2 Mayflies as bioindicators of water quality and environmental change on a regional and global scale

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International conferences on Ephemeroptera already have a tradition of their own, and their standard and importance are growing. They reflect progress in the biological sciences, evident in publications from the conferences where studies in other disciplines — ecology, anatomy, physiology, molecular biology — as well as applied ones, increasingly appear in addition to taxonomic papers. The conferences are a forum for discussing further orientation of the research. In this contribution, which is intended as an invitation to discussion, I am going to focus on mayflies as indicators of local and regional changes in different types of water. This research topic has attracted much attention over the last three years. Also, researchers are investigating the possibility of using mayflies to assess global change; here, we are only at the beginning.

Mayflies are excellent objects for the bioindication of changes induced in waters by human activities for the following reasons:

- The order is phylogenetically very ancient, so that the adaptations are relatively "old", stable and very pronounced. Reaction to the changing environment is gradual, long-term and it is usually represented by a relatively easily interpreted data series.
- Mayfly larvae inhabit almost all aquatic freshwater habitats. The species live on different substrates, in decomposing organic matter and debris, on submerged vegetation, in strong currents and in still water.
- Most mayflies are detritivores or omnivores, which means that they feed on practically homogenized material in which toxic substances are evenly dispersed.
- In general, the fecundity of mayflies is extremely high. The number of eggs is markedly dependent on many biotic and abiotic factors and reflects the environmental conditions (Soldán 1981).

- Developmental cycles have been thoroughly studied. The development of mayflies is long (from several months to three years), so that cumulative long-term effects are distinct (Landa 1968; Hynes 1970; Sowa 1975).
- Mayflies display little vagility; short-lived adults lay their eggs mostly at the places of their emergence so that mixing of local populations is minimal (Sweeney and Funk 1991).
- Most genera and species are easily determined by the existing keys.

There are of course some disadvantages too, above all difficulties involved in maintaining long-term laboratory cultures. However, there are laboratory techniques enabling us to rear at least some species (Courtemanch and Gibbs 1980; Rodrigues and Kaushik 1984).

The purpose of bioindication, either local or regional, has in essence three aspects:

1) Detection of changes occurring in connection with any short- or long-distance human impact. They are manifested by the disappearance of some species, by decimation of populations, or by malfunctions (for example, impaired fecundity) or by accumulation of toxic substances in various tissues, which may, but need not, affect the functions of organism.
2) Monitoring recovery in streams where the causes of pollution have been removed.
3) Prediction of changes that can be expected after planned perturbations.

The numbers of studies on these subjects correspond with the above sequence in descending order. Most papers report changes due to short- and long-term pollution. So far there have been few papers on the recovery of destroyed waters and prediction of changes, methodological papers and reports on actual cases (Cairns 1986a; Furse et al. 1984; Rutt et al. 1990; Weatherley and Ormerod 1990; Leps et al. 1990).

Most of the authors have used various invertebrates including some mayflies species. The larger the sample, the more reliable are the results. However, the quality of comprehensive studies depends on the level of knowledge of the actual organisms.

Our knowledge of mayflies in relation to their use as bioindicators is summarized in the following seven topics.

1) Our knowledge of larval taxonomy is generally good, especially for Holarctic species. Thus, anybody studying changes at any locality can usually have his or her species identified. Of course, there are closely related "biological species" even in areas that have been thoroughly investigated, and their position must be defined in relation to their value as a bioindicator.

2) We also have quite good knowledge of species distribution, enabling us to study changes at the local and the regional level. There are a number of monographs and many reports include detailed data on the distribution of mayfly species in individual zones of streams and in different types of waters.

3) We have gathered a vast amount of valuable data on the distribution of species in waters and habitats of different types and on their responses to changes in natural conditions and to pollution of various kinds (Brittain 1982). So-called indicators, sensitive species that are used in practice for determining the degree of water quality, have been selected. However, we should keep in mind that the universal value of a single species is limited (Cairns 1986b), especially in cases of specific long-lasting pollution. A group of species should always be used, as their larvae living in different habitats are valuable sources of information. It follows that ecological studies of individual species, and mayflies as components of biocoenoses, should be given priority not only at the general level but also with regard to specific factors, in particular widely used toxic substances. There are several important recent publications (Hefti and Tomka 1988; Brittain 1990; Flannagan and Cobb 1991).

4) At the present time, mayflies are the focus of interest as indicators of the presence of toxic substances. Toxicity evaluation is based upon: a) finding out whether the effects of a compound are reversible or irreversible, they are evident in the drift of larvae in streams; and b) determining the cumulation of toxic substances in various organs of the body. The amounts are easily determined by analytical methods, showing us the short- and long-term actions of compounds affecting whole biocoenoses and, ultimately, humans. Studies in this field deal with the cumulation and effects of heavy metals (Sochtig 1989; Aoki et al. 1989; Hare et al. 1991), PCB (Novak et al. 1968), effects of pesticides (Gobas et al. 1989 — chlorinated hydrocarbons, Kreutsweiser and Sibley 1991 — permethrin, Sundaram et al. 1991 — diflurbenzon, Sebestien et al. 1989 — methoxychlor), a broad complex of pollutants (Leland et al. 1989; Saltveit 1989), pollutants leaching from fertilized fields (Sochtig 1989; Nelson et al. 1990). Pontasch and Cairns (1991) devised a multiplex toxicity test using indigenous organisms, and mayflies proved to be the most sensitive of all. Pontasch et al. (1989) described the susceptibility of four mayfly species.

