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Fishing for diatoms: fish gut analysis reveals water quality changes over a 75-year period

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Abstract Defining the reference state of some perturbed streams and rivers is challenging since their non-altered state is undocumented. Despite the near-absence of pristine sites in highly anthropogenic areas, information about aquatic communities that existed prior to human disturbance can be obtained from historic sources. Sediment coring is commonly used in paleolimnology to estimate past environmental conditions of lakes, but this technique is often not appropriate for studies of lotic systems. An alternative is to use diatom assemblages present in the guts of fish that were captured in the streams prior to significant human disturbance. The purpose of the present study was to evaluate the biological integrity of several streams in Ontario and Québec during the early twentieth century based on "paleo" diatom assemblages extracted from the guts of fish stored in museums. The Eastern Canadian diatom index (IDEC: Indice Diatomées de l'Est du Canada) was used to evaluate the biological status of "paleo" and "modern" diatom assemblages. The IDEC shows the position of diatom assemblages on a general pollution gradient. The comparison of IDEC values calculated for the 1925–1948 and the 2003–2007 periods showed that several streams were severely polluted in the early 1900s. In general, present water quality has declined compared to the early 1900s. The biological integrity of only three of the 22 sites has increased. IDEC values were not influenced by the species of fish studied.

Keywords Biological integrity · Cyprinid fish · Diatom assemblages · Diatom index · Past conditions · Streams

Introduction

Aquatic ecosystem degradation is currently a subject of primary interest for governmental agencies, scientists, and the general public in Canada, as it is throughout most of the world. Although water resources are one of the major concerns of the twenty first century, their degradation started long before. The great industrial expansion of the late 1800s was responsible for heavily polluting many water bodies through point source effluents, with contaminants discharged from industries such as pulp and paper, textiles, and metal mining. Water resources were then seen as a convenient site for disposal of waste products. Regulations that were developed since the 1970s have helped greatly to cut down on point source pollution, mainly from the industrial and municipal areas that now have to comply with strict legislation. However, some aquatic ecosystems are still severely

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polluted, even though the type of pollution and its sources may be different than what they were during the late 1800s and early 1900s. Point source pollution, directly discharging high levels of toxic materials from industries, has now been replaced mainly by non-point source pollution at the watershed scale, complicating water resource management. The most important factors responsible for water quality degradation are the increasing human population, changes in land use, intensive farming and logging.

Water management agencies have the mandate to restore and preserve water bodies. This task can not be successfully achieved without specific objectives based on reference conditions. A better understanding of these reference conditions is needed to identify target communities representing the level of ecological integrity necessary for stream restoration. However, defining the reference state of some perturbed sites is challenging because their non-altered state is undocumented. For practical purposes, in lowland areas characterised with intense agricultural activities, the reference status is often defined by the "least disturbed" conditions present because non-impacted environments can not be found. Locating pristine sites among the intensively farmed and heavily populated areas of Ontario and Québec proved to be a challenge during the development of the Eastern Canadian diatom index (IDEC: Indice diatomées de l'Est du Canada) (Grenier et al. 2006).

Although there is a near absence of pristine sites in highly anthropogenic areas, information based on communities that existed prior to human disturbance can be obtained from historic sources. Sediment coring is commonly used in paleolimnology to estimate past environmental conditions of lakes, but it is often is not appropriate for studies of lotic systems where sediments are periodically washed downstream. Several studies have examined diatom assemblages present in the guts of fish that were captured in the streams prior to significant human disturbance. Diatoms are an important source of food for herbivorous fish (McCollum et al. 1998) and diatom flora can be examined within the intestines of fish preserved in museum collections. Sellman et al. (2002) noted that diatoms extracted from stoneroller minnows did not differ significantly from diatoms sampled on stream substrates such as rocks, gravel, and coarse sands. Rosati et al. (2003) observed that the diatom assemblages extracted from stoneroller minnows, bluntnose minnows, and creek chubs were similar to human collected diatom assemblages from rocks and wood substrates. The fish-gut content approach has successfully been used in other studies with differing purposes, for example, to describe ecological changes in the Rio Grande and to infer a possible cause of the decline in the silvery minnow (*Hybognathus amarus*) (Shirey et al. 2008), and to reconstruct historical diatom community structure in a river based on fish acquired from a 30-year series of museum collection (Sray 1998).

