HANDBOOK 2
WATER POLLUTION

Monitoring
of
Sediment
and
Riverbed invertebrate fauna

NREB
Natural Resources
and Environment
Board

DANCED
Danish Co-operation
for Environment and
Development
Handbook 2
Water Pollution

Monitoring of Sediment
and Riverbed Invertebrate Fauna

1st Edition (1st Print)
October 2001
100 copies
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Printed by UM Colour Printing Company
Report No. SUD-02-48
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FOREWORD

In June 1999, the State Government of Sarawak, in collaboration with the Danish Co-operation on Environment and Development (DANCED), initiated the Sustainable Urban Development Project in Sarawak (SUD) to implement an Environmental Management System (EMS) for the city of Kuching.

As part of the system the concentrations of selected pollutants in riverbed sediments and impacts of pollution on riverbed invertebrate fauna, have been selected as indicators for river quality.

This handbook describes the strategy for monitoring of sediment pollution and impacts on riverbed invertebrate fauna in rivers and tributaries, which are running through the city of Kuching. Specific procedures for sampling and laboratory analysis are described as well. The methods described in the handbook are applicable for lower reaches of rivers. For upper reaches of rivers other methods must be used especially regarding riverbed invertebrates.

This is the second book of the series, which deals with standard methods and procedures for specific measurements pertaining to river and waste pollution in Kuching, Sarawak.

I would like to take this opportunity to record our gratitude to DANCED for its support. In addition, I would like to record our appreciation to many individuals from various Federal and State Government departments, who provided valuable support and co-operation in this matter.

"TOWARDS TOTAL ENVIRONMENTAL QUALITY MANAGEMENT"

CHONG TED TSIUNG
Acting Controller of Environmental Quality/Project Director
Natural Resources & Environment Board/Sustainable Urban Development Project SARAWAK
1. Background and monitoring strategy

1.1 Sediment

Pollutants are accumulating in the bottom sediments of a river.

Measurements of pollutants on sediment samples often provide a more stable, integrated picture of the degree of river pollution than measurements on surface water samples.

Concentrations of pollutants in surface water fluctuate significantly due to fluctuations in discharge, rainfall and tide.

Dissolved trace elements such as heavy metals, hydrocarbons, PAH and pesticides are generally encountered in very low levels in surface water and analytical detection limits are sometimes higher than actual levels. The reason for the low levels in even very polluted areas is that most trace elements are readily adsorbed onto particulate matter, which is subject to sedimentation.

The generally low levels of dissolved trace elements in surface water also make it very difficult to measure concentrations correctly, as there is a high risk of contamination of the sample during sampling, pre-treatment and storage. Therefore, there is a considerable risk that any observed increase in concentration between two sampling rounds may be due to a slight contamination of the sample and not a real increase.

Reliable monitoring results for heavy metals, total hydrocarbons, PAH and pesticides can therefore, only be obtained by measuring concentrations in sediment samples.
1.2 Invertebrate fauna

Riverbed invertebrate fauna comprise a wide variety of species such as insect larvae, oligochate worms, mussels, snails and crustaceans living in burrows of the sediment or on the sediment surface. This fauna is well suited for monitoring of impacts of pollution in rivers. Different species have preferred habitats defined by physical, chemical and biological factors and the sensitivity to pollution varies greatly between species. Variation of environmental factors and pollution can lead to stress on individuals and possibly reduction in the total numbers of species or organisms that are present. In extreme situations of environmental change, perhaps due to contamination, certain species will disappear completely from the area concerned, either as a result of death or due to migration. Benthic species are especially suited as monitoring organisms due to the fact that most are stationary or only migrates very little. Therefore, the composition of benthos on a site reflects the sum of effects which environmental factors have had on each individual during a longer period (Figure 1).

Two main approaches of using benthos as monitoring organisms have been used internationally:

- Methods based on “indicator” organisms; and
- Methods based on community structure.

An indicator organism is a species selected for its sensitivity or tolerance to various kinds of pollution or effects of pollution e.g. metal pollution or oxygen depletion. The application of indicator organisms implies a thorough knowledge on the ecology and tolerance of different species or group of species, which presently is not available for river ecosystems in Sarawak. Study of invertebrate fauna, habitat preferences and tolerance is a task, which will take several years and require considerable manpower. Therefore, application of methods based on indicator species is not feasible in
the short-term perspective. In addition, the species generally used as indicators are often sensitive species of caddisflies, mayflies and stoneflies, which are only found in upper reaches of rivers with clear, fast flowing water and with stones on the riverbed. These groups of invertebrates are generally not encountered in turbid, slow flowing lower reaches of rivers with more silty sediments, like the stretch of Sg. Sarawak, which is passing through the city of Kuching.

