Benthic Macroinvertebrate Communities

An Indicator of Ecosystem Health and Water Quality in Lake Saint-Pierre

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Background

Water quality is often assessed using conventional methods that measure a series of physical and chemical parameters which are then compared to proven quality criteria or standards. This approach has its limitations, since it may predict an impact when there isn't one or fail to predict an impact when there is one. According to one American study (Thomas, 1993), this can happen in 36% and 6% of cases, respectively. The traditional approach can be beneficially complemented by biological monitoring, which involves using living organisms such as microorganisms, plants or animals to measure the effects of water pollution. For instance, biological monitoring takes into consideration the combined effects of chemicals, the effect of contamination peaks as well as the impact of ecological disturbances such as eutrophication, the presence of exotic species or habitat degradation.

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Sampling station at Lake Saint-Pierre

Measurement methods based on biological assessment use living organisms to provide an overview of environmental conditions and stresses. Various groups of species have been used in such assessments, although benthic macroinvertebrates continue to be among the most useful. Visible to the naked eye, benthic invertebrates are small animals with no backbone that live on the bottom of lakes and rivers (Figure 1). They include organisms such as shrimp, worms, crayfish, aquatic snails, mussels and the aquatic larval stage of various insects such as libelluids (dragonflies), ephemeropterans (mayflies), trichopterans (caddisflies) and dipterans (mosquitoes, black flies), which are sensitive to changes in water and aquatic ecosystem quality. There are several advantages to using benthic invertebrates as bioindicators. First, they are sedentary organisms that are continuously exposed to the effects of pollution. They have a relatively long life cycle (one to three years in the water of temperate regions of the Northern Hemisphere), which makes it possible to take account of environmental stressors and their cumulative impacts over time. In addition, benthic invertebrates are made up of a highly diversified group of organisms, thus offering a window into how different species react and respond to different types of perturbations. Macroinvertebrates are also found in the vast majority of aquatic ecosystems in Canada and occupy an important role in food webs, where they play an essential ecological role. Lastly, macroinvertebrates are commonly used in many countries, making it possible to transpose and adapt experimental protocols tested in the Canadian context.

Figure 1 Different types of macrobenthic invertebrates

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Macroinvertebrates have been used to assess water quality since the beginning of the second half of the 20th century. The studies involved observing the effect of organic pollution on the proliferation or decline of indicator species such as freshwater shrimp (gammarids) or snails. This approach was subsequently refined in order to more effectively consider macroinvertebrate communities[1] by observing the number of species (diversity) and the species present (composition), and then comparing disturbed sites (test sites) with reference sites, which have experienced little or no disturbance from human activity, in order to establish biological assessment criteria.

In the case of the St. Lawrence River, the reference sites chosen are in Lake Saint-Pierre. This widening of the St. Lawrence River downstream of Sorel-Tracy is interesting in several respects: its shores remain largely in their natural state and it has relatively intact riparian wetlands and high biodiversity.

1. A benthic invertebrate community is a series of organisms belonging to populations of different species constituting a network of relationships.

Overview of the Situation

A study of the effects of environmental factors on freshwater benthic communities was carried out in Lake Saint-Pierre in the fall of 2004 (Figure 2). A series of sampling stations were set up in the low marshes, taking into consideration the type of sediment and water masses present (mix of Ottawa River-Great Lakes, Great Lakes, and south shore tributaries-Great Lakes water masses). One of the primary objectives was to determine the impact of the rivers draining the surrounding agricultural land on the benthic fauna of Lake Saint-Pierre. To this end, the benthic macroinvertebrate communities of the stations located in relatively unaffected areas (reference stations) were compared to the communities of the stations under the influence of tributary plumes (test or plume stations). The macroinvertebrates were identified and counted to the *family* level and, in certain cases, to the *class* level.

