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Science-Based Solutions
Solutions fondées sur la science

Development of this series of factsheets was coordinated by the National Guidelines and Standards Office of Environment Canada to consolidate information on the variety of existing approaches to the assessment of sediment quality in Canada and to highlight sediment assessment programs developed by Environment Canada. Additional factsheets will be added to the series as new sediment assessment tools or programs are developed to highlight significant work across the Federal government.

SEDIMENT ASSESSMENT SERIES

Biological Guidelines for the Assessment of Sediment Quality in the Laurentian Great Lakes

Factsheet 3

Program Description

This factsheet describes the development of sediment assessment tools for the near-shore areas of the Great Lakes of North America. Two types of biological sediment assessment tools, developed by the National Water Research Institute and Ontario Region of Environment Canada, are described:

- biological guidelines for the assessment of freshwater sediment based on community-based criteria, or the BEnthic Assessment of SedimenT (BEAST)
- bioassay guidelines based on toxicity scores that compare normal bioassay responses for sediments from reference sites to responses for sediments from sites of concern

These tools are recommended for the assessment of sediment in harbours and embayments for possible remediation, and for assessing sediment removed in navigational or other dredging projects.

Issue Statement

Almost all of the Great Lakes Areas of Concern have documented historic sediment contamination; in fact, chemical concentrations in many of these areas exceed both national and provincial numerical sediment quality guidelines (Painter 1992). However, little is known about the direct impacts of sediment-associated contaminants on biota in specific areas of the Great Lakes.

In order to maintain the biological integrity of these aquatic systems, there is a need for the development and application of

What's Inside

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sediment assessment tools that examine direct biological responses to changes in environmental quality.

Approach Used

The approach for the development of biological sediment guidelines relies on the use of invertebrate community assemblage structure and toxicity testing as appropriate field and laboratory components, respectively. The characteristics of the observed community groups and range of bioassay responses to normal sediment variability form the basis for the community-based and bioassay approaches. The development of these guidelines is presented briefly here; however, more complete descriptions can be found in Reynoldson and Day (1998) and Reynoldson et al. (1995).

The BEAST

The three key elements for the development of the BEAST are: developing the model, applying the model and interpreting the results.

Developing the Model

Fundamental to the development of the BEAST is the reference condition approach. The reference condition is defined as a description of the best available condition of sediment quality in the Great Lakes. A series of selection criteria (see box below) were established for the 252 reference sites chosen to develop the reference condition for the Great Lakes.

Reference Site Data

- **Benthic Community Structure:** abundance, richness
- **Ten acute and chronic bioassay endpoints sampled over three years** (candidate reference sites were excluded from the analysis if less than 50% of any one test species survived at a particular site in any given year): survival and growth of *Chironomus riparius*, *Hyalella azteca* and *Hexagenia* spp.; survival and reproduction (percent hatch, number of cocoons per adult; number of young per adult) of *Tubifex tubifex*
- **Environmental variables:** geographic location, sediment attributes, physicochemical parameters

Reference sites were then statistically grouped, using cluster analysis based on benthic community structure attributes. Groups were identified that describe specific benthic community assemblages and represent the "reference condition" for the Great Lakes.

Based on these groups and a set of predictor variables, predictive models were developed using stepwise discriminant function analysis and principal axis correlation. The purpose of the models was to predict the type of benthic assemblage that would be expected to occur at non-impacted Great Lake sites, based on the pre-established predictor variables.

Predictor variables that are not expected to be influenced by human activity were statistically determined based on their ability to best describe the benthic habitat of the community assemblage, and that reflected the biological structure of the reference condition groups (see box below). Based on these variables, the models are able to predict up to 88% of the reference sites to the correct reference condition group (Reynoldson and Day 1998).

