Biomonitoring with the Reference Condition Approach for the Detection of Aquatic Ecosystems at Risk

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ABSTRACT

One of the most effective techniques for biomonitoring and detecting habitats at risk in aquatic ecosystems is the reference condition approach (RCA). The RCA uses benthic community structure as a measure of a system's condition. With the RCA, the benthic community of a potentially stressed ecosystem is compared with that of unstressed reference sites that have similar environmental conditions. Benthos have several advantages over other indicators: there are many species; they are relatively sedentary; and they represent a diverse range of trophic positions and tolerance to disturbance. The RCA will soon be used for monitoring in the Fraser River basin (FRB) based on data from 219 reference sites in the FRB. The reference collections were made in early autumn and 1 question is the extent to which predictions of expected communities at test sites are dependent on the season when samples are collected. Results showed that the RCA was reasonably robust, but changes to the benthic community between seasons were large enough for us to recommend collecting test samples in the autumn.

Key words: aquatic, benthic, biomonitoring, Fraser River, invertebrate, reference condition approach, seasonal variation, streams.

Anthropogenic impacts that can stress aquatic ecosystems and place them at risk come from a multitude of point and non-point sources. Because of the multitude of possible impacts and response levels, there is a need for effective monitoring techniques and remediation. Biomonitoring uses biological responses to identify and monitor changes in the environment. In aquatic ecosystems, biomonitoring can be used to monitor changes in water quality, changes in the stream habitat, or even changes to surrounding watersheds. Use of biological responses to identify changes in an environment gives biological relevance to those changes.

This paper provides an introduction to what biomonitoring is and why benthic invertebrates are favoured organisms for biomonitoring, and a brief overview of some biomonitoring techniques. The reference condition approach (RCA) as a biomonitoring technique is discussed, including how the predictive model is built, the way the reference condition approach is applied in the Fraser River basin (FRB), and limitations due to seasonal variation of benthic invertebrate communities.

BIOMONITORING

Invertebrates as Indicators

Biomonitoring requires the selection of 1 organism or a suite of organisms whose response to changes in the environment will be monitored. Although plankton, fish, and invertebrates can all be used for biomonitoring in aquatic ecosystems, benthic invertebrates are the most frequently used. There are several reasons for this bias. First, they tend to move very little and are therefore representative of the area in which they are collected. Second, invertebrate life cycles are relatively short compared to fish and will therefore more quickly reflect changes in the environment through changes to population and community structure. Third, invertebrates live and feed in, on, and around sediments where toxins tend to accumulate. Because of this, the benthos themselves accumulate toxins and pass them up the food chain (Reynoldson 1987, Reice and Wohlenberg 1993). Fourth, benthic organisms vary in sensitivity to stressors and may respond to pollutants in the water column as well as those in the sediments (Schindler 1987). Finally, invertebrates are important components of the ecosystem. They are the primary food source of many fish, and play a critical role in the breaking down of organic matter and nutrient cycling.

Biomonitoring Techniques

There are several different biomonitoring techniques employed in aquatic ecosystems. The selection of an appropriate technique depends on the issues being addressed and available resources. Potential biomonitoring techniques include use of indicator species, biotic indices, rapid bioassessment, and predictive models. Use of indicator species for biomonitoring involves monitoring of invertebrate abundance, life cycles, reproductive success, and/or morphological deformities. Biotic indices use presence/absence and abundance of taxa with different levels of stress tolerance to monitor changes in the environment. Biomonitoring using rapid bioassessment techniques can include measures of richness, enumeration, community diversity measures, biotic indices, or combinations of these measures. When biotic indices are used in rapid bioassessment, only a few habitats may be sampled, few samples are collected, the samples may be small, and the invertebrates are identified to higher taxonomic levels. Predictive models for biomonitoring use multivariate techniques, and information on benthic macroinvertebrate communities and associated environmental variables from a large number of reference sites to make predictions as to the expected benthic community at test sites. Predictive models are proving to be effective for biomonitoring. The reference condition approach is an example of a predictive model.

THE REFERENCE CONDITION APPROACH

One of the most effective techniques for biomonitoring and detecting habitats at risk in aquatic ecosystems (or their watersheds) is the reference condition approach. The RCA involves creating a predictive model from benthic invertebrate and associated environmental data collected from a large number of reference sites. Reference samples from a large number of habitats allows a wide variety of habitats and invertebrate communities to be included in the model. The model can then be used to predict the expected benthic community at a test site. If the test-site community differs from the one predicted, the conclusion can be drawn that the site is impacted.