In this study, the diatom flora extracted from the gut content of fish in museum collections were used (1) to recover diatom assemblages from the early 1900s to examine the past biological status of streams, (2) to evaluate how lotic ecosystems in Ontario and Quebec have responded to major changes in their watersheds between the early 1900s and the present, and (3) to evaluate whether "paleo" assemblages from the early 1900s represent reference conditions that can be used as targets for stream recovery after restoration. This study also provides additional information on the techniques to determine past conditions based on fish gut analyses.

Materials and methods

This study was conducted in streams and rivers from Ontario and Québec, Canada. The selected sites were distributed between London (Ontario) and the Eastern part of Québec, representing a large geographic area. The site selection was based on the fish database from the Royal Ontario Museum (ROM), Canada. The ROM's ichthyology collection consists of over 82,000 catalogued collections of fishes representing an estimated 7,500 species from all over the world. Within the collection, 30,574 catalogued lots representing an estimated 423,000 specimens of 171 different fish taxa were collected in the fresh waters of Ontario. Additional fish were provided by the Ministère des Ressources Naturelles et de la Faune (Québec).

The fish species selected for the present study were bluntnose minnow (*Pimephales notatus*), common shiner (*Luxilus cornutus*), northern redbelly dace (*Phoxinus eos*), and creek chub (*Semotilus atromaculatus*). These species were selected because they are common in the ROM fish collection, are present in numerous streams in Ontario, and are omnivorous fish prone to ingesting a large amount of diatoms. Bluntnose minnow, creek chub, common shiner, and stoneroller minnows (*Campostoma anomalum*) have already been used in previous studies and proved to be appropriate samplers of benthic diatoms (Sellman et al. 2002; Rosati et al. 2003). However, it was not possible to select the stoneroller minnow for the present study because it was introduced in Ontario in the 1970's and no specimens captured prior to this period were in the ROM collection. "Modern" assemblages of diatoms were sampled using the traditional rock-scraping method, rather than fish gut analysis. Little difference in diatom assemblage composition has been shown among substrate types (Winter and Duthie 2000; Potapova and Charles 2005), habitats (Lavoie et al. 2005), or sampling methods (Prygiel et al. 2002; Lane et al. 2007). We therefore made the assumption that the four species of fish chosen for the present study were representative samplers of benthic diatoms and that the potential differences between the diatom flora compositions obtained from fish or rock scrapes would not have an effect on the water-quality assessment.

To limit the number of sites sampled for "modern" diatom assemblages and to limit the number of samples analysed, an effort was made to use any of the four fish species captured at sites that were already visited in 2003 for the development of the IDEC (Lavoie et al. 2006). Due to the difficulty in finding sites which had been sampled for the museum collection and had been visited in 2003 for benthic diatom sampling, additional sites were selected and sampled in 2007 for diatom assemblages. Those sites were chosen because of fish availability in the collection and proximity of the sites. Fish that were captured between the months of December and March were not used because the IDEC was developed based on diatom communities collected during the late summer and fall. For the selected species and sampling sites, the ROM collection did not include fish specimens captured before 1925, which was identified as a possible limitation for the identification of reference conditions.

Fish specimens were gutted to obtain intestinal contents. Matching diatom communities representing modern conditions at each site were collected either during 2003 or 2007. Some of the sites selected were not suitable for the study due to an insufficient number of diatoms extracted from the fish guts. Other difficulties encountered when trying to match "paleo" and "modern" communities were associated with the occasional complexity of finding the exact sampling site as described in the museum database, or with the fact that some sites were not flowing at the time of re-sampling in August 2007. As a result, the final database for this study had 22 sites that included "paleo" assemblages extracted from either *Luxilus cornutus* (13 sites) *Pimephales notatus* (12 sites), *Semotilus atromaculatus* (2 sites) or *Phoxinus eos* (4 sites), and "modern" assemblages collected from rock scrapes at the matching sites. More than one of the selected fish species was available at 9 of the 22 sites, which allowed for the comparison between the diatom assemblages extracted from the intestines of different species.

Diatom sampling and analysis

"Modern" assemblages were sampled by scraping the top surface of rocks using a toothbrush. One composite sample of five rocks per site was collected from riffles where possible. The algae collected were preserved with Lugol's iodine and stored until the samples were processed. Subsamples of the scrapes were digested in 30% hydrogen peroxide. The diatom samples extracted from fish guts included the intestines of 3–6 specimens to obtain a composite sample for each "paleo" assemblage. Depending on the available samples, fish specimens ranging in size from approximately 3–15 cm were used. The diatoms were extracted from the fish guts by digestion of the whole intestine in 30% hydrogen peroxide. For both "modern" and "paleo" assemblages, the clean diatom material was mounted onto microscope slides using Naphrax. A minimum of 400 valves were counted and identified per slide following Lavoie et al. (2008).