5) Water acidification is a major concern in the Northern Hemisphere. Actually, it is a global problem that is apparent in various degrees locally and regionally (Schindler 1988). The most detailed data concern Canadian lakes (Kerekes 1989; Kerekes et al. 1990) and North European lakes.

Mayflies are reliable indicators of water acidification even when the change is slow. Increasing acidity reduces the number of species and causes changes in the composition of biocoenoses (Weatherly et al. 1990; Guerold et al. 1991; Nielsen et al. 1982). Data from Czechoslovakia also confirm that mayflies are good indicators of acidification (Landa and Soldán 1989; Soldán and Landa 1989).

6) To be able to use mayflies as indicators we must know more about their larval development and about the effects of pollutants on their vital functions, above all fecundity. Decreasing fecundity, hatching success and changes in spermiogenesis and oogenesis are sensitive indicators of the presence of even small doses of biologically active compounds. The same applies to other functions, such as respiration and the endocrine system. There are several recent studies on the effects of changes in pH on vital functions (Rowe et al. 1987; Rowe et al. 1989; Raddum and Fjelheim 1987).

7) Molecular biological methods are increasingly used in the study of changes in organisms living in the deteriorating environment. It will also be necessary to promote their application to the study of mayflies as indicators. So far they have been used for solving taxonomic problems (Hefti and Tomka 1989; Savolainen et al. 1991; Zurwerra et al. 1987).

Adverse local and regional environmental changes may spread, acquiring a new quality and turning into global problems. Typical global problems include increasing temperatures, increasing penetration of ultraviolet light through the atmosphere and increases in carbon dioxide and other greenhouse gases in the atmosphere. Acidification is also becoming a global problem. Toxic compounds, which are commonly used or arise as byproducts, are a growing problem. Similarly, radioactive fallout can be a global problem.

Dealing with global problems requires a broad scientific basis. Therefore, UNEP, IUBS, SCOPE, MAB-UNESCO as well as IIASA with its scenarios based on climatic change have also directed their activities towards this aim. ISCU "Global Change" is a synthetic program and diversity is an issue of special importance within its framework.

All these programs, however well evaluated mathematically, need actual data. I suggest that the order Ephemeroptera as a whole, as well as its species, genera and families, are ideal objects for such studies.

Can we succeed in this work?

1) We have good compendia on the mayfly fauna of the Northern and Central America, Europe and Australia. We also have many monographs and separate reports from other parts of the world. Thanks to our fellow ephemeropterists we have a fairly good picture of the mayfly fauna even

from areas little explored by other entomologists. An admirable piece of work is "Mayflies of the World" by M.D. Hubbard (1990), where lists of families and genera are supplemented with data on distribution. The distribution of mayflies can be reliably mapped on the basis of this catalogue, which, moreover, enables us to trace the historical development from which the present situation has ensued. Studies on historical geography at a continental level are rare (Peters 1988; Illies 1966), and precise studies of this kind are very important with regard to global change, because there is an interlinked circle of historical development between the present state and possible development under certain scenarios. We should then have at least hypotheses on the history of mayfly faunas a) within regions or b) within groups. A pioneer work in this respect is a comprehensive study on Potamanthidae by Y.J. Bae and W.P. McCafferty (1991), which includes an extensive chapter on the biogeography of this family.

2) In the sequence of historical development from present distribution to expected development in certain circumstances, the monitoring and determination of changes that have occurred during the short period of the last 30-50 years are of special importance. Of course it is difficult to distinguish the global nature of these changes from temporary local and regional changes. However just the study of short-term changes will enable us to predict possible trends of mayfly distribution and thus contribute to the program "Global Change".

An important criterion in assessing the nature of global changes is, for example, extinction of species or a drastic decrease in their occurrence. As a student, one of us (V. Landa) collected *Palingenia* and *Prosopistoma* and saw large swarms of *Ephoron* and *Oligoneuria.* Now, these genera are becoming extinct throughout Europe and the same is happening to other species in other continents, although the occurrence of other mayflies is on the increase. A study of species on the brink of extinction would doubtless provide valuable data for assessing global changes. From 1950 through 1960 we carried out a thorough study of more than 2500 localities in Czechoslovakia and collected over 600,000 mayfly larvae. The material was kept for future reference. Around 1985 we sampled about 150 of the localities and found many changes in the composition of the Czechoslovak fauna, as well as reduced diversity. Some species advanced northwards from the lowlands of Pannonia during a mere three decades (Landa 1984; Landa and Soldán 1985; Landa and Soldán 1989; Soldán and Landa 1989; Leps et al. 1990). We have detailed old data from the Sumava Mountains where acidity has dramatically decreased. It would be useful to repeat this research jointly with ephemeropterists from other countries and compare its results with the zero state of three to four decades ago. I am sure that there are several places in the world where records have been kept for many years and similar results could be obtained.

The sum of results of mayfly studies can be profitably applied to the use of mayflies as indicators at all levels. It is important that we be aware of this fact. Of particular importance is the possibility of using mayflies within the framework of the Global Change program. The existing data are very useful, but much remains to be done. The main thing seems to be to organize long-term studies of changes in selected catchment areas at various places on our planet. I am convinced that such a project could get support from international resources.

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