**Figure. 1. Environmental parameters, which may affect the composition of riverbed invertebrate fauna on a site**

Methods based on community structure (i.e. number of individuals of different species on a site) do not require specific knowledge on sensitivity and habitat requirements for different species, especially when the monitoring programme is designed so that the sampling sites are located along gradients of pollution.

The best monitoring results are obtained when:
• The sampling sites are located along a suspected gradient of pollution; and

• Simultaneous measures of benthic fauna composition and concentration of pollutants on each sampling site are available.

This strategy may enable us to assess whether a certain level of pollution actually affects the fauna. If only chemical analyses are made, it will not reveal whether the concentration levels of pollutants or the combination of pollutants present actually have any ecological effects in the river. Conversely, if only biological parameters are measured it may be difficult to interpret the results in terms of which factors are causing an observed variation in the composition of fauna (i.e. whether the variation is in fact caused by pollution or by other environmental factors).

The monitoring of riverbed invertebrates for the EMS for Kuching is based on the latter approach i.e. simultaneous monitoring of invertebrate community structure (fauna composition) and concentrations of pollutants in sediments on the same sites along a suspected gradient of pollution.

2 Procedures Sediment

2.1 Sampling

The sediment samples are collected using a Van Veen grab sampler (Fig.2).

One sample of the sediment surface must be collected at each station. The upper 0-2 cm of the sediment is collected from the sampler, which can be opened from the topside (Fig 2). The sediment is collected using a spoon.

The sample is divided into three:
• One for analysis of organic pollutants which is stored in aluminium trays;

• One for analysis of heavy metals which is stored in plastic bottles or plastic bags; and

• One for analysis of grain size distribution.

The samples are kept cool and frozen as soon as possible after sampling. In the laboratory, the samples are stored in a freezer until analysis.

Figure 2. Sediment sampling using a Van Veen grab

Before the samples are divided and stored, the sediments are at first characterised in terms of

1) Sediment type;
2) Colour of sediment; and
3) Smell.

Re 1) Sediment type

The sediments are characterised visually with respect to the following categories:

- Mud
- Muddy sand
- Sandy mud
- Sand
- Gravel
- Rock
- Other

Re 2) Colour of sediment

The colour of the sediment may give an indication of the Redox State of the sediment (i.e. the oxygen condition). The sediment is described using the following characteristics:

- Black surface (indicating that the entire sediment surface is reduced);
- Black spots on surface (indicating that there are reduced spots on the surface);
- Occurrence of a white layer covering a black surface (indicating the presence of sulphur bacteria, which may occur following oxygen depletion); and
- Surface not black (indicating that the surface layer is oxidised).

Re 3) Smell of sediment

The sediments are characterised in terms of smell using the following categories:

- No smell
- Smell of H$_2$S
- Smell of petroleum hydrocarbons
- Other

2.2 Laboratory analysis

The sediment samples shall generally be analysed for: sediment parameters, nutrients, heavy metals, hydrocarbons, pesticides, cyanide and phenols.

The specific recommended parameters are shown in Table 1. Other parameters may be included depending on conditions. The methods of analysis indicated in the table must be applied.

Results must be reported on a dry weight basis (in order to be able to compare with sediment quality guidelines, which are expressed in dry weight (cf. Table 2 below).

Table 1. Parameters for which the collected samples are analysed. The methods of analyses for each parameter are indicated

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Method of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment parameters</td>
<td></td>
</tr>
<tr>
<td>Grain size distribution</td>
<td>Method BS 1377 (sieving/hydrometer analysis)</td>
</tr>
<tr>
<td>Loss on ignition *</td>
<td>Furnace combustion at 550°C</td>
</tr>
<tr>
<td>Nutrients</td>
<td></td>
</tr>
<tr>
<td>Ammonium (NH$_4$-N)</td>
<td></td>
</tr>
<tr>
<td>Nitrate (NO$_3$-N)</td>
<td>Aqueous extraction followed by cadmium reduction/C: limetric APHA 4500 NO$_3$E</td>
</tr>
<tr>
<td>Total Nitrogen (Tot-N)</td>
<td>Kjeldahl Method/Titrimetric (RRIM**)</td>
</tr>
<tr>
<td>Total Phosphorous (Tot-P)</td>
<td>RRIM** Ammonia Molybdate/Vanadate Method</td>
</tr>
<tr>
<td>Heavy metals</td>
<td></td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>EPA 245.5/APHA 3111B Cold Vapor AAS.</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>ASTM D3974-8 (Extraction) APHA 3114 B &amp; C (Hydride AAS).</td>
</tr>
</tbody>
</table>