Statistical analyses

The IDEC was used to evaluate the biological status of "paleo" and "modern" diatom assemblages. The IDEC shows the position of diatom assemblages on a general pollution gradient. For the purpose of this study, the sub-index IDEC-Alkaline was used (see Lavoie et al. 2006 and Grenier et al. 2006 for details on the IDEC sub-indices). The index value indicates the distance of each diatom community from its specific reference community, and values are expressed on a scale from 0 to 100. A high index value represents a non- or less-impacted site whereas a low index value represents a more heavily impacted site. For the purpose of this study, a difference in IDEC value ≤5 between "paleo" and "modern" assemblages was considered to be non-significant. This threshold was also used to compare the IDEC values between the different species of fish gutted. This value of 5 IDEC units was based on a previous study that showed that the standard deviation between replicate samples was 5.2 IDEC units (Lacoursière 2008).

The positions of the diatom assemblages collected in this study were graphically presented on the correspondence analysis (CA) plot used to develop the sub-index IDEC-Alkaline (Lavoie et al. 2006). The distribution of the "paleo" and "modern" assemblages was graphically shown to evaluate their position on the general pollution gradient, and to ensure that they were not clustering toward the extremes of the ordination because assemblages never were encountered during the development of the IDEC. All the assemblages were included as passive samples in the correspondence analysis (CA) used to develop the sub-index IDEC-Alkaline. Including passive samples in the IDEC-Alkaline CA does not change the index model, but allows for a graphical representation of the distribution of the "paleo" and "modern" assemblages on the general pollution gradient. The software CANOCO 4.5 (ter Braak and Smilauer 2002) was used to run the correspondence analysis.

The Shannon diversity index was calculated for the "paleo" and "modern" diatom assemblages. Analyses of variance (ANOVA) were conducted to verify that there was no effect from the type of sampling method, such as fish or from rock scrapes, or the species of fish gutted. Theses analyses were necessary to ensure that the differences between the "paleo" and "modern" assemblages reflected a change in water quality, not a change in diversity.

Results

The samples extracted from fish included a total of 238 diatom taxa, while the samples from rock scrapes included 237 taxa. There were 194 diatom taxa common to both the "paleo" and "modern" assemblages. The IDEC values calculated for the diatom assemblages revealed that most sites (15/22) had significant declines in biological integrity in the 60–75 years between "paleo" and "modern" samples (Fig. 1; Table 1). The most drastic changes were observed in Etobicoke Creek, Au Sable River, and Châteauguay River, where the biological integrity declined 79, 77, and 57 IDEC units respectively. The biological integrity of four sites (Castor River, Rideau River, Ouelle River, and Mimico creek) had not changed markedly between the two periods, as the IDEC values did not vary more than 5 units. The IDEC values calculated for Moira, Humber, and Kemptville Rivers suggested that the water quality improved compared to the past conditions. The IDEC values calculated for the "paleo" assemblages showed that only four sites were at reference status and six had a good biological integrity 60–75 years ago (Table 2). There were no sites classified as reference condition based on the "modern" diatom assemblages; nine sites represented poor biological status and seven sites

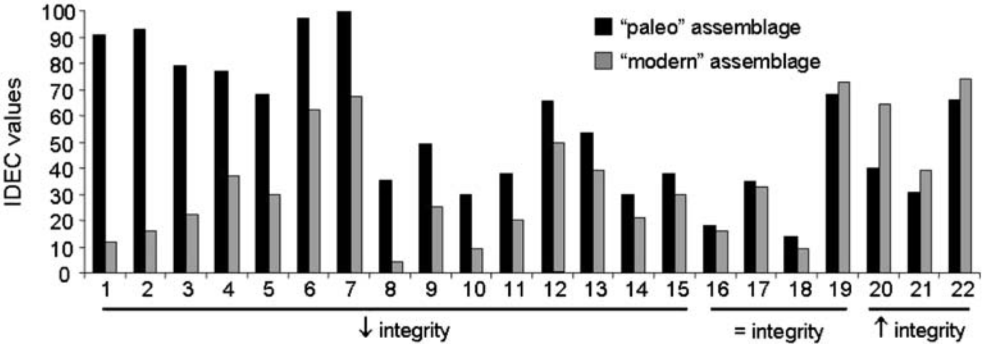

Fig. 1 Histogram showing the IDEC values of the "paleo" and "modern" assemblages for the 22 sites. When more than one species of fish was available, the average IDEC value was used. River names associated with the 22 sites are presented in Table 1

