis and Interpretation

Within each of the five data sets (July and August Surbers, July and August scoops and August artificial substrates), the 8 indices were compared with one another in terms of their rankings of the study sites from the least to the most degraded. The degree of correlation between site rankings for a given pair of indices was determined by Spearman's rank correlation coefficient (r_s). The reliability of an index was judged by its ability to classify the control sites as unstressed, while temporal stability was determined by comparing the rankings of sites in July and August (Surbers and scoops only). To directly compare the responses of the riffle-dwelling, infaunal and colonizing components of the benthic community in terms of their site rankings, a subset of seven sites for which all five data sets were available was used.

3. RESULTS

3.1 Comparisons Among Indices for each Sampling Method

Site ranking comparisons are presented in Tables II-VI and seasonal comparisons in Table VII.

3.1.1 Surber Samples

The site rankings for the indices S, BBI, TBI and %OLIGO were significantly correlated with one another in both July (Table II) and August (Table III), except that the TBI/%OLIGO and S/TBI combinations were only significant in August when sites 31 and 35 were not sampled. H' and D were also significantly correlated with each other in both months, however, their site rankings were very different from those of all other indices. N and %CHIR were not correlated with each other or with any of the other indices.

Averaging the site rankings for S, BBI, TBI and %OLIGO in each month yielded the following results, with sites arranged in order from the least to the most degraded:

JULY:	3,	36,	8,	35,	37,	31,	12,	32,	5, 9.
AUGUST:	3 &	36 &	8,		37,		12,	32,	9, 5.

Correlations between site rankings in both months were significant for each of these four indices, except for S where r_s was just below significance (Table VII). These indices were therefore very consistent over time. They also identified the control sites as the least stressed both in terms of their rankings and their classifications. In contrast, H', D, N and % CHIR ranked the sites very differently between months (Table VII). Furthermore, H' and D ranked some agricultural and sewage sites as less stressed than the controls. Although %CHIR is supposed to be an indicator of metal pollution, it ranked control site 36 as contaminated and municipal/industrial site 9 as heavily contaminated in July and uncontaminated in August, among other inconsistencies.

To determine whether there was a better degree of site discrimination in early or late summer, the range of values for each index in July was compared with the range in August, using the eight sites for which data were available in both months. Ranges were found to be similar for most indices, with site 9 accounting for most of the differences observed as its pollution status either declined or improved substantially depending on the index consulted. Based on trends indicated by the majority of indices, pollution worsened with advancing season at site 32 and 5, improved slightly at site 12 and did not change at site 36. Results were variable for sites 3, 8 and 37 and, as noted above, extremely variable for site 9.

Considering the municipal/industrial sites only, averaging all of the indices for both months generated the same rankings as averaging S, BBI, TBI and % OLIGO for July, that is, the sites ranked as follows in order of increasing pollution: 8, 37, 12, 5 and 9. Agricultural sites 31 and 32 could only be compared for the month of July, when site 32 ranked as more degraded. The agricultural sites appeared to rank intermediate between the control and sewage sites in terms of severity of pollution effects.

3.1.2. Scoop Samples

Eleven sites were sampled with the scoop sampler in both July and August. As for Surbers, site rankings for H' and D were very significantly correlated in both months (Tables IV and V). Unlike Surbers, however, H' was also significantly correlated with several of the other indices. In fact, H', TBI and %OLIGO were significantly correlated with one another in both months. S was also significantly correlated with H' in both months and with %OLIGO in July only, while D was significantly correlated with TBI in July and N with %CHIR in August.

When the site rankings for H', TBI and %OLIGO in each month were averaged, the following orders emerged:

JULY: 36, 8, 3, 35, 33, 30, 4, 9, 32, 5, 37.

AUGUST: 36, 8, 3, 33, 30, 35, 9, 37 & 32, 4, 5.

The arrangement of sites was similar in both months except for the positions of sites 4 and 37. Correlations in site rankings between months were also significant for each of these three indices (Table VII), indicating that they are temporally stable. The BBI was not correlated with other indices, did not give consistent rankings between months and frequently ranked control sites as more degraded than polluted sites. The diversity index D also performed poorly, and N and %CHIR were neither correlated with other indices nor consistent between months. Site 33 had the lowest value for N in both months and site 5 had the highest, but this was the only consistent trend for this index. Abundance increased in August at sites 3, 4, 5, 8 and 30, decreased at sites 9, 33, 36 and 37 and remained the same at sites 35 and 32, therefore the site rankings were completely rearranged between months. According to %CHIR, all sites except site 37 in July and site 33 in August were severely polluted with heavy metals. A good gradient of values was observed for %OLIGO when applied to scoop samples, but not to Surbers, while %CHIR exhibited the reverse response.

To determine whether there was a better degree of site discrimination in early or late summer, the range of values for each index was compared between months for all eleven sites. As was the case for Surbers, there were few differences. Where differences were observed, they were due to an unusually high or low value for a single site such as the values of H' and D for site 37 in July and the value of N for site 5 in August. Based on trends indicated by the majority of indices, pollution worsened with advancing season at site 5, improved at sites 9, 30, 32, 33 and 37 and did not change for sites 3, 8 and 35. Results were variable for sites 4 and 36.

Considering the municipal/industrial sites only, averaging all of the indices for both months gave the following site rankings in order of increasing degradation: 8, 9, 4, 37 and 5. Among the agricultural sites, site 32 consistently ranked as more degraded than site 30 which, in turn, was consistently more degraded than site 33. The agricultural sites appeared to have a similar range in severity of impact as the sewage sites, as they did not all rank consistently above or below the sewage sites.

3.1.3. Artificial Substrates Samples

The indices S, H', D and TBI were significantly correlated with one another when applied to artificial substrate samples (Table VI). The remaining indices all gave separate and distinct site rankings, as none were correlated with the above indices or with each other, with the exception of S and BBI. Oligochaetes accounted for a very minor proportion of the total organisms at all sites except site 5, therefore %OLIGO was not considered to be a useful index for artificial substrate samples. %CHIR classified all sites as contaminated with metals, with site 33 perhaps the least contaminated. According to N, the control sites ranked intermediate in abundance.