The low marshes of Lake Saint-Pierre support highly diversified benthic invertebrate fauna, with 61 taxa. However, five groups alone account for more than 80% of the total abundance of organisms (Figure 3; Table 1). In order of importance, these groups are gammarids (small shrimp) at 27.8%, oligochaetes (aquatic worms) (18.8%), chironomids (9.8%), branchiopods (4.5%), *Asellidae* crustaceans (isopods) (6.9%), and copepods (3.8%). Their total abundance and relative abundance vary depending on which shore of the St. Lawrence River is considered

Figure 2 Study areas and sampling stations

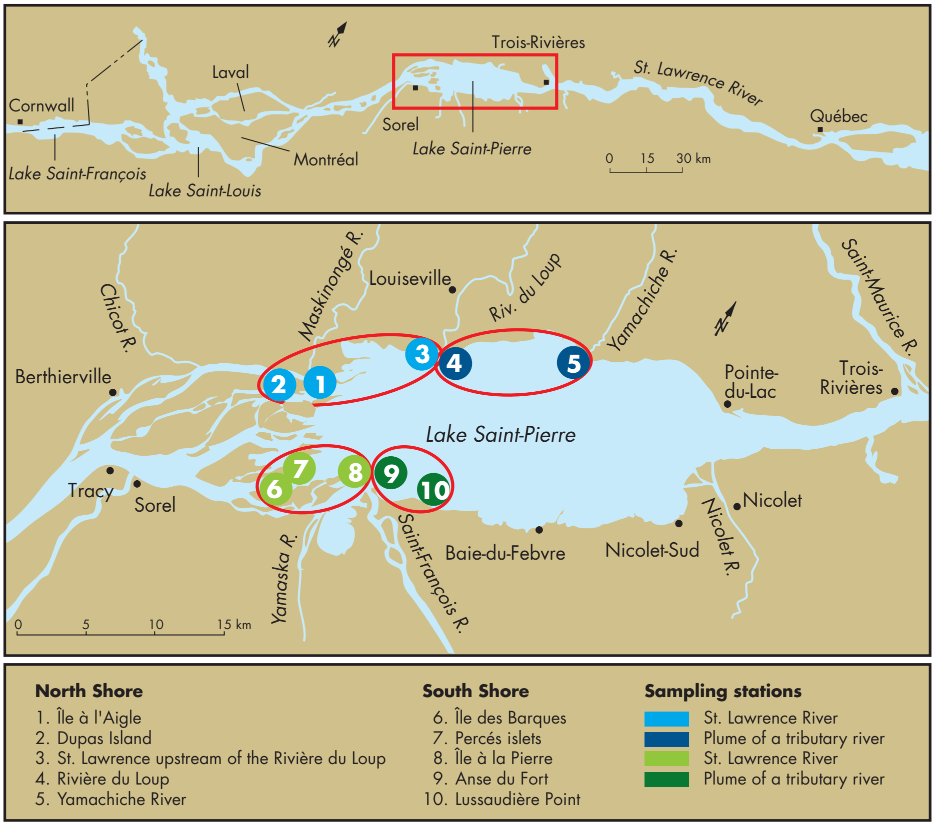
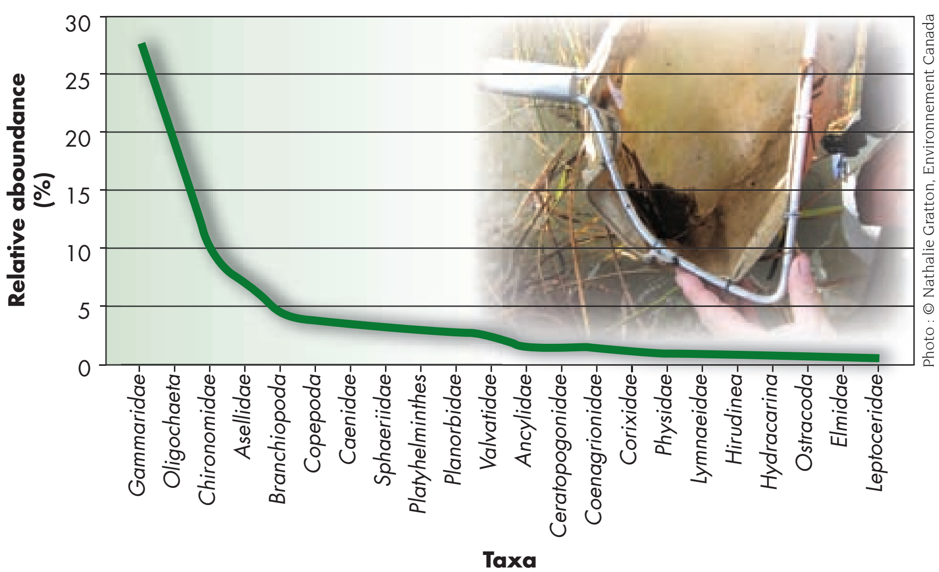


Figure 3 Dominance curve



Source: Adapted from Tall et al., 2008.