Table 1 IDEC values for each site calculated from “paleo” and “modern” assemblages

Site	River name	“Paleo” IDEC	“Modern” IDEC	Delta IDEC	Time interval (years)
Degradation					
1	Etobicoke (Ontario)	91 (1925)	12 (2007)	−79	82
2	Au Sable (Ontario)	93 (1936)	16 (2007)	−77	71
3	Châteauguay (Québec)	79 (1942)	22 (2003)	−57	61
4*	Thames (1) (Ontario)	77 (1936)	37 (2007)	−40	71
5	Baltimore (Ontario)	68 (1941)	30 (2007)	−38	66
6*	Medway (Ontario)	97 (1936)	62 (2007)	−35	71
7	Garry (Ontario)	100 (1938)	67 (2007)	−33	69
8*	Don West (Ontario)	35 (1947)	4 (2007)	−31	60
9*	Rouge (Ontario)	49 (1935)	25 (2003)	−24	68
10	Becketts (Ontario)	30 (1939)	9 (2007)	−21	68
11*	Delisle (Ontario)	38 (1938)	20 (2007)	−18	69
12	Gananoque (Ontario)	65 (1937)	49 (2007)	−16	70
13*	Thames (2) (Ontario)	52 (1936)	39 (2007)	−13	71
14	Spring (Ontario)	30 (1938)	21 (2007)	−9	69
15	Beaudette (Ontario)	38 (1938)	30 (2007)	−8	69
No change					
16*	Castor (Ontario)	18 (1937)	16 (2007)	−2	70
17	Rideau (Ontario)	35 (1937)	33 (2007)	−2	70
18	Mimico (Ontario)	14 (1935)	9 (2003)	−5	68
19*	Ouelle (Québec)	68 (1941)	73 (2007)	5	66
Recovery					
20	Moira (Ontario)	40 (1948)	64 (2003)	24	55
21	Humber (Ontario)	31 (1934)	39 (2003)	8	69
22*	Kemptville (Ontario)	66 (1937)	74 (2007)	8	70

Dates of fish captures and algae samples are in brackets

* Indicates the sites where two species of fish were gutted. The IDEC value for the sites where two species of fish were available represents the average

Table 2 Number of sites classified in each biological status category for the “paleo” and “modern” assemblages

Classes	“Paleo” conditions	“Modern” conditions
Excellent	4	0
Good	6	5
Fair	3	1
Poor	7	9
Very poor	2	7

The IDEC categories are based on Lavoie et al. (2006)

showed very poor biological integrity. The average IDEC values for the 1925–1948 and the 2003–2007 samples were 52 and 34, respectively.

The CA showed that the “paleo” and “modern” diatom assemblages included as passive samples in the model used to develop the sub-index IDEC-Alkaline spanned the entire general pollution gradient (Fig. 2). The ordination showed that there were three assemblages from the same site (two “paleo” assemblages and one “modern” assemblage) that were positioned apart from the other assemblages at the bottom right. As a general trend, the “paleo” assemblages were distributed more uniformly along the first axis of the IDEC gradient compared with the “modern” assemblages that were more concentrated in the second half of the pollution gradient. The CA showed that the “paleo” assemblages collected from two species of fish captured at one site were positioned very closely to each other with respect to the first axis, indicating that the IDEC values were similar. The similarity between IDEC values calculated for the nine sites for