(Continued overleaf)
<table>
<thead>
<tr>
<th>Method of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead (Pb)</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
</tr>
<tr>
<td>Copper (Cu)</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
</tr>
<tr>
<td>Polyaromatic hydrocarbons (PAH)</td>
</tr>
<tr>
<td>Total petroleum hydrocarbons (TPH)</td>
</tr>
<tr>
<td>Aldrin</td>
</tr>
<tr>
<td>Dieldrin</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
</tr>
<tr>
<td>DDT</td>
</tr>
<tr>
<td>Heptachlor, Heptachlor Epoxide</td>
</tr>
<tr>
<td>Lindane</td>
</tr>
<tr>
<td>Methoxychlor</td>
</tr>
<tr>
<td>Methamidaphos</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
</tr>
<tr>
<td>Malathion</td>
</tr>
<tr>
<td>Dimethoate</td>
</tr>
<tr>
<td>Cyanide (CN)</td>
</tr>
<tr>
<td>Phenols</td>
</tr>
</tbody>
</table>

*Loss on ignition is a measure of the organic content of the sediment;**

**Rubber research Institute of Malaysia**
2.3 Reporting

The reporting of sediment results must include a comparison of the data with sediment quality criteria in order to assess the potential for adverse biological effects due to heavy metals, hydrocarbons and pesticides in the sediment.

There are currently no sediment quality criteria developed for Malaysia. In recent years, however, a considerable international effort has been made to develop quality criteria for sediments, which relates sediment chemistry data to the potential for adverse biological effects, the most recent and relevant being Canadian Sediment Quality Standards published in 1999 (Ref. 2).

Based on a considerable number of field and laboratory studies on the correlation between concentration and toxicity, a threshold effect level (TEL) and a probable effect level (PEL) was established for a wide number of pollutants in sediments.

These standards will be applied in the EMS, when assessing the monitoring results from sediments. Table 2 presents the TEL and PEL for relevant pollutants in the EMS.

The two guideline values delineate three concentration ranges for a particular chemical:

- Sediment chemical concentrations below the TEL are not expected to be associated with any adverse biological effects;

- Concentrations equal to and above TEL, but below the PEL represent a possible-effects range within which effects may occasionally be observed;

- Concentrations equivalent to and above the PEL value are expected to be frequently associated with adverse biological effects.
The use of these two values is a practical means of characterising sites as being of minimal, potential, or significant toxicological concern.

Accuracy of predictions of toxicity based on the developed sediment quality guidelines has been tested (refs. 4 and 5). The toxicity of a sample was predicted from the concentrations of contaminants. Performing biological toxicity tests on the same sample tested the prediction.

Based on these analyses of predictive ability, it appears that the guideline values provide reasonably accurate estimates of chemical concentrations that are either non-toxic or toxic in laboratory bio-assays. When not exceeded, the TEL was highly predictive of non-toxicity and when exceeded, the PEL was also reasonably predictive of toxicity in the tests.