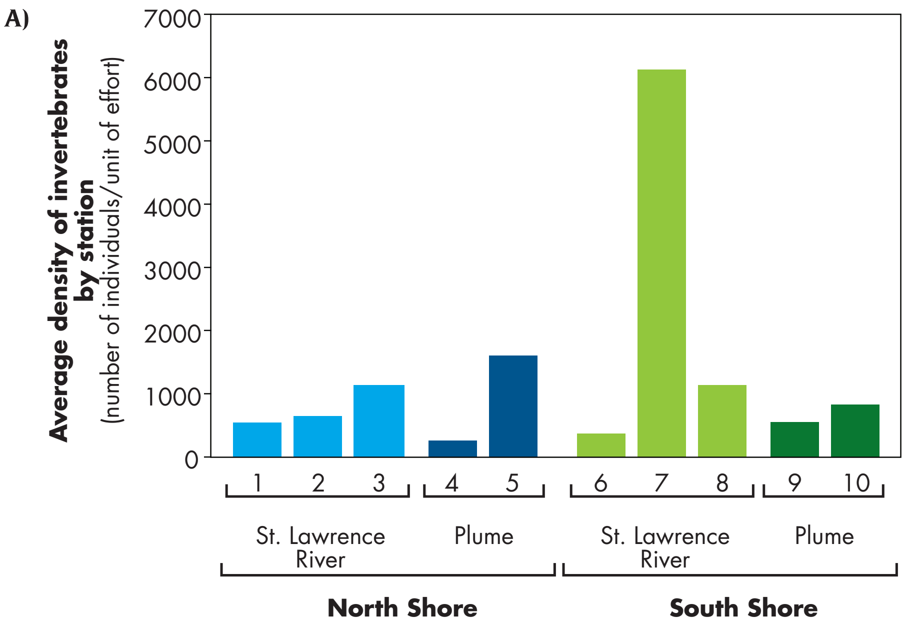
and on whether or not a station is under the influence of a plume from a tributary of the St. Lawrence (Figure 4a). The stations located on the north shore have a lower average abundance. This is largely due to the extreme abundance observed at the Station 7 (Îlets Percés), where more than 6000 organisms were observed during a three-minute sampling. This high abundance increases the average of the south shore stations, and if the results of this station are excluded, abundances for both shores are similar. The influence of the dispersion plumes of the tributary rivers of the St. Lawrence is reflected in a significant decrease in macroinvertebrate abundance. There are also notable differences in the relative abundance of the various taxa between the two shores and between the stations located in the river plumes and the reference stations (Figure 4b). For instance, insects and oligochaetes are more abundant at the north shore stations, while, conversely, the south shore stations have a higher abundance of crustaceans, molluscs and other invertebrates. It should be pointed out that the species composition of the benthic community of the Station 7, which is remarkable from the standpoint of total abundance, is similar to that of the other south shore stations. As noted earlier, there are significant differences between the St. Lawrence River stations and the stations under the influence of tributary plumes. For instance, the fluvial benthic communities, compared to those of the plumes, are characterized by higher abundances of crustaceans and molluscs, while the plumes, on the other hand,