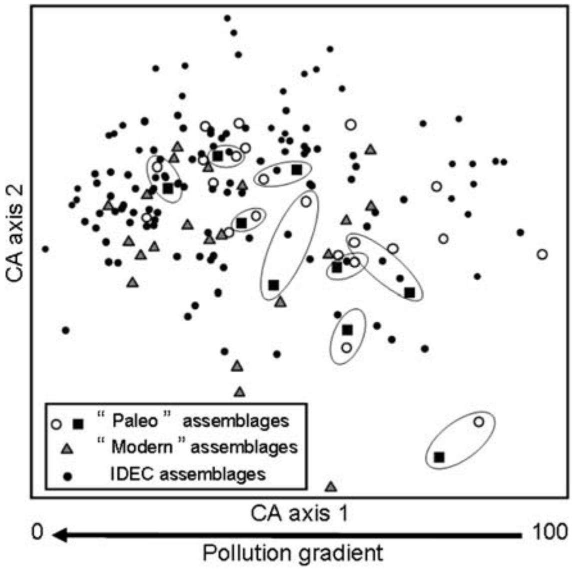

Fig. 2 Correspondence analysis (CA) showing the distribution of the diatom assemblages (filled circles) used to develop the IDEC (sub-index alkaline) (Lavoie et al. 2006). The “paleo” and “modern” assemblages observed in the present study are positioned on the general IDEC pollution gradient (open circles, black squares, and grey triangles) as passive samples. The black squares represent the additional “paleo” diatom assemblages for the sites where two species of fish were available to recover past conditions from gut content analysis. The ellipses join the two “paleo” assemblages (open circles and black squares) recovered from the same site using two species of fish

which two species of fish were available are presented in Fig. 3.

Shannon’s diversity index varied from 1.7 to 3.4 for the “paleo” assemblages, and from 1.9 to 3.6 for the “modern” assemblages. ANOVAs revealed that the Shannon’s diversity index was not influenced by the type of sampling method (fish guts or rock scrapes; $F_{(1,51)} = 0.055$, $P > 0.05$) or by the species of fish gutted ($F_{(3,27)} = 0.81$, $P > 0.05$). Diversity was not correlated with IDEC values ($r = -0.26$, $n = 44$, $P > 0.05$). Changes in IDEC values, therefore, were not attributed to variability in diversity between the sampling methods or the species of fish used.

Discussion

Fish as samplers of diatom assemblages

In this study, past diatom assemblages recovered from the intestines of fish in museum collections were compared with recent diatom assemblages collected on rocks. This study was not designed to collect “modern” assemblages from fish for several reasons: (1) diatom counts from 2003 (rock scrapes) were already available and were used for certain sites to limit traveling, (2) capturing fish to extract diatoms at the sites visited in 2007 was not possible because the equipment and the expertise were not available at the time of sampling, and (3) other studies have shown that diatom assemblages extracted from the guts of the bluntnose minnow and the creek chub are comparable to samples collected from rock scrapes (Rosati et al. 2003).

IDEC values were not influenced by the species of fish gutted, which suggests that northern redbelly dace, which have not been used in previous studies, are also representative samplers of benthic diatoms. There was no significant difference in Shannon’s diversity index values among the assemblages from the different fish species. The diversity was also not influenced by the sampling method, which is contradictory to Sellman et al. (2002) who found that the Shannon diversity was higher in fish gut samples than in the samples collected from rock scapres. In this study, the comparison between the species of fish gutted was conducted on IDEC values rather than directly on diatom assemblages. Therefore, it is possible that structural differences in diatom assemblages were present between the species of fish gutted, but that these differences did not result in IDEC differences. In a biomonitoring perspective, this situation is not problematic because similar biological status may be represented by various diatom assemblages. In addition, the objective of this study was not to compare feeding strategies and habitat preferences between fish species, but to evaluate their potential use to recover past environmental conditions for biomonitoring purposes. Because the fish selected in the present study were not exclusively herbivorous, it is possible that a significant proportion of the diatoms extracted from the fish guts actually originated in invertebrates. Algae are an important source of food to many stream invertebrates (Dudley et al. 1986) that are subsequently consumed by fish. In the context of this study, the origin of the diatom assemblages extracted from fish intestines was not a concern.

The results from the correspondence analysis showed that the “paleo” and “modern” assemblages