When the site rankings for S, H', D and TBI were averaged, the following orders emerged:

AUGUST: 37, 8 & 36, 3, 4, 32, 33 & 9, 5, 31, 30.

The most striking differences between the results for the artificial substrate samples and those for Surbers and scoops were in the rankings of sites 4, 37 and 30. Site 4 ranked as less stressed according to its colonizing community than its infaunal community, while site 37 ranked as least stressed according to its colonizing community, most stressed according to its infaunal community and intermediate for its riffle community. Artificial substrate samples designated site 30, an agricultural site, as the most degraded site of all.

Considering the municipal/industrial sites only, the average rankings for all indices combined were: 8, 37, 4, 5 and 9. Among the agricultural sites, site 30 was clearly the most degraded, sites 32 and 33 were the least stressed and site 31 was intermediate. These rankings were different from those generated by the scoop samples. According to the invertebrate assemblages collected by the artificial substrates, agricultural sites were as degraded as, or even more degraded than, the sewage sites.

3.2 Direct Comparisons among Sampling Methods

A complete data set for comparing sampling methods was available only for sites 3, 5, 8, 9, 32, 36 and 37 (Table VIII). These seven sites represented a wide range of pollution conditions. The index N was omitted from consideration because it is dependent on the volume or area of substrate sampled, and this differed among methods. The best correlations between sampling methods were observed for August surbers and scoops, where four indices were significantly correlated in their site rankings (S, BBI, TBI and % OLIGO) and a fifth index (H') was nearly significant. In addition, S gave significant correlations for all three methods in August and a fairly good, but not statistically significant, correlation for July Surbers and scoops. The BBI gave similar rankings for Surbers and scoops in both July and August. It appears that the two resident communities, that is, the riffle-dwelling and infaunal communities, were more similar in their comparative assessments of the study sites than the colonizing community.

4. DISCUSSION

The water quality assessment of thirteen Yamaska River sites impacted with municipal/industrial or agricultural pollution was strongly influenced by the index of macroinvertebrate community structure used to summarize the data. The performance of the eight diversity and biotic indices which were evaluated varied considerably in terms of reliability, stability over time, sensitivity and their rankings of municipal/industrial vs. agricultural sites. Furthermore, the performance of individual indices, as well as intercorrelations among indices in terms of their site rankings, varied with the component of the benthic community sampled.

When the indices were applied to Surber data, S, BBI, TBI and %OLIGO were found to be significantly correlated in terms of their ranking of sites from the least to the most degraded, reliable as judged by their ability to classify the control sites as unstressed, and consistent between months. A different combination of indices, namely H', TBI and %OLIGO, met the above criteria when applied to scoop data, and S, H', D and TBI were significantly correlated with one another and reliable when applied to artificial substrate data. In each case, at least one diversity index and one biotic index were significantly correlated in their site rankings, and the biotic index TBI performed well throughout. The indices N and %CHIR were not correlated with any other indices including each other, regardless of the sampling method used to collect the data, and were not consistent between months in their site rankings. D performed well only for artificial substrates and was inconsistent between months for scoops and Surbers, while the BBI performed well only for Surber samples and was also inconsistent for scoops.

The diversity indices H' and D ranked the sites very similarly throughout, with correlations between site rankings for these two indices ranging from r_s = .927 - .955 for all five data sets (July and August Surbers and scoops and August artificial substrates). However, neither index gave consistent site rankings over time when applied to Surber samples and D was also inconsistent for scoops. Pinder et al. (1987) also observed an excellent correlation (r_s = .91) between these two indices when applied to samples of macroinvertebrates collected from gravel, soft sediments and macrophytes in the River Frome, an English chalk stream, and Pinder and Farr (1987) also found that neither H' nor D was consistent in its ranking of 5 sites along a gradient of agricultural pollution when applied to samples collected every two months over a nine month period. Similarly, Murphy (1978) observed that temporal variations in H' completely masked any spatial patterns of water quality based on riffle-dwelling macroinvertebrate communities in two rivers in South Wales.

Several investigators have found that H', which is the most frequently used diversity index, is not only variable over time in its assessment but also insensitive. For example, Cook (1976) was unable to discriminate among sites on a New York stream which were mildly polluted with domestic effluents and agricultural practices by means of this index, as it rated all sites as unpolluted. In a study of six Missouri Ozark streams, Jones et al (1981) also found that H' classified pristine to slightly enriched sites as unpolluted and several grossly polluted sites as only moderately polluted. The application of H' to the assessment of metal pollution has yielded mixed results. Perkins (1973) found that H' gave false negatives when used to discriminate among five streams in Texas which were contaminated with copper. In contrast, Roline (1988) found that values of H' mirrored known inputs of heavy metals at several locations along the length of the upper Arkansas River in Colorado.

According to Kovalak (1981), H' reflects changes in benthic community structure which are normally associated with organic pollution. Organic pollution causes a decrease in diversity as sensitive organisms are lost and an increase in the abundance of tolerant organisms due to nutrient enrichment. This results in a decrease in the evenness of the distribution of individuals among the species. Toxic pollution causes a decrease in both diversity and abundance and, frequently, an increase in evenness. Because H' is more sensitive to changes in evenness than diversity, the value of H' may actually be greatest at the site most heavily contaminated with toxic chemicals. In such cases, H' will give an erroneous assessment.

S is a very simple indicator of diversity which is unaffected by measures of abundance or evenness. In the present study, S performed more consistently than either H' or D. Although S was not considered to be as suitable for assessing the infaunal community as H', TBI or % OLIGO, it was nevertheless significantly correlated with H' and %OLIGO in July and with H' in August, and was at worst (r_s = .491) reasonably correlated with these indices. In contrast, H' and D, both of which were less suitable than S, BBI, TBI or %OLIGO for assessing the riffle community, were poorly correlated with the latter three indices in July (r_s = .106 - .418) and D was not significantly correlated with any of these indices in either month. These comparisons provide further evidence that H' and D may generate erroneous assessments.