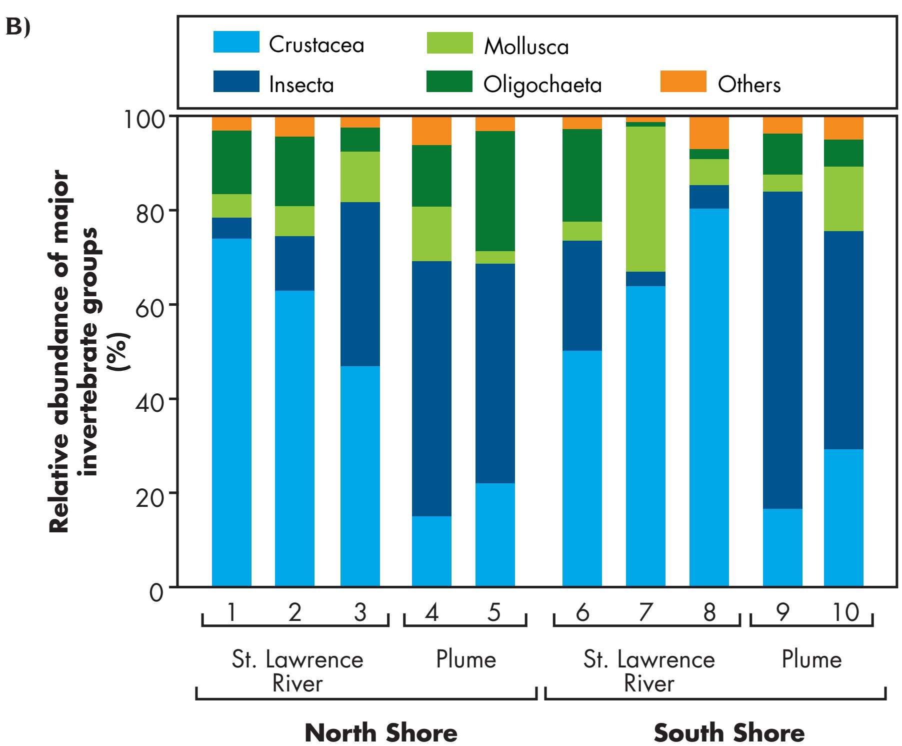
Table 1 Main metrics associated with the benthic communities of Lake Saint-Pierre

	North shore		South shore	
	St. Lawrence River	Plume	St. Lawrence River	Plume
Taxonomic richness				
S (taxonomic richness)	15	17	19	21
Total ephemeropterans	1	2	2	3
Total plecopterans	0	0	0	0
Total trichopterans	1	0	1	2
Total EPT*	2	2	3	5
Total dipterans	2	1	3	3
Total coleopterans	0	0	1	2
Total odonates	1	1	1	1
Species composition				
% EPT	0.31	0.67	13.78	21.69
% ephemeropterans	0.22	0.67	6.47	17.60
% plecopterans	0.00	0.00	0.00	0.00
% trichopterans	0.09	0.00	7.31	4.09
% coleopterans	0.00	0.00	2.51	3.30
% odonates	0.44	4.68	0.94	4.60
% tribe Tanytarsini	1.56	0.00	0.00	0.00
% EPT/chironomids + EPT	3.25	4.35	25.78	51.63
% chironomids	7.49	14.72	39.67	24.13
% trichopterans belonging to Hydropsychidae	0.00	0.00	0.00	0.00
% ephemeropterans belonging to Baetidae	0.00	0.00	0.42	0.28
% dipterans + non-insects	96.94	94.65	76.41	67.92
Diversity				
H' (Shannon-Wiener) diversity index	1.93	2.15	2.15	2.26
D (Simpson's diversity index)	0.80	0.85	0.80	0.83
Evenness (equitability)				
J' (Pielou's evenness index)	0.70	0.76	0.73	0.74
E (Simpson's evenness index)	0.33	0.40	0.27	0.29
Dominance				
% dominant taxon	30.72	23.41	39.67	33.80
% of two dominant taxa	55.99	43.48	52.19	47.56
% of five dominant taxa	84.04	80.27	73.28	71.48
Pollution				
HBI (Hilsenhoff's biotic index)	6.91	6.88	6.32	6.26
No. of intolerant taxa	2.67	3.00	3	4.050
% of tolerant individuals	67.68	63.88	34.03	42.78
Functional groups				
% collector-gatherers	86.84	85.95	79.54	76.31
% predators	4.65	6.02	14.61	14.41
% filterers	2.29	3.01	3.13	2.24
% scrapers	6.19	5.02	2.71	7.04
% shredders	0.04	0.00	0.00	0.00
Number of clinger taxa	1	2	2	2
Number of long-lived taxa	2	3	3	4

* EPT: Ephemeroptera, Plecoptera and Trichoptera.