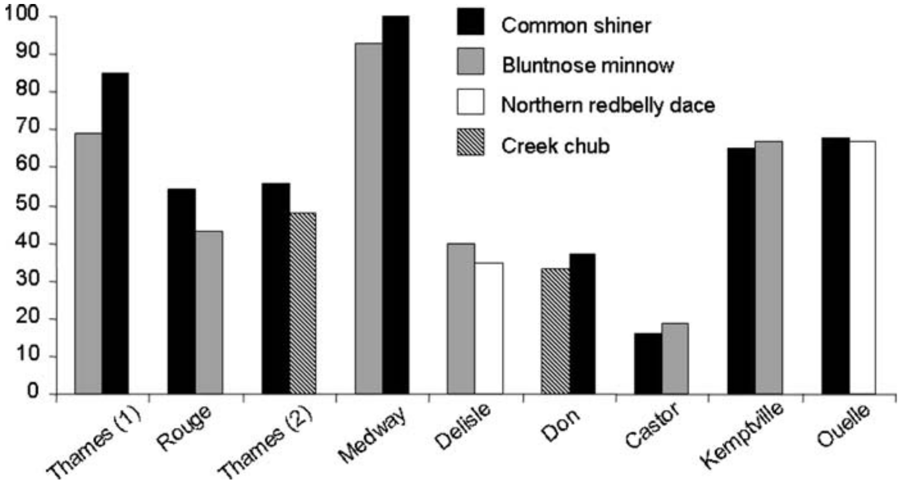

Fig. 3 Histogram showing the IDEC values for the nine sites for which two species of fish were available to recover past diatom assemblages from their gut content

were well distributed along the IDEC pollution gradient and that they were not clustered toward the extremities of the ordination. The fact that the assemblages from this study were widely spread in the IDEC ordination underscores the utility of such an index for the evaluation of past environmental conditions. One exception was noted for the three assemblages from Medway Creek that were located apart from the distribution obtained for the development of the sub-index IDEC-Alkaline. This result suggests that Medway Creek was characterised with diatom assemblages that were different than the assemblages that were observed in the present study or during the development of the IDEC. One potential explanation for this situation is the abundance of the small species *Staurosira construens* Ehrenberg, *S. construens* var. *venter* (Ehrenberg) Hamilton, *Staurosirella pinnata* (Ehrenberg) Williams and Round, and *Pseudostaurosira brevistriata* (Grunow) Williams and Round in the samples from Medway Creek. These species are usually typical of slightly acidic waters and may reflect the effect of locally significant wetlands present in the Medway creek watershed. These species were usually not abundant in the samples used to develop the sub-index IDEC-Alkaline and this may explain their remote position in Fig. 3. For this reason, the three samples from Medway Creek might have been more appropriate in the sub-index IDEC-Neutral that was developed for sites having a naturally more neutral to slightly acidic pH. However, for simplification purposes, the samples from Medway Creek were kept in the sub-index alkaline because the objectives of the study were not affected.

Watershed history

Of primary interest for monitoring agencies is the fact that for the area investigated in this study, diatom assemblages extracted from fish captured in the 1930s were generally not appropriate to recover pristine conditions and reference communities. To pursue reference diatom assemblages representing the level of biological integrity typical of undisturbed conditions, fish captured prior to the early 1900s should be used. The results from this study showed that the biological integrity of certain sites was already significantly disturbed 60–75 years ago, and that this situation has not improved since then. The Don River in Toronto is a good example of a historically impacted site that has continued to decline in quality over time, with an IDEC value of 37 in 1947 dropping to 4 in 2003. By the 1850s, the Don River watershed had become an industrial setting. Numerous industries such as paint factories and paper mills were constructed along the banks of the river, multiple sewage treatment facilities were built, and landfills for garbage and industrial wastes were developed (Howard et al. 1996). The low index value calculated from the “paleo” assemblage at this site is, therefore, not surprising. However, even with the removal of most of these point source effluents, the biological status of the Don River has experienced further decline, likely as a result of non-point sources of pollution in the heavily urbanized area, including polluted stormwater runoff and overflow from sewers.

A significant degradation of water bodies that were relatively pristine 60–75 years ago was also observed in the present study. This situation may be attributed to a considerable increase in human activities in the watershed, such as farm land intensification, urbanisation, and industrialisation. A major drop in IDEC values was particularly evident in Au Sable and Châteauguay Rivers and Etobicoke Creek. The severe drop in IDEC value in the Châteauguay River was probably caused by the intense human activities of the last 60 years. Although settlements already occupied the territory in the 1700s, it was only at the end of the 1700s and the early 1800s that agriculture and agro-forestry destroyed most of the forested area and transformed the landscape in the watershed. In the late 1800s and early 1900s, industries multiplied along the river. An important 60% of the watershed is now occupied by farmland, and 69% of this farmland is characterised by row crops (Simoneau 2007). Certain municipalities in the watershed still dump their effluents directly in the river.