De Pauw and Vanhooren (1983) assessed all of the major river systems in Belgium using the Belgian Biotic Index and concluded that this index accurately reflects the general ecological degradation which occurs as a result of organic as well as toxic pollution. Although the preferred sampling method for use with this index is the handnet, which is applied to all available habitats, De Pauw et al. (1986) reported that artificial substrates gave similar assessments and were therefore a valid alternative. Despite the supposedly broad applicability of this index, the TBI was found to be more suitable for assessing the health of benthic invertebrate communities in the Yamaska River. While the TBI provided accurate and stable bioassessments for all components of the community, the BBI was suitable only for the riffle-dwelling community. There are several possible reasons for the superior performance of the TBI. First of all, Hilsenhoff's (1987) Biotic Index, from which the TBI is derived, was developed specifically for North American fauna. Secondly, the BBI is a much "coarser" index of water quality, as demonstrated by the fact that it assigned many sites the same index value based on general diversity and the presence or absence of key indicator organisms. In contrast, the TBI considers the tolerances and abundance of all species present and, therefore, yielded a gradient of values for the study sites. The poor performance of the BBI may be due more to insensitivity than to inaccuracy. The Trent Biotic Index, from which the BBI is derived and differs only slightly, has also been criticized for insensitivity. Pinder et al. (1987) suggested that it could only be used to detect major differences in water quality due to its restricted range of values (also 0 - 10). The BBI appears to have the same drawback.

%CHIR was very poorly correlated with all other indices, and was also temporally unstable for both Surber samples and artificial substrates. As this index supposedly indicates metal pollution, a lack of correlation with indices of organic pollution would not necessarily be unexpected. When applied to Surber samples, this index gave a gradient of values ranging from 11.2% to 98.4% in July and from 17.6% - 42.2% in August, suggesting good potential for site discrimination when applied to the riffle community. However, due to obviously erroneous classifications and poor correlations between months in terms of site rankings (r_s = -.143), this index was not useful. Although %CHIR was developed for use with riffle-dwelling organisms, Roline (1988) found that riffle sites in the upper Arkansas River which had water concentrations of Cd, Cu, Fe, Pb and Zn well above limits recommended for the protection of aquatic life, and which were shown by the diversity index H' to be polluted, were classified as only minimally to moderately polluted with heavy metals according to the %CHIR index of Winner et al. (1980).

Because the infaunal arthropod community was dominated by chironomids, %CHIR classified all but one site in July and another in August as heavily polluted with metals. The same trend was observed for the colonizing community, but it was even more pronounced because chironomids also dominated oligochaetes. %CHIR was judged unsuitable for assessing either community because both the scoop sampler and artificial substrates select for chironomids, thus giving too many "false positives". Pinder et al. (1987) encountered a similar problem when sampling the invertebrate fauna of macrophyte beds in the River Frome. They concluded that macrophytes were of little use as a substrate for surveillance because they were so dominated by Simulium and Brachycentrus that their capacity for site discrimination would be very limited.

%OLIGO was also expected to be seriously affected by sampling factors. It was anticipated that artificial substrates, and to a lesser extent the Surber sampler, would selectively exclude oligochaetes. %OLIGO did perform poorly when applied to artificial substrate samples. However, the occurrence of large numbers of oligochaetes among the colonizers at site 5 indicated that these organisms were not physically excluded. Although artificial substrates are generally described as "water column" samplers, those used in the Yamaska River study were attached to a concrete block base and were obviously accessible to sediment-dwelling organisms. As expected, %OLIGO performed well when applied to scoop data. It was highly correlated with several other indices and stable between months, and the broad range of values observed for the study sites (0 - 99.4%) suggested a high capacity for site discrimination. Interestingly, %OLIGO also performed well when applied to Surber samples, despite very much smaller catches of organisms. This suggests that oligochaetes may be very sensitive indicators of pollution.

N was not correlated with any of the other indices. Because N increases in response to nutrient enrichment and decreases in response to toxic pollution, control sites should occupy the middle range where both types of pollution are represented. In the present study, values of N for the control sites 3, 35 and 36 were consistently in the low to moderate range for all sampling methods in both months, suggesting that nutrient enrichment may be the predominant impact at both sewage and agricultural sites. Measures of abundance are of limited use when considered in isolation, however, and are best interpreted in conjunction with a measure of diversity (S). As noted by Mason et al. (1985), undisturbed sites will be characterized by high diversity and moderate to high counts of individuals, organically polluted sites by low diversity and high counts and toxic environments by low diversity and low counts. Considering S and N together, control sites 3, 35 and 36 appeared to be undisturbed as they exhibited high diversity and moderate counts of individuals. Among the polluted sites, the only consistent findings were that site 5 was mainly impacted by nutrients (very low diversity and very high counts), while site 33 showed evidence of toxic pollution (very low diversity and very low counts). The results for all other sites varied so extensively between months and among components of the community that no other trends could be identified.

One of the characteristics used to evaluate the performance of the eight summary indices was temporal stability. Furse et al. (1984) showed that seasonal life cycle factors had only a minimal effect on the classifications of 268 relatively unpolluted running-water sites in Great Britain and concluded that samples of invertebrates collected in spring, summer or fall would provide similar assessments. To obtain the most comprehensive assessment, Pinder et al. (1987) recommended sampling in spring or early summer when populations are large and a substantial proportion of the taxa are represented by aquatic forms. Even under polluted conditions, assessments should be consistent over time unless the pollution source itself is subject to seasonal fluctuations or is sporadic in nature. De Pauw and Vanhooren (1983) found that the BBI was very consistent over time when applied to the assessment of unpolluted to heavily polluted rivers and streams in Belgium. Murphy (1978) found that biotic indices were more temporally stable than diversity indices over a wide range of pollution conditions. In the present study, better between-season correlations were also observed for several biotic indices (TBI, BBI, %OLIGO) than for the diversity indices (S, H' and D).