Applying the Model

In order to assess sediment quality at a site using this method, the following steps are required:

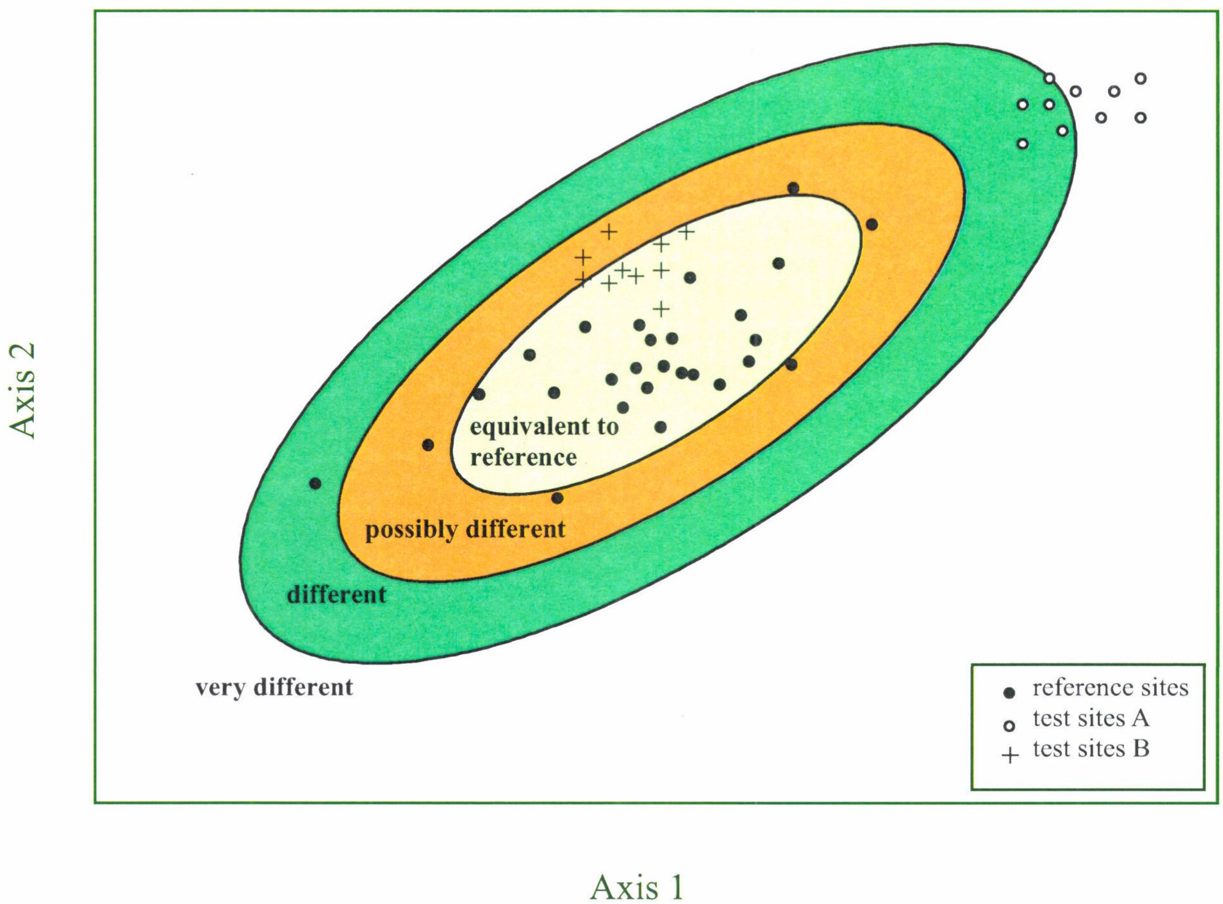
> **Predictor Variables**
>
> - **Geographic location:** latitude, longitude
> - **Sediment attributes:** TOC, TN, K, Ca, Mg, Mn, Si
> - **Physical/chemical parameters:** water depth, alkalinity, pH

1. Collect data on the benthic community structure (abundance and richness) and 12 predictor variables.
2. Generate the expected community assemblages for the site, based on the predictive model and the 12 variables (see box).
3. Compare the predicted and measured benthic community structures.

Software designed exclusively for the BEAST automates the calculation (Reynoldson and Day 1998).