Figure 4 **Total abundance and relative richness of the benthic communities in Lake Saint-Pierre**





Source: Adapted from Tall et al., 2008.

Note: See Figure 2 for sampling stations location.

have higher abundances of insects, oligochaetes and other invertebrates. The higher count of insects many be the result of a drift phenomenon, with the Another way of assessing the differences between the communities is to compare different indices such as the simple index or the composite index, which describe various aspects of species richness, diversity, dominance, sensitivity to organic pollution and functional groups of the benthic communities. All these indices show few differences between the reference stations (St. Lawrence River) and the test (plume) stations (Table 1). However, a few differences can be observed: for instance, the south shore stations have higher taxa richness than the north shore stations, which is reflected in the indices as the percentage of ephemeropterans, plecopterans and trichopterans, their total number and the Shannon-Wiener diversity index (H'), for which higher values are observed, indicating healthier communities. Similarly, dominance is less pronounced in the south shore stations. Finally, a larger number of organic pollution-tolerant individuals are observed in the benthic communities of the north shore. The spatial variation of the Hilsenhoff Biotic Index[2] clearly illustrates this difference between the two shores, with the north shore stations showing high index values, indicating a benthic community associated with organic enrichment (Figure 5). Hence, there is a clear

2. The Hilsenhoff index is the sum of the relative abundances of benthic organisms, multiplied by their organic pollution tolerance index. This tolerance index is a value between zero (non-polluted water taxon) and ten (polluted water taxon).

decreasing gradient of the Hilsenhoff index from upstream to downstream, with better water quality being associated with the stations located in the eastern part of Lake Saint-Pierre. However, the latter results must be qualified. Grouping species by family leads to an underestimation of the level of pollution since species within the same family may have a broader range of tolerance values. In addition, this index must be adapted to Eastern Canada.

Other types of statistical analyses, called multivariate analyses, have made it possible to identify the environmental factors that influence the composition of benthic communities, factors associated with either habitat, physical and chemical parameters, the metal content of sediments or the fluvial landscape. Habitat is essentially defined by the dominant type of vegetation at a given station. For instance, the presence of two plant species, Narrow-leaved Cattail (*Typha angustifolia*) and Great Bulrush (*Scirpus lacustris*), explains, respectively, 20% and 12% of the variability observed in the species composition of benthic communities. Sediment quality (aluminum and arsenic concentrations) and water quality (dissolved organic carbon and total phosphorus levels) also explain, respectively, 16% and 13% of the variability of benthic communities. It should be pointed out that the presence of aluminum and arsenic in the sediments of the St. Lawrence River is due to natural erosion processes of the clays of the Champlain Sea and the rocks of the Canadian Shield (EC and MDDEP, 2007). In addition, the fluvial landscape-in this case, the diversity of riparian habitats assessed using aerial photographs-explains 9% of the variability of the benthic communities (Figure 6).