In order to maximize the detection of pollution and to guarantee the best discrimination among polluted sites, it would make sense to sample during the season in which pollution would be the most severe. For the assessment of point source discharges such as municipal and industrial effluents, the most desirable season would likely be late summer when flows are low and dilution is therefore at a minimum. In the case of agricultural pollution, however, the maximum impact will likely occur in early summer during the main pesticide application period, which also coincides with frequent run-off events (Muir et al., 1978). Both types of pollution occur in the Yamaska River system. Although the ranges of index values for both riffle and infaunal communities were similar in both months, suggesting that the degree of overall site discrimination did not differ between early and late summer, some individual sites improved while others deteriorated with advancing season. Despite considerable variability in the data, it was apparent that sewage site 5 deteriorated substantially in August, while agricultural sites 30, 32 and 33 improved.

Very few studies have addressed the influence of sampling technique on bioassessments with stream invertebrates. All sampling techniques are habitat-selective, and all habitats have characteristic and distinct assemblages of invertebrates. What is important for bioassessment purposes is not whether absolute index values differ among components of the benthic community sampled by different methods, but whether some components are more sensitive than others to pollution and, more importantly, whether different components give conflicting assessments.

Riffle communities are naturally richer than infaunal or colonizing communities, because they occupy a more diverse habitat. Pinder et al. (1987) collected 147 species of benthos from gravel (riffle) habitats, 69 from macrophyte beds and only 40 from the soft sediment at a site on the River Frome. They attributed the higher diversity of the riffle habitat to the fact that it had elements of both of the other habitats and, therefore, more available niches. The same trend was observed for the Yamaska River, where Surber samples collected the most taxa (153 in July and 148 in August), followed by artificial substrates (126) and scoops (92 in July and 99 in August), although differences between sampling methods were not as great as those reported by Pinder et al. (1987). Considering only the sites sampled by all three methods, the ranges of numbers of taxa collected were similar for Surbers (42 and 41 in July and August, respectively) and substrates (37), and only slightly lower for scoops (32 and 28). This suggests that there were not major differences among sampling methods in terms of their potential for site discrimination.

In the present study, different sampling methods produced assessments which differed in some aspects but also had some similarities. Sites 3, 36 and 8 were identified as the least stressed sites by all sampling methods. Sites 3 and 36 were controls and site 8 was expected to be the least impacted municipal/industrial site. Site 35 was apparently not as suitable a control as sites 3 and 36, as it consistently ranked below the above three sites. Site 5 was consistently classified as severely degraded, with site 9 nearly as degraded. Site 12 was sampled only by Surber, but it appeared to rank intermediate between site 8 (cleanest) and sites 5 and 9 (most severely stressed). There were major differences between sampling methods in the rankings of sites 37 and 4, and in the rankings of the agricultural sites both in relation to the municipal/industrial sites and among themselves.

Site 4 was sampled in both July and August by scoops and also in August by artificial substrates. The infaunal community at this site was characterized in both months by low diversity, low abundance, and H', BBI and TBI values indicating moderate pollution, heavy pollution and very poor conditions, respectively. Colonizing communities at this site, however, were moderately diverse with high counts of individuals, and had values of H', BBI and TBI indicating moderate pollution, slight pollution and fairly poor conditions, respectively. Whether a difference of 5-6 BBI units between communities could be expected on the basis of inherent differences in the communities alone is not known. However, De Pauw et al. (1986) determined that differences between BBI values for riffle and colonizing communities in streams and rivers in Belgium and Portugal representing a wide range of water quality did not usually exceed 2, or rarely 4, units.

Site 37 ranked as one of the most degraded of all sites according to its infaunal community, intermediate according to its riffle community and less stressed than the control sites according to its colonizing community. The infaunal community was characterized by low to moderate numbers of taxa and moderate to high counts of individuals, with H', BBI and TBI values indicating moderate to heavy pollution, moderate pollution and very poor conditions, respectively. %OLIGO values suggested moderate to heavy nutrient enrichment. The riffle community was moderately diverse and abundant, with slightly higher values of H', BBI and TBI values indicating unpolluted to slightly polluted and good to very good conditions and very little nutrient enrichment as determined by %OLIGO. The colonizing community was also moderately diverse with high counts of individuals and had a value of H' that was higher than for either the infaunal or riffle communities. The values of BBI, TBI and %OLIGO indicated slight pollution, fair conditions and little organic enrichment. The reason why sites 4 and 37 ranked lowest according to their infaunal communities could be due to the presence of sediment-bound contaminants such as heavy metals or persistent organic compounds at these sites. Exposure to such contaminants would be much greater for burrowing organisms than for either riffle-dwellers or colonizers.

According to Croteau et al. (1984), the most severe metal contamination in the Yamaska basin occurs in the Yamaska Nord downstream of Waterloo. This location corresponds with site 37 in the present study.

Rankings of the agricultural sites in relation to the municipal/industrial sites varied among sampling methods. The riffle community assessment placed agricultural sites 31 and 32 intermediate between control and sewage sites, while the infaunal assessment indicated that agricultural sites had a range in severity of impact similar to sewage sites. The colonizing community assessment, which considered all four agricultural sites, ranked two sites as more degraded than the most impacted sewage sites and two sites as less degraded than sites 5 and 9 but more degraded than all other sites. These results suggest than agriculture may impose stresses on the benthic invertebrate communities of rivers and streams which are at least as severe as those imposed by heavy municipal and industrial pollution.

Contrary to the situation described for sewage sites 4 and 37, agricultural pollution appeared to have its most severe impact on organisms living in the water column, that is, the organisms colonizing the artificial substrates. This suggests that poor water quality, as opposed to poor sediment quality, may be the major problem at sites impacted by agriculture. Site 30 was expected to show the greatest impact due to the significant application of insecticides in this watershed, and this was certainly true for the colonizing community.

In the Yamaska River study, it was not possible to sample with all three methods at all thirteen sites due to physical restrictions.