Interpreting the Results

Figure 1: Example of Probability Ellipses Derived for Reference Sites*

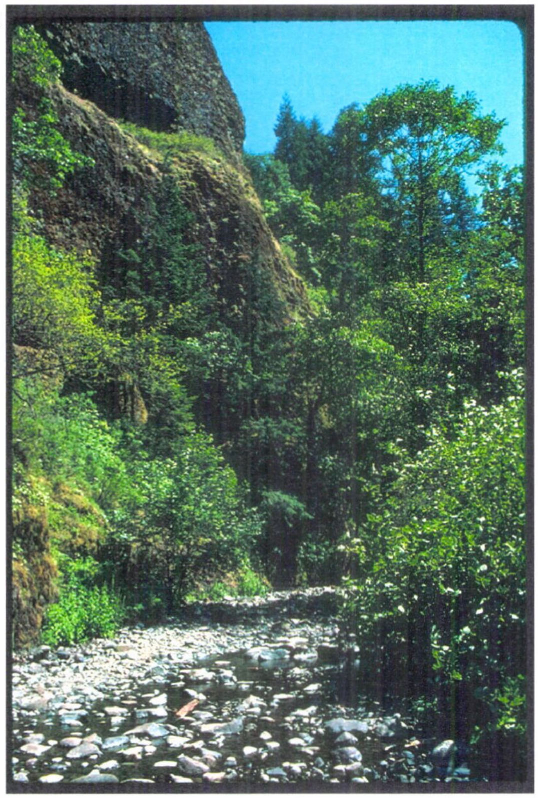


*Invertebrate communities at test sites that fall within the 90% probability ellipse are considered equivalent to reference sites; within the 99% probability ellipse are possibly different; within the 99.9% probability ellipse are different; and outside the 99.9% probability ellipse are very different (modified from Reynoldson and Day 1998). Invertebrate assemblages in test sites A would be considered different to very different from reference sites and would require management action, while those from test sites B might not, as they are mainly equivalent to the reference sites.

The assemblage of invertebrates from reference sites is described by its distribution in ordination space, and the assemblage at any given site is characterized by its position in the XY space (see Figure 1) (Reynoldson and Day 1998). The greater the similarity between the reference sites and the test sites, the closer together they are in XY space. Test sites located within the smallest ellipse (90% probability) are considered equivalent to the reference sites and therefore unstressed. Test sites located between the smallest (90%) and the largest probability ellipse (99.9%) are different from the reference sites. Test sites located outside the 99.9% probability ellipse are considered very different from the reference sites. Observed differences may represent a response to either anthropogenic or natural stressors (Reynoldson and Day 1998).

Bioassay Guidelines

Another type of biological assessment tool is the comparison of the normal bioassay responses to sediments from reference sites to the responses to sediments from sites of concern. The acute and chronic toxicity responses of four benthic invertebrate species (*Chironomus riparius*, *Hyalella azteca*, *Tubifex tubifex*, and *Hexagenia* spp.; see box "Reference Site Data") to sediments collected from the previously mentioned reference sites in the Great Lakes were used to establish ranges in bioassay responses to normal sediment variability.



Three categories of sediments have been defined based on the range of biological responses to the test endpoints: non-toxic, potentially toxic and toxic. The *non-toxic* category of sediments was established at two standard deviations (SD) below the mean response (survival, growth or reproduction) for the reference database; this represents the 95% confidence limit for the response. The *toxic* category of sediments was set at three times the SD below the mean response for an endpoint; this represents the 99.7% confidence limit. The range of responses between two and three times the SD represents the *potentially toxic* category and may indicate sediments that have low or moderate toxicity and, therefore, some detrimental effects (Reynoldson and Day 1998).

These categories form the basis for the development of biological tools based on toxicity scores, which compare bioassay responses to sediments from sites of concern with mean bioassay responses to reference site sediments (Reynoldson and Day 1998). In practice, the acute and chronic responses of the four test species (*Chironomus riparius*, *Hyalella azteca*, *Tubifex tubifex*, and *Hexagenia* spp.) to sediment collected from a site of concern can be compared individually to toxicity response categories (see Table 1), but integration of the results from the 10 test endpoints is done using a multivariate approach.