The reference condition approach is being used for biomonitoring and detecting habitats at risk in the Fraser River basin. The Fraser River basin predictive model was created using benthic invertebrate data and associated environmental conditions collected from 219 reference sites from throughout the FRB (Reynoldson et al. in prog.). Sites were selected as reference sites if they had no or minimal impacts (Rosenberg et al. in prog.)

In general, creation of the predictive model involves identifying reference groups with similar species composition, identifying which environmental variables can best discriminate between the reference groups, and then using the environmental variables to predict a test site to a reference group. Cluster analysis of the reference-site invertebrate data is used to form reference groups (Fig. 1). As a result, each reference group contains sites with similar species composition, and sites are allocated to reference groups objectively. Based on the reference groups, discriminant function analysis (DFA) can then be used to identify environmental variables that best discriminate between the reference groups, and can therefore be used as predictor variables (Fig. 1).

Once the environmental predictor variables are selected, DFA can then be used to predict a test site to a reference group. A test site is defined as a site which is meant for comparison with the reference condition. DFA uses the environmental conditions from the test site, to predict the site to a reference group with similar environmental conditions. The test site is then expected to have a benthic invertebrate community composition similar to the reference sites included in the reference group. If the actual test-site community differs from the one predicted, then the conclusion can be drawn that the system is stressed or impacted.

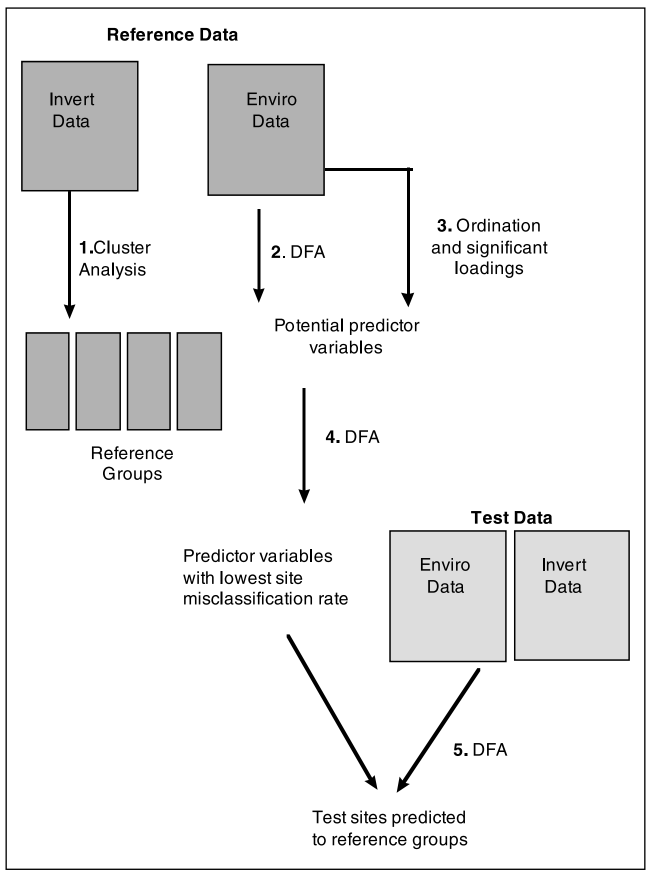

Figure 1. An overview of the steps required to make a predictive model and to predict test sites to reference groups. (DFA = discriminant function analysis.)

Similarity of a test-site invertebrate community to the reference condition is determined using probability ellipses. Invertebrate data for each reference group are ordinated. Probability ellipses of 90, 99, and 99.9% are then calculated based on ordination scores of the reference sites included in a reference group. Use of probability ellipses allows invertebrate community responses to be viewed along a gradient of response levels—from reference to potential impact-response levels. After the probability ellipses are calculated, the ordination score of the test site is plotted in the reference group ordination space. If the test site falls within the 90% ellipse, the site is considered equivalent to reference. If the test site falls between the 90 and 99% ellipses the site is considered to be potentially different from the reference condition. A test site outside of the 99% ellipse is different from the reference condition, and one outside of the 99.9% ellipse is very different from the reference condition.

Limitations of the RCA Due to Seasonal Change of Invertebrate Communities

Accurate predictions as to the expected benthic community are limited to the range of environmental conditions and benthic data included in the reference database. The predictive model constructed for the FRB contains a large amount of spatial variation, but at this point in time it does not contain seasonal variation. The reference samples were collected only once a year—in the autumn—but over 3 years (1994, 1995, and 1996). There was the potential that sampling only once in a year may not provide enough information to accurately apply the model to test samples collected at other times of the year. This is because the benthic community may change seasonally as invertebrates move though their life cycles.