This is not an uncommon problem, and is one of the main reasons why artificial substrates were developed. Direct comparisons among sampling methods were only possible for seven sites, but the data revealed that the two resident communities (riffle and infaunal) generated a more similar comparative assessment of these sites than the colonizing community. The colonizing and infaunal communities were the most dissimilar. Whether colonizing communities are in fact representative of local conditions has been a topic of some debate. As noted by Benzie (1984), there are four possible sources of colonizers for artificial substrates. These are downstream drift, upstream movements, aerial sources and sediments. He found all sources to be significiant and that most taxa colonized from all directions. He concluded that random foraging movements were mainly responsible for colonization rather than major dispersal movements such as drfit. This implied that most of the colonizing organisms were derived from very short distances away and were therefore representative of local conditions. De Pauw et al (1986) described the following succession of groups colonizing artificial substrates: drift-dominated groups such as mayflies and net-spinning caddisflies first, followed by snails and case-dwelling caddisflies, followed by oligochaetes and chironomids only after organic material has accumulated in the interstices. They found that 3 weeks was adequate for these processes to occur in streams in Belgium and Portugal. Despite these positive findings concerning artificial substrates, the results of the Yamaska River study indicated that measures of the community structure of colonizing communities gave a less reliable assessment of pollution conditions than those of the resident riffle and infaunal communities.

5. CONCLUSIONS

The Yamaska River in Quebec provided a unique opportunity for investigating the effects of both heavy municipal and industrial pollution and intense agricultural activities on a Canadian river system. Benthic invertebrate communities have long been recognized as one of the most sensitive sectors of the ecosystem on which to base ecosystem health assessments, mainly because they are representative of local conditions and capable of a graded response to a broad spectrum of environmental stresses. Many different sampling methods have been employed in combination with a wide variety of diversity and biotic indices to measure the responses of benthic invertebrate communities to pollution. The results of this study provided insight into the performance of several commonly used sampling methods and summary indices applied to the assessment of both domestic and industrial discharges and agricultural pollution. The major findings of the study are summarized below.

Different indices were found to be appropriate for use with different sampling methods, although the diversity index S and the biotic index TBI appeared to be universally applicable. The presence of toxic chemicals at some sites and nutrient enrichment at others was indicated by characteristic deviations from control site values for both diversity and abundance. The diversity indices H' and D gave erroneous assessments under certain conditions, possibly due to the presence of toxic pollution, and were therefore unreliable. The Belgian Biotic Index suffered from a lack of sensitivity. Where sampling methods selected for oligochaetes or chironomids, indices based on these groups were insensitive, giving too many false positives. Sampling methods which selectively excluded such groups also performed poorly, giving too many false negatives. %CHIR was probably the least useful index evaluated because it gave assessments which were obviously incorrect and it was unstable over time and not correlated with any of the other indices. %OLIGO, however, was a sensitive and stable index when applied to collections of either riffle-dwelling or infaunal organisms.

Temporal stability has been shown to be a desirable attribute of a water quality index, and biotic indices tended to be more consistent in this regard than diversity indices. However, seasonal changes in pollution confounded the evaluation of temporal stability, with municipal/industrial pollution more severe in late August due to lower flows and agricultural pollution more severe in early July when most pesticides are applied and storm events occur.

All three components of the benthic invertebrate community which were sampled, namely, the riffle-dwelling, infaunal and colonizing components, appeared to be equally sensitive to differences in pollution status among the study sites. However, they did not always give the same assessment. Where either pristine or severely degraded sites were considered, all sampling methods and all indices gave similar assessments. Where pollution fell into the moderate range or where there were differences in the impact of a pollution source on water vs. sediment quality, different indices and sampling techniques generated different assessments and the results required considerable interpretation. Generally, the colonizing community was less reliable in its assessment than resident riffle and infaunal communities. However, there were indications that colonizers may be more sensitive to the presence of toxic, but non-persistent, water-borne contaminants such as many of the pesticides in current use in the Yamaska River watershed.

The most important finding of the study was that agricultural activities of the intensity occurring in the Yamaska River basin are potentially as severe a source of impact on stream ecosystems as municipal and industrial effluents receiving only primary treatment. Further research on the effects of agricultural practices on aquatic systems is clearly needed.

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Table I. Classification of study sites based on type and degree of pollution.

CLASSIFICATION OF SITES	DOMESTIC SEWAGE POLLUTION Population (community)[a]	INDUSTRIAL POLLUTION Major industries and # employees (# plants) Textiles[b]	Foundries[c]	Organic chemicals[c]	Surface finishing[c]	AGRICULTURAL POLLUTION Percent farmed area sprayed with herbicides[d]	Percent farmed area sprayed with insecticides[d]
Control sites:							
35	-	-	-	-	-	8%	0
36	-	-	-	-	-	8%	<0.5%
3	300 (Brome)	-	-	-	-	3%	<0.5%
Municipal/ industrial sites:							
8	2500 (Valcourt)	-	-	-	<500 (1)	2.5%	<0.5%
37	4500 (Waterloo; Warden)	-	<50 (1)	-	300-500 (1)	3.5%	0
4	11,500 (Cowansville)	169 (1)	-	<50 (1)	-	7%	2.5%
9	4500 (Acton Vale)	290 (1)	-	300-550 (2)	-	13.5%	0.5%
12	38,500 (Saint-Hyacinthe)	425 (2)	200-350 (2)	-	NA (1)	30.5%	3.5%
5	38,500 (Granby)	1400 (6)	-	<50 (1)	200-400 (2)	3.5%	0
Agricultural sites:							
31	-	-	-	-	-	13%	<0.5%
32	1000 (Saint-Nazaire-d'Acton)	-	-	-	-	33%	1.5%
30	-	-	-	-	-	48%	10%
33	-	-	-	-	-	53%	1.0%

a Statistics Canada (1987b)
b Marc Sinotte, Environnement Québec (personal communication)
c Entraco (1989)
d Statistics Canada (1987a)

Table II. Site rankings based on eight summary indices applied to July Surber samples (Index values in brackets).*