This approach uses ordination to capture the variation within the toxicity endpoints. Ordination is a powerful multivariate method specifically designed to identify and map (usually in two or three dimensions) the similarity between objects. The toxicological data are range standardized, as the variables are measured on different scales and in different units. Euclidean distance, a similarity measure, was selected as the distance coefficient. To determine variability in the toxicity endpoints among reference sites, sites are plotted in ordination space (usually in three dimensions) and probability ellipses are constructed around the reference sites. Other non-reference or exposed sites can then be compared to these probability ellipses within this same ordination space (Reynoldson et al. 2000), usually 90%, 99% and 99.9% probability ellipses, as for community data (Reynoldson et al. 2002).

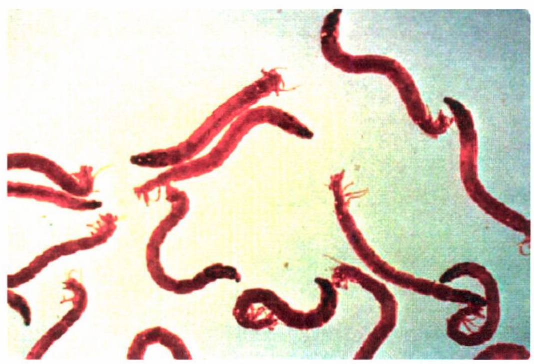
Table 1: Criteria for Determination of Three Categories of Toxicity for Near-Shore Sediments of the Great Lakes.

Test species	Category 1 Non-toxic	Category 2 Warning of Potential Toxicity	Category 3 Toxic
Chironomus riparius			
% Survival	≥ 67.7	58.8 - 67.7	< 58.8
Growth	0.21 - 0.49	0.14 - 0.20	< 0.14
Hyalella azteca			
% Survival	≥ 67.0	57.1 - 66.9	< 57.1
Growth	0.23 - 0.75	0.10 -0.22	<0.10
Hexagenia spp.			
% Survival	≥ 85.5	80.3 - 85.5	< 80.3
Growth	0.9 - 5.0	0.0 - 0.8	---
Tubifex tubifex			
% Survival	≥ 88.9	84.2 - 88.9	< 84.2
% Hatch	38.1 - 78.1	28.1 -38.0	<28.1
No. Cocoons/Worm	7.2 - 12.4	5.9 - 7.1	< 5.9
No. Young/Worm	9.9 - 46.3	0.8 -9.8	< 0.8

Limits given for Category 1 (non-toxic) are 2xSD above and below the means (the upper limits indicate exceptionally high growth or reproduction). Limits given for Category 3 (toxic) are 3xSD above and below the means. Limits for Category 2 (warning of potential toxicity) are interposed between those of the non-toxic and toxic categories (2xSD).

Strengths and Limitations

These approaches describe methods for developing site-specific freshwater sediment biological guidelines tailored to a specific geographic region — the Laurentian Great Lakes. The numeric values are statistically based and natural variability is integrated into the sediment assessment and decision-making process. The community-based approach uses predictive models to relate species to their environment, thus linking habitat to community structure. The guideline values are based on the normal response of the bioassay endpoints (survival, growth and reproduction) to normal sediment variability (Reynoldson and Day 1998).



The application of multivariate methods requires some degree of specialization in their development and interpretation, and the results may be perceived as difficult to communicate to managers and the public (Gerritsen 1995). However, the development of the BEAST software tool automates the methodology summarized here, greatly simplifying the data manipulation and interpretation steps of the method (Reynoldson and Day 1998).

Outcome

These guidelines can be used to assess the effects of sediment quality on biological processes. They can also assist in the identification and management of contaminated sediment, and aid in the decision-making process regarding sediment disposal and remediation. This approach has been developed for the Laurentian Great Lakes; however, the ecological principles which form the basis of this approach are relevant to other situations where sediment quality is of concern.

WANT MORE INFORMATION?

Website: www.nwri.ca/issues/cabin/beast.html

National Water Research Institute
Website: www.nwri.ca

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