Figure 5 Hilsenhoff index of the benthic communities in Lake Saint-Pierre

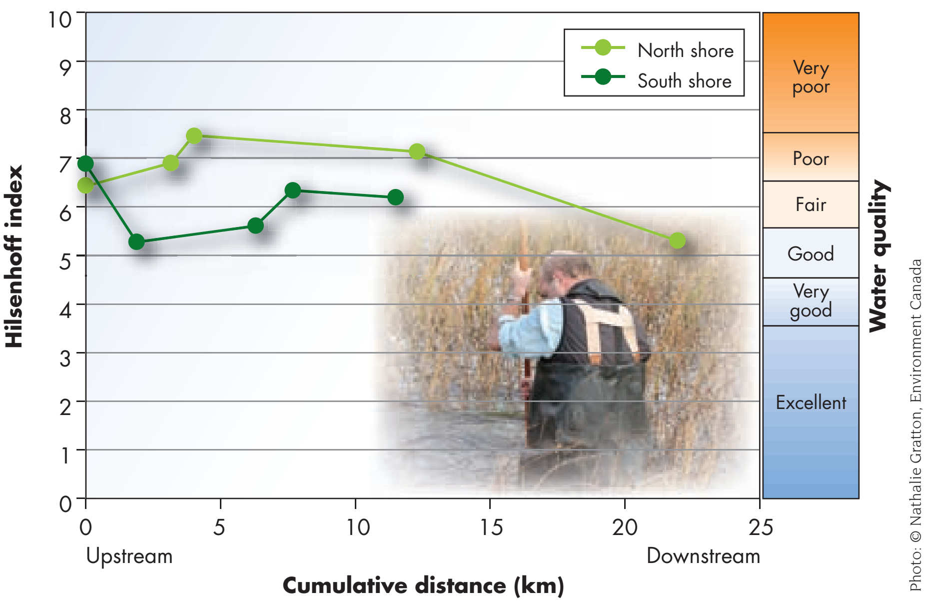
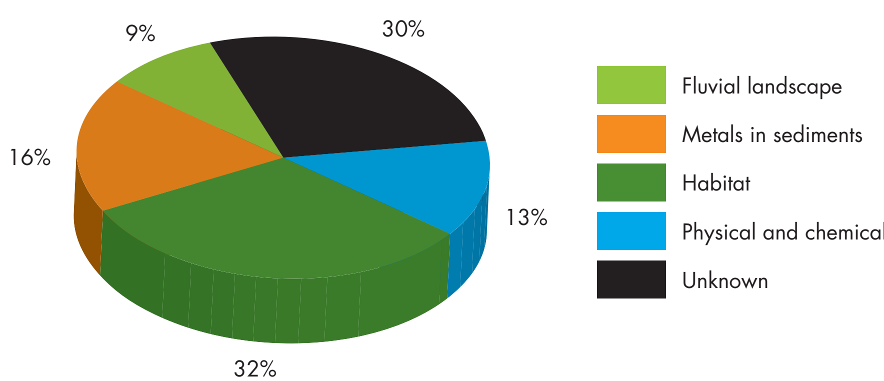


Figure 6 Main environmental factors explaining the variability of benthic communities in Lake Saint-Pierre



Source: Adapted from Tall et al., 2008.

Outlook

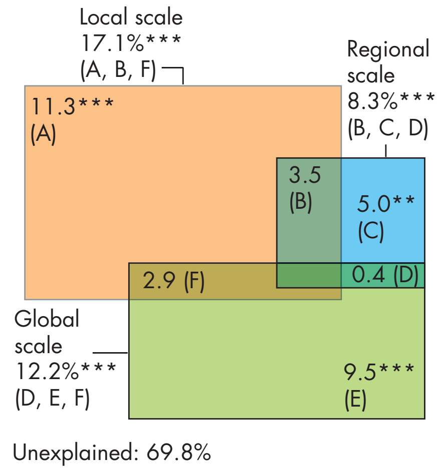
The comparison of the reference sites and test sites made it possible to determine the environmental factors that influence the composition of the benthic communities in Lake Saint-Pierre-namely, habitat structure and composition, water quality and sediment quality. The characteristics of the habitat best explain the variability of the benthic communities of the

Lake Saint-Pierre littoral zone. These preliminary results also highlight the importance of a more in-depth comparison, with new data, to more accurately determine the complex relationships between the benthic communities of Lake Saint-Pierre and habitat, water quality and sediment quality.

This pilot project shows that the macroinvertebrates in the littoral wetlands of Lake Saint-Pierre constitute good bioindicators of the health status of streams, rivers and lakes. However, the specific and reciprocal influences of these environmental factors must still be demonstrated. In fact, macroinvertebrates respond simultaneously to all the different factors associated with vegetation type, water masses and sediment contamination, and each of these factors is partly influenced by other factors associated with fluvial hydrology, erosion and agricultural land use (Figure 7).

Over the coming years, the increase in spatial coverage, especially in the other lakes and fluvial sections of the St. Lawrence, as well as repeated measurements at regular intervals, will make it possible to establish, with the help of this bioindicator, a more detailed picture of the changes and trends in the quality of the fluvial environment over a longer period of time.