S	N	H'	D	BBI	TBI	%CHIR	%OLIGO
36 (75)	35 (1022)	35 (3.287)	35 (0.057)	3 (10)	3 (3.440)	3 (11.2)	36 (0.3)
31 (64)	3 (1077)	3 (3.161)	31 (0.061)	8 (10)	37 (4.270)	37 (15.4)	3 (0.4)
8 (64)	9 (1657)	31 (3.089)	3 (0.061)	36 (10)	8 (4.290)	8 (15.6)	8 (0.5)
3 (57)	37 (2262)	36 (2.995)	5 (0.071)	37 (9)	35 (4.908)	32 (28.1)	12 (0.9)
35 (56)	31 (2764)	32 (2.956)	36 (0.076)	35 (8)	36 (5.626)	35 (28.3)	35 (1.0)
32 (51)	36 (4170)	5 (2.880)	32 (0.077)	12 (8)	32 (5.756)	12 (29.7)	31 (4.3)
5 (49)	8 (4287)	8 (2.715)	8 (0.108)	31 (8)	12 (5.971)	5 (33.4)	32 (4.3)
37 (47)	5 (5258)	9 (2.515)	9 (0.118)	5 (7)	31 (6.063)	36 (56.1)	37 (9.6)
12 (41)	32 (5920)	12 (2.239)	37 (0.182)	32 (7)	5 (7.113)	31 (65.2)	5 (24.5)
9 (33)	12 (6358)	37 (2.238)	12 (0.191)	9 (3)	9 (7.767)	9 (98.4)	9 (29.6)

Correlation matrix (Critical value of r_s @ α=0.05, n=10 = .648):

	%OLIGO	%CHIR	TBI	BBI	D	H'	N	S
S	.717*	.091	.389	.672*	.576	.638	.103	-
N	.006	.103	.345	.175	.499	.455	-	
H'	.418	.006	.188	.187	.948*	-		
D	.225	-.018	.122	.106	-			
BBI	.841*	.536	.810*	-				
TBI	.588	.879*	-					
%CHIR	.321	-						
%OLIGO	-							

* In Tables II - VI, sites are ranked in descending order from the least to the most degraded.

Table III. Site rankings based on eight summary indices applied to August Surber samples.

S	N	H'	D	BBI	TBI	%CHIR	%OLIGO
3 (70)	3 (2596)	8 (3.070)	8 (0.068)	8 (10)	8 (5.025)	5 (17.6)	36 (0.1)
8 (68)	37 (3578)	12 (3.029)	12 (0.072)	3 (10)	36 (5.031)	3 (20.3)	3 (0.2)
36 (61)	12 (3854)	3 (2.983)	36 (0.087)	36 (10)	3 (5.059)	9 (20.7)	8 (0.5)
12 (51)	36 (4018)	36 (2.900)	32 (0.103)	12 (7)	37 (5.279)	32 (26.2)	37 (1.0)
37 (49)	9 (5180)	32 (2.564)	3 (0.109)	37 (7)	32 (5.607)	12 (27.4)	32 (2.5)
32 (33)	5 (6816)	37 (2.369)	37 (0.143)	32 (6)	12 (5.921)	8 (34.5)	9 (2.6)
9 (32)	8 (7438)	5 (1.981)	5 (0.233)	9 (6)	9 (6.191)	36 (34.7)	12 (8.6)
5 (29)	32 (7794)	9 (0.860)	9 (0.592)	5 (6)	5 (8.779)	37 (42.2)	5 (71.1)

Correlation matrix (Critical value of r_s @ $\alpha=0.05$, $n=8$ = .738):

	%OLIGO	%CHIR	TBI	BBI	D	H'	N	S
S	.786*	-.333	.857*	.945*	.667	.833*	.429	-
N	.286	-.143	.119	.441	-.143	.095	-	
H'	.429	-.310	.690	.756*	.929*	-		
D	.381	-.476	.667	.630	-			
BBI	.819*	-.441	.882*	-				
TBI	.905*	-.595	-					
%CHIR	-.476	-						
%OLIGO	-							

Table IV. Site rankings based on eight summary indices applied to July scoop samples.

S	N	H'	D	BBI	TBI	%CHIR	%OLIGO
36 (40)	33 (209)	8 (2.632)	8 (0.096)	8 (8)	36 (6.166)	37 (67.6)	36 (1.1)
3 (37)	4 (352)	36 (2.413)	35 (0.128)	3 (7)	8 (6.606)	33 (91.6)	8 (3.2)
8 (30)	30 (360)	35 (2.305)	36 (0.139)	36 (7)	3 (6.631)	8 (92.8)	3 (4.8)
9 (21)	8 (445)	3 (2.271)	3 (0.181)	37 (5)	30 (6.756)	35 (94.1)	33 (8.6)
33 (21)	35 (578)	33 (1.931)	5 (0.210)	33 (5)	35 (7.225)	36 (94.2)	30 (15.6)
5 (20)	32 (905)	4 (1.848)	33 (0.243)	5 (5)	33 (8.225)	4 (96.8)	35 (18.0)
35 (19)	3 (942)	5 (1.797)	32 (0.247)	30 (3)	32 (8.876)	3 (97.0)	9 (20.8)
37 (15)	36 (1079)	9 (1.595)	4 (0.270)	35 (2)	4 (8.955)	30 (98.6)	4 (28.4)
4 (13)	9 (3956)	32 (1.569)	9 (0.319)	32 (2)	9 (9.182)	5 (98.9)	32 (64.2)
30 (11)	37 (3985)	30 (1.100)	30 (0.551)	4 (2)	5 (9.612)	32 (100.0)	5 (94.8)
32 (8)	5 (6888)	37 (0.609)	37 (0.711)	9 (2)	37 (9.899)	9 (100.0)	37 (99.0)

Correlation matrix (Critical value of r_s @ α=0.05, n=11 = .623):

	%OLIGO	%CHIR	TBI	BBI	D	H'	N	S
S	.691*	.182	.500	.600	.591	.709*	-.236	-
N	.391	.282	.391	-.082	.091	.245	-	
H'	.764*	.318	.718*	.482	.927*	-		
D	.618	.209	.655*	.491	-			
BBI	.545	.573	.536	-				
TBI	.936*	.164	-					
%CHIR	.218	-						
%OLIGO	-							

Table V. Site rankings based on eight summary indices applied to artificial substrate samples.