However, for samples with intermediate chemical concentrations (between TEL and PEL), the sediment quality criteria should be applied with care.
Table 2. Threshold effect levels (TEL) and Probable effect levels (PEL) for various pollutants (from Ref. 2)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Unit</th>
<th>TEL</th>
<th>PEL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heavy metals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>mg/kg dry weight</td>
<td>0.17</td>
<td>0.49</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>mg/kg dry weight</td>
<td>35.0</td>
<td>91.3</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>mg/kg dry weight</td>
<td>5.9</td>
<td>17.0</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>mg/kg dry weight</td>
<td>123.0</td>
<td>315.0</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>mg/kg dry weight</td>
<td>0.6</td>
<td>3.5</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>mg/kg dry weight</td>
<td>37.3</td>
<td>90.0</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>mg/kg dry weight</td>
<td>35.7</td>
<td>197.0</td>
</tr>
<tr>
<td><strong>Polyaromatic hydrocarbons (PAH)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acenaphthene</td>
<td>μg/kg dry weight</td>
<td>6.71</td>
<td>88.9</td>
</tr>
<tr>
<td>Acenaphthylene</td>
<td>μg/kg dry weight</td>
<td>5.87</td>
<td>128.0</td>
</tr>
<tr>
<td>Anthracene</td>
<td>μg/kg dry weight</td>
<td>46.9</td>
<td>245.0</td>
</tr>
<tr>
<td>Benz(a)anthracene</td>
<td>μg/kg dry weight</td>
<td>31.7</td>
<td>385.0</td>
</tr>
<tr>
<td>Benzo(a)pyrene</td>
<td>μg/kg dry weight</td>
<td>31.9</td>
<td>782.0</td>
</tr>
<tr>
<td>Chrysene</td>
<td>μg/kg dry weight</td>
<td>57.1</td>
<td>862.0</td>
</tr>
<tr>
<td>Di-benz(a,h)anthracene</td>
<td>μg/kg dry weight</td>
<td>6.22</td>
<td>135.0</td>
</tr>
<tr>
<td>Fluoranthene</td>
<td>μg/kg dry weight</td>
<td>111.0</td>
<td>2355.0</td>
</tr>
<tr>
<td>Fluorene</td>
<td>μg/kg dry weight</td>
<td>21.2</td>
<td>144.0</td>
</tr>
<tr>
<td>2-Methylnaphthalene</td>
<td>μg/kg dry weight</td>
<td>20.2</td>
<td>201.0</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>μg/kg dry weight</td>
<td>34.6</td>
<td>391.0</td>
</tr>
<tr>
<td>Phenanthrene</td>
<td>μg/kg dry weight</td>
<td>41.9</td>
<td>515.0</td>
</tr>
<tr>
<td>Pyrene</td>
<td>μg/kg dry weight</td>
<td>53.0</td>
<td>875.0</td>
</tr>
<tr>
<td><strong>Pesticides</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dieldrin</td>
<td>μg/kg dry weight</td>
<td>2.85</td>
<td>6.67</td>
</tr>
<tr>
<td>Chlordane</td>
<td>μg/kg dry weight</td>
<td>4.50</td>
<td>8.87</td>
</tr>
<tr>
<td>DDT</td>
<td>μg/kg dry weight</td>
<td>1.19</td>
<td>4.77</td>
</tr>
<tr>
<td>Heptachlor epoxide</td>
<td>μg/kg dry weight</td>
<td>0.60</td>
<td>2.74</td>
</tr>
<tr>
<td>Lindane</td>
<td>μg/kg dry weight</td>
<td>0.94</td>
<td>1.38</td>
</tr>
</tbody>
</table>
3 Procedures invertebrate fauna

3.3 Sampling

Sampling sites

Riverbed invertebrate fauna is collected at the same sites and at the same time as the sediment samples for chemical analysis.

Sampling methods

Quantitative grab samples of invertebrate fauna is collected by the use of an Ekman Grab with a sampling area of 225 cm$^2$ (Fig. 3).

Immediately after sampling, all the collected sediment is carefully washed through a series of sieves of varying mesh sizes viz. 5 mm, 3 mm and 1 mm.

All invertebrates are handpicked from each of the sieves, placed into vials and preserved with 90% ethanol (Fig 4). The vials are labelled with date and station number.

Three replicate samples must be collected at each station.

3.2 Laboratory analysis

The invertebrates are identified and enumerated in the laboratory using a stereo microscope.

Relevant taxonomic keys for identification of species from Sarawak are:

- Ward and Whipple; (Ref. 8)
- Abbott; (Ref 1) and
Fiene-Severns et al. (Ref. 3)

The abundance (number of individuals of each species per m$^2$) on each site is then calculated based on the total numbers found in the three replicate samples (each representing a sample area of 225 cm$^2$). The results are presented in a table (Cf. Table 3).

**Table 3. Example of a table of abundance of different species (from Ref. 7)**

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Station S1</th>
<th>Station S2</th>
<th>Station S3</th>
<th>Station S6</th>
<th>Station S7</th>
<th>Station S8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OLIGOCHAETA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tubifex tubifex</em></td>
<td>395</td>
<td>296</td>
<td>98</td>
<td>98</td>
<td>197</td>
<td></td>
</tr>
<tr>
<td><em>Limnodrillus sp.1</em></td>
<td>98</td>
<td>98</td>
<td></td>
<td>197</td>
<td>98</td>
<td>197</td>
</tr>
<tr>
<td><em>Limnodrillus sp.2</em></td>
<td></td>
<td></td>
<td></td>
<td>691</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Limnodrillus sp.3</em></td>
<td></td>
<td></td>
<td>294</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Limnodrillus sp.4</em></td>
<td></td>
<td></td>
<td></td>
<td>197</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Limnodrillus sp.5</em></td>
<td></td>
<td></td>
<td></td>
<td>197</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Limnodrillus sp.6</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Limnodrillus sp.7</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>197</td>
</tr>
<tr>
<td><em>Limnodrillus sp.8</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>395</td>
</tr>
<tr>
<td><em>Stylaria sp.</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>197</td>
</tr>
<tr>
<td><em>Turbellaria sp A</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>197</td>
</tr>
<tr>
<td><em>Turbellaria sp B</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>98</td>
</tr>
<tr>
<td><strong>AMPHIPODA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Gammarus sp</em></td>
<td></td>
<td></td>
<td></td>
<td>98</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total abundance</strong></td>
<td>493</td>
<td>492</td>
<td>392</td>
<td>1676</td>
<td>689</td>
<td>887</td>
</tr>
<tr>
<td><strong>Total no species</strong></td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Figure 3. Ekman sampler