Figure 7 Relative influence of environmental factors, at different spatial and temporal scales, on the benthic communities of the Lake Saint-Pierre wetlands



Source: Armellin et al., in preparation.
Significance: $p < 0.0001$***, $p < 0.001$**.

Photo: © Nathalie Gratton, Environment Canada

KEY VARIABLES

Determining the reference conditions for the study

The «reference conditions» approach or RCA involves establishing criteria or standards based on existing biological communities. Reference sites are selected based on their ecological integrity —that is, they have not been altered by human activity. However, such sites can be difficult to find in some regions, in which case, the reference sites will be those presenting the best possible environmental conditions. To compare a study site to reference sites, it is necessary to: 1) describe the relationship between the characteristics of the habitat and the benthic communities in the reference sites in order to produce an empirical prediction model; 2) using habitat data, match a study site with reference sites that are physically similar to the study site; 3) and, finally, compare the macroinvertebrate community of the study site with that of the reference sites, based on presence-absence data. It is thus possible to assess the state of health of a stream, river or lake to the extent that it supports benthic macroinvertebrates predicted by the empirical model in the absence of degradation of anthropogenic origin.

Developing a predictive model requires, concurrently with the collection of macroinvertebrates, quantifying and determining various physical and chemical parameters and producing a description of the habitat. Generally, it is necessary to look for streams, rivers or lakes whose watershed has remained relatively unaffected by human activity. Where this proves impossible, it is then necessary to look for the best existing conditions.

In addition to contributing to the St. Lawrence Plan, this work is part of the biomonitoring program of the Canadian Aquatic Biomonitoring Network (CABIN) (http://cabin.cciw.ca/intro.asp), a national program aimed at establishing a network of sites for assessing the biological health of fresh water in Canada.

To Know More

BAILEY, R., R.H. NORRIS, and T.B. REYNOLDSON (eds.). 2004. *Bioassessment of Freshwater Ecosystems: Using the Reference Condition Approach*. Norwell, Massachusetts. Kluwer Academic Publishers. 170 pp.

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EC and MDDEP – Environment Canada and Ministere du Developpement Durable, de l'Environnement et des Parcs du Quebec. 2007. *Criteria for the Assessment of Sediment Quality in Quebec and Application Frameworks: Prevention, Dredging and Remediation*. 39 pp.

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THOMAS, J.D. 1993. Biological monitoring and tropical biodiversity in marine environments: a critique with recommendations, and comments on the use of amphipods as bioindicators. *Journal of Natural History* 27: 795–806.

Interested readers are encouraged to check the following sites on benthic communities:

Page on benthic community health of the Great Lakes Monitoring Program of the U.S. Environmental Protection Agency (EPA): http://www.epa.gov/glindicators/biology/benthicb.html

Abundances of the Benthic Amphipod *Diporeia* spp. – Indicator 123: http://www.solecregistration.ca/documents/0123%20Diporeia%20(SOLEC%202008).pdf

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State of the St. Lawrence Monitoring Program

Under the current Canada–Quebec agreement, the St. Lawrence Plan for a Sustainable Development, six government partners—Environment Canada, the Ministère du Développement durable, de l'Environnement et des Parcs du Québec, Fisheries and Oceans Canada, the Ministère des Ressources naturelles et de la Faune du Québec, the Canadian Space Agency, and the Parks Canada Agency—together with Stratégies Saint-Laurent, a non-governmental organization that works actively with riverside communities, are pooling their expertise to provide Canadians with information on the state of the St. Lawrence River at regular intervals.

To obtain the fact sheets and additional information about the State of the St. Lawrence Monitoring Program, please visit our website at:

www.planstlaurent.qc.ca

Published by Authority of the Minister of the Environment

Published by Authority of the Ministre du Développement durable, de l'Environnement et des Parcs du Québec

Catalogue No.: En84-81/2010E-PDF
ISBN 978-1-100-17409-9
Legal deposit – Library and Archives Canada, 2010
Aussi disponible en français sous le titre : *Les communautés de macroinvertébrés benthiques – Un indicateur de la qualité de l'eau au lac Saint Pierre*