S	N	H'	D	BBI	TBI	%CHIR	%OLIGO
8 (38)	33 (56)	8 (2.777)	33 (0.082)	36 (8)	36 (5.940)	33 (35.0)	36 (0)
3 (33)	36 (336)	33 (2.700)	8 (0.098)	8 (7)	8 (6.590)	36 (76.7)	3 (7.5)
37 (29)	35 (513)	3 (2.585)	9 (0.123)	35 (6)	3 (7.302)	35 (79.8)	30 (11.0)
9 (28)	32 (868)	36 (2.503)	3 (0.123)	32 (6)	30 (7.306)	30 (86.8)	8 (20.5)
36 (27)	4 (1184)	9 (2.353)	35 (0.134)	37 (6)	35 (7.558)	32 (87.1)	33 (23.2)
35 (21)	37 (1596)	35 (2.298)	36 (0.181)	3 (6)	33 (7.661)	9 (88.7)	35 (25.5)
33 (21)	8 (1757)	30 (2.115)	4 (0.182)	33 (5)	32 (8.931)	8 (89.4)	37 (41.9)
32 (21)	9 (1918)	4 (2.090)	30 (0.195)	5 (5)	9 (8.982)	37 (92.3)	9 (60.5)
30 (18)	3 (1920)	37 (2.068)	37 (0.211)	9 (5)	4 (9.081)	3 (93.0)	32 (70.0)
4 (16)	30 (2328)	32 (1.974)	32 (0.235)	30 (5)	37 (9.188)	4 (100.0)	4 (71.3)
5 (10)	5(11200)	5 (1.098)	5 (0.418)	4 (3)	5 (9.994)	5 (100.0)	5 (99.4)

Correlation matrix (Critical value of r_s @ α=0.05, n=11 = .623):

	%OLIGO	%CHIR	TBI	BBI	D	H'	N	S
S	.555	.082	.491	.555	.573	.655*	.064	-
N	.164	.682*	.236	.464	.327	.282	-	
H'	.718*	.427	.745*	.327	.936*	-		
D	.482	.409	.518	.154	-			
BBI	.445	.382	.555	-				
TBI	.900*	.527	-					
%CHIR	.518	-						
%OLIGO	-							

Table VI. Site rankings based on eight summary indices applied to artificial substrate samples.

S	N	H'	D	BBI	TBI	%CHIR	%OLIGO
8 (65)	33 (801)	37 (2.568)	36 (0.130)	3 (10)	37 (5.783)	33 (72.2)	8 (0)
3 (52)	31 (1190)	36 (2.485)	37 (0.132)	8 (10)	8 (5.947)	8 (79.7)	4 (0.1)
36 (43)	5 (1365)	8 (2.468)	8 (0.156)	4 (8)	36 (6.467)	3 (88.4)	9 (0.1)
37 (38)	9 (1435)	3 (2.340)	32 (0.157)	32 (7)	4 (6.490)	31 (90.1)	3 (0.1)
4 (35)	32 (1587)	32 (2.185)	3 (0.185)	36 (7)	3 (6.524)	5 (91.7)	32 (0.4)
33 (32)	36 (1619)	4 (2.136)	4 (0.186)	5 (6)	9 (6.667)	9 (92.7)	31 (0.5)
31 (31)	3 (1968)	9 (1.946)	33 (0.216)	33 (6)	5 (7.061)	37 (93.8)	36 (0.7)
32 (31)	4 (4532)	33 (1.937)	5 (0.226)	31 (6)	32 (7.112)	32 (95.2)	37 (2.3)
9 (29)	8 (4952)	5 (1.921)	9 (0.253)	37 (6)	31 (7.154)	4 (95.9)	33 (3.0)
5 (28)	37 (5037)	31 (1.822)	31 (0.334)	30 (5)	33 (8.497)	36 (97.5)	30 (3.1)
30 (20)	30(14178)	30 (0.566)	30 (0.864)	9 (5)	30 (9.824)	30 (99.3)	5 (56.3)

Correlation matrix (Critical value of r_s @ α=0.05, n=11 = .623):

	%OLIGO	%CHIR	TBI	BBI	D	H'	N	S
S	.536	.345	.736*	.664*	.764*	.791*	-.255	-
N	-.182	.491	-.445	-.109	-.291	-.382	-	
H'	.400	-.009	.882*	.436	.955*	-		
D	.273	-.027	.791*	.527	-			
BBI	.482	.255	.373	-				
TBI	.473	-.018	-					
%CHIR	.164	-						
%OLIGO	-							

Table VII. Correlations between July and August site rankings for summary indices applied to Surber and scoop samples.

Index	Correlations for Surbers[a]	Correlations for scoops[b]
S	.613	.598
N	.524	.400
H'	.167	.700*
D	-.167	.415
BBI	.974*	.568
TBI	.786*	.982*
%CHIR	-.143	.228
%OLIGO	.786*	.855*

[a] Critical value of r_S @ α=0.05, n=8 = .738.
[b] Critical value of r_S @ α=0.05, n=11 = .623.

Table VIII. Correlations between sampling methods in the rankings of sites 3, 5, 8, 9, 32, 36 and 37 as determined by seven summary indices.*

Index	July Surbers vs. scoops	August Surbers vs. scoops	August Surbers vs. art. substrates	August Scoops vs. art. substrates
S	.643	.786*	.964*	.821*
H'	.464	.750	.500	.464
D	.536	.342	.714	.036
BBI	.964*	.808*	.753	.683
TBI	.214	.917*	.679	.543
%CHIR	.571	.536	.464	.679
%OLIGO	.714	.964*	.324	.378

*Critical value of r_s @ α=0.05, n=7 = .786.