Figure 4. Handpicking of invertebrates from a sieve
Figure 5. Crustacea (Gammarus sp.)

Figure 6. Cluster of oligochate worms
3.4 Reporting

The reporting must include the calculation of community structure indices and descriptive analyses of abundance and number of species.

Community structure indices

The Shannon Wiener (H’) and Margalefs (D) indices are used to assess the diversity and species richness of the riverbed invertebrate fauna.

The Shannon Wiener index is calculated as:

\[ H' = \sum_{i=1}^{s} \frac{n_i}{n} \ln \left( \frac{n_i}{n} \right) \]

where
- \( s \) = number of species
- \( n \) = total number of individuals
- \( n_i \) = number of individuals of species \( i \)

The Margaleff index is calculated as:

\[ D = \frac{s-1}{\ln n} \]

where
- \( s \) = number of species
- \( n \) = number of individuals

The Jaccard Index and Czekanowski Coefficient (Cz) are used to compare the similarity of the composition of the fauna on the sampling stations.

The Jaccard Index of similarity between two stations is calculated as:

\[ J = \frac{n_c}{(n_i + n_j)} \]
where \( n_c \) = the number of species common to station i and j
\( n_i \) = the number of species on station i
\( n_j \) = the number of species on station j

The Czekanowski coefficient of similarity between two stations is calculated as:

\[
Cz = \frac{2W}{A + B}
\]

where \( W \) = sum of the smallest number of individuals of each species
\( A \) = total number of individuals on station A
\( B \) = total number of individuals on station B

**Descriptive analysis**

In the descriptive analyses the estimated abundance and the number of species is compared to the sediment data and the data on water quality, which are collected in connection with the EMS.

It is attempted to interpret the pattern of abundance and number of species along the gradient of pollution in terms of known response of fauna to different types of pollution.

Basically the riverbed invertebrate fauna may be affected by

1) Toxic substances; and

2) Organic matter.
Re 1

Toxic substances may kill some animals and weakening others, which in the end will result in a change of the community. In severe cases, all animals may be killed.

Assessment of risks of impacts due to toxic substances is made by comparison of concentrations of pollutants in sediments with threshold effects levels (TEL) and probable effect levels (PEL) (Cf. Section 2.3).

Re 2

Organic matter affects the fauna in a characteristic manner. Based on a substantial amount of data from northern Europe, Pearson & Rosenberg (Ref. 6) found a general succession pattern of benthic (bottom dwelling) invertebrate fauna in response to increased input of organic material to the sediment in space or time (Cf. Fig.7):

- Initially increasing input of organic matter will result in an increase in the number of species and the density (abundance) of organisms because the amount of food for organisms increases (many benthic species feed on organic matter on the seabed).

- When the input reaches a certain level, the number of species, and the density decline. The reason being that the oxidised layer of the sediment becomes thinner because the organic matter consumes oxygen.

- At very heavy loads, oxygen depletion in and above the sediment may periodically take place. Only very few species can tolerate such conditions so the number of species decrease further as a result. Longer periods of oxygen depletion lead to the extinction of the fauna. In case oxygen conditions improve, the
area will rapidly be re-colonised by a very few so-called opportunistic species, which may be found in high densities.

![Figure 7. General succession pattern of benthic (bottom dwelling) invertebrate fauna in response to increased input of organic matter to the sediment. S = number of species. A = abundance (number of individuals/m²).]

The baseline study of river quality in Kuching indicated that the fauna in Sg. Sarawak showed the same succession pattern in response to organic load. The fauna data obtained in the monitoring programme for the EMS may therefore be interpreted in terms of the Pearson & Rosenberg succession theory.

4 References