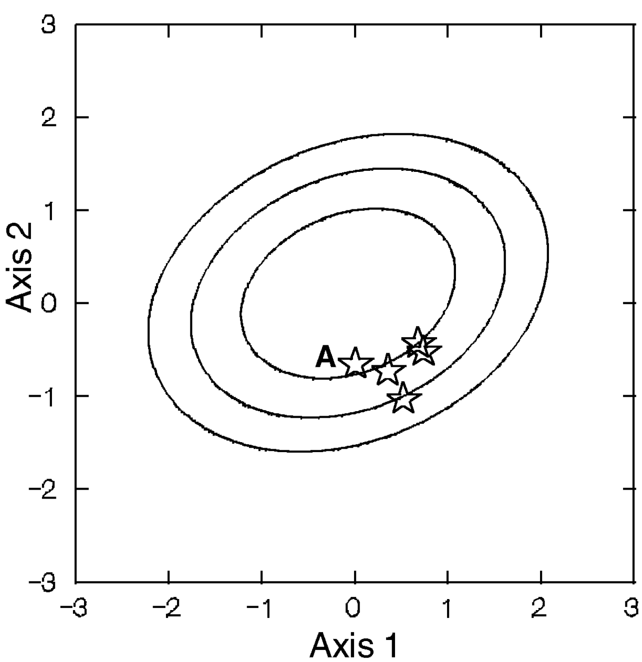

Figure 2. Location of Spring Creek seasonal samples in the ordination space of the reference group into which the site was classified based on the autumn (A) sampling. The invertebrates were identified to the genus level. The 90, 99, and 99.9% probability ellipses are based on the ordination scores of the reference data.

We looked at what implications seasonal variation in the benthic community had on using the RCA in the FRB by collecting seasonal samples from 6 reference sites. The samples were collected over a period of 1 year: in the spring, summer, autumn, and winter, and then a second spring. The seasonal invertebrate data for each site were ordinated and the points plotted in the respective reference group ordination spaces. Figure 2 illustrates the results for Spring Creek, and Table 1 summarizes the results for all 6 sites, (invertebrates were identified to the lowest possible taxonomic level; Reece et al. in prog.).

Our study and others have shown that stream benthic invertebrate community composition changes seasonally (Hynes 1970, Furse et al 1984). Seasonal changes of the invertebrate communities were enough to place some of the sampling dates outside of the reference ellipses. The magnitude and direction of the seasonal change in ordination space was not consistent between sites or seasons and creates uncertainty. The uncertainty comes from the inability to separate typical seasonal changes from changes caused by stress on the system. Thus seasonal changes of the invertebrate community affect how the Fraser River predictive model should be used.

When using the Fraser River predictive model, test samples should be collected in the same season as when the reference samples were collected (autumn). This should prevent misclassification of the state of a test site simply due to seasonal variation. In future, reference samples could be collected over multiple seasons and added to the reference database. This would allow seasonal variation to be incorporated into the model.

CONCLUSIONS

In conclusion, use of biomonitoring for the measurement of changes to an ecosystem gives biological relevance to those changes. In aquatic ecosystems, invertebrates have been the most commonly used organisms for biomonitoring and there are several good reasons for this preference. Once an initial reference database is established, the reference condition approach is a quick and accurate technique for detecting changes in benthic invertebrate communities. In the Fraser River basin, test samples should be collected in the autumn—when reference samples were collected. This will

Table 1. Summary of the reference groups into which the seasonal test sites were classified based on the autumn sampling, and where the seasons fall in the ordination space. Invertebrates were identified to the genus level.

Study site	Season	Reference group	Location[a]
Glimpse	spring '95	5	>99.9
	summer	5	>99.9
	autumn	5	in
	winter	5	>90
	spring '96	5	>90
Beak	spring '95	5	in
	summer	5	in
	autumn	5	in
	spring '96	5	in
Spring	spring '95	6	>90
	summer	6	>90
	autumn	6	in
	winter	6	>99
	spring '96	6	>90
Mayfly	spring '95	2	in
	summer	2	>90
	autumn	2	>90
	winter	2	>90
	spring '96	2	>90
North Alouette	spring '95	2	>90
	summer	2	in
	autumn	2	in
	winter	2	in
	spring '96	2	in
Thompson	spring '95	2	>99
	summer	2	>90
	autumn	2	>90
	winter	2	in
	spring '96	2	>99

[a] in = within the 90% probability ellipse; >90 = between the 90 and 99% ellipses; >99 = between the 99 and 99.9% ellipses; >99.9 = outside the 99.9% ellipse.

minimize misclassification of test sites until seasonal reference site data can be added to the reference database.

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