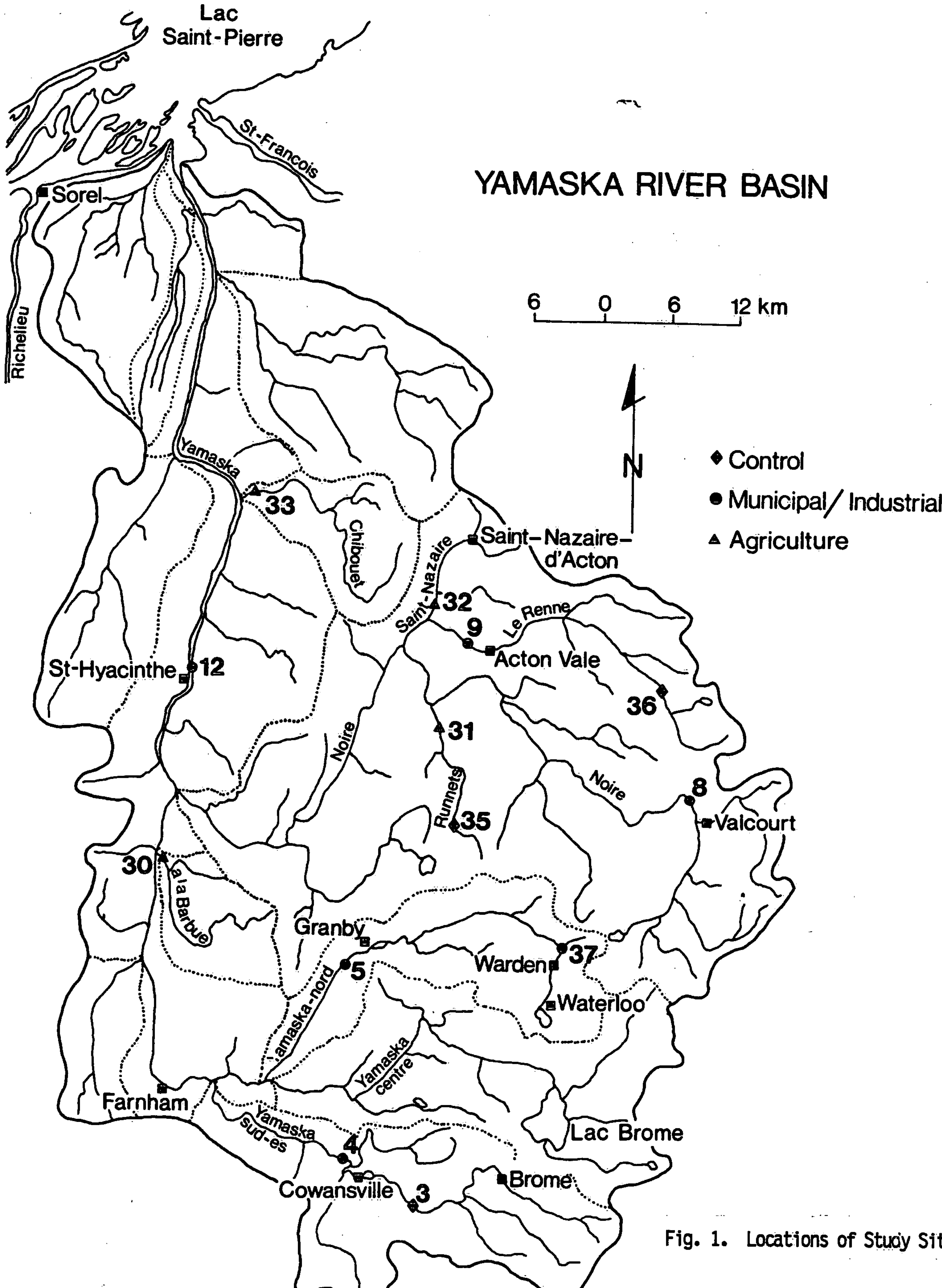

Fig. 1. Locations of Study Sites.

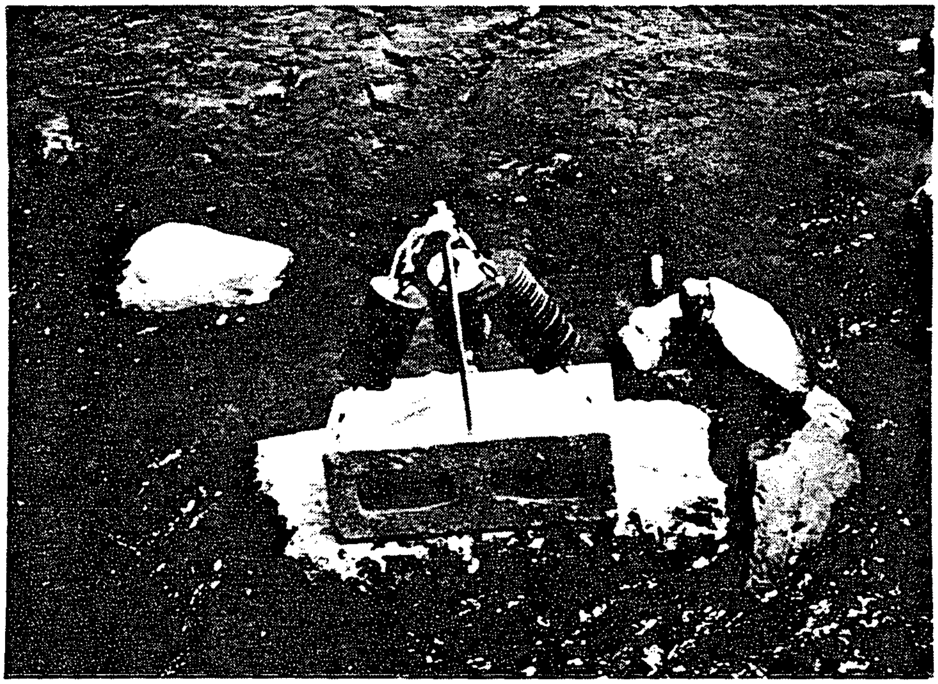

Fig. 2. Deployment Apparatus for Artificial Substrate Samplers.

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