The course of the Au Sable River was significantly altered in the 1800s by dams and the construction of a channel excavated to divert the flow from a sharp 180° turn (Veliz et al. 2006). However, the IDEC value from 1936 indicated an excellent biological integrity of the site, which suggests that the human activities in the late 1800s and early 1900s had no significant impact on the water quality in terms of eutrophication. The severe drop in IDEC value in 2003 may be attributed to intensive farming in the watershed. More than 80% of the Au Sable watershed is now occupied by agricultural activities, where row crops represent the dominant land use (54%; Veliz et al. 2006).

Etobicoke and Mimico Creeks flow in the urbanised area of Toronto and, as a result of years of urbanization, have become among the most highly developed and degraded watersheds in the region. Etobicoke and Mimico Creeks were rated poor for conventional pollutants and heavy metals and organic contaminants in 2006 (TRCA 2002). Only 5.5% natural cover exists in the Etobicoke Creek watershed and 2.4% natural cover in Mimico Creek. It is, therefore, not surprising that the diatom assemblages sampled in 2003 and 2007 reflect a very poor biological status. The index values calculated in the present study, however, showed that Etobicoke Creek had an excellent biological status in 1925, whereas Mimico Creek was already seriously impaired in 1935. These watersheds were transformed into agricultural settlements in the late 1700s, and within 10 years, towns and villages started to multiply. The creeks were treated as open sewers for municipal and industrial effluents, until sewers were installed in the 1960s. Except for the upper reaches of Etobicoke Creek and its tributaries, the watersheds were almost totally urbanised by the twentieth century (TRCA 2002). The fact that Etobicoke Creek was not totally urbanised in the early 1900s might explain the good water quality observed in 1925, compared to Mimico Creek.

This study showed that three sites have increased in biological integrity over the years. The largest recovery was observed in the Moira River, where the IDEC increased from 40 to 64. There is a long history of mining in the Moira River watershed (Deloro Mines, Ontario). The gold mines that had operated since the 1860s closed in the early 1900s, and the site was then used to process silver and cobalt ores. Pesticides were produced from the arsenic by-products of the smelting operations until the late 1950s. By the time all operations were shut down, a wide variety of waste materials had affected the quality of the Moira River. The increase in IDEC value may indicate that the actions taken by the Ontario Ministry of the Environment in 1979 were successful, and that the system has partly recovered from over a century of hazardous materials in the watershed. However, the IDEC value calculated from the sample collected in 2003 indicated that the biological status of the site is “good”, but still close to the “fair” category. Agricultural activities and the presence of small towns and cottages may be hindering the complete recovery of the Moira River.

From point source to diffuse pollution

The IDEC values suggest that several sites showed a poor biological status in the 1930s, when the populations and the farming activities in the watersheds were not as widespread and intensive as they are now. In addition, the water quality of most of the sites in this study has declined since the early 1900s, despite changes in water resource management. This situation may be due to a shift in the type of pollution between the two time periods. Although the great industrial expansion was responsible for point-source pollution with various toxic wastes, water agencies now have to deal increasingly with diffuse pollution sources. Currently, the major causes of water degradation are a steadily increasing urban population, road construction, logging, golf course development, and intense agriculture. Overflows during heavy rains and misconnection in the sewers are commonly seen in numerous watersheds and contribute to nutrient increase in water bodies. Run-off from streets and parking lots adds sediments, hydrocarbons, and metals. Warm waters from hard surface runoff increases water temperature and may constitute an additional stress to native aquatic organisms. Water treatment plants clean out some of the pollutants but leave various chemicals (e.g. drugs, hormones, solvents) to reach aquatic ecosystems. Waters from the 2000s may not be flowing in multiple bright colors due to paint factory wastes as during the past, but the eutrophication problems are far from being resolved, despite the efforts that have been made to preserve water resources.

Conclusion

Fish gut analysis is informative about past environmental conditions in streams, and for relating water quality changes to human activities in watersheds. There has been a decline in water quality over the last century in several streams and rivers of Quebec and Ontario, but many of these water bodies were already showing evidence of negative impacts as early as the 1930's. Environmental reconstruction based on fish captured in the past underscores the value of museum collections for environmental research. Budgetary shortfalls sometimes jeopardize the financial support for curatorial work and storage of such collections, although the collections are essential for a great number of scientific and societal interests. These collections should be adequately supported because they may represent an inestimable source of information for future environmental investigations.

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