The use of Ephemeroptera to assess aquatic biodiversity in the rhithral part of the Luxembourgish rivers

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Abstract

In a multi-field survey conducted during the period 1994-1998, 39 species of Ephemeroptera were recorded in the rhithral part of the Luxembourgish rivers. They belong to 22 genera and represent 8 families out of the 15 encontered in Europe. The relationship of these macroinvertebrates between their distribution and the abiotic/biotic factors were elucidated with the multivariate Canonical Correspondance Analysis (partial CCA) technique. The results of the partial CCA ordination using environmental variables obtained by forwarded selection show that 9.8 % of the variance in species occurrences are accounted by the first two axes and 73.1 % of the variation could be explained by the environmental variables. The four main factors having an important significance for larvae were the conductivity, the slope, the organic pollution and the stream order. Ephemeroptera constitute a very interesting group for studying running water and can therefore be considered as a useful group for assessing aquatic biodiversity in rivers.

Keywords: mayflies, indicator species, ordination, water quality, Luxembourg.

Research Update on Ephemeroptera & Plecoptera
2003, E. Gaino (Ed.), University of Perugia, Perugia, Italy.

Introduction

The Ephemeroptera display ecological and behavioural specializations which enable them to colonize a wide range of lotic and lentic waters. In addition, Ephemeroptera are abundant and represent an important component of the biotic diversity in streams of Luxembourg. In a precedent analysis, Ephemeroptera proved to be the third most diverse group, just after Diptera and Trichoptera and followed by Coleoptera, Plecoptera and other groups of macroinvertebrates (Dohet, 2000).

The aim of this survey is to characterize the Ephemeroptera fauna of the study area and to detect the main spatial pattern of distribution across environmental gradients.

Material and Methods

Study area

Luxembourg is divided into two major defined regions: the homogeneous schistous hercynian massif in the North (Oesling) with a mean altitude approaching 500 m and the Triassic and Jurassic layers on a Devonian base in the South (Gutland). The total area represents 2586 km^2 (Fig. 1) The climate in Luxembourg can be considered as temperate. The Oesling is a wooded area with low anthropogenic disturbances. On the contrary, the Gutland is more influenced by human activities. 149 sites were chosen over the whole country in order to cover the main types of rivers as well as different degrees of human impact.

Species data

39 species belonging to 8 families of Ephemeroptera were recorded in the rhithral part of the Luxembourgish rivers (Dolisy, 2000). The most diverse families are Baetidae and Heptageniidae each containing 13 and 11 species of all species, respectively. Within the Baetidae the most diverse genera is *Baetis* which contains 8 species. In the other families specific diversity is more equally distributed and contains between 1 and 4 species. Species names and codes used in CCA are listed in Table 1.

Environmental data

149 collecting sites in the rhithral part of the streams were chosen over the whole country in order to cover the main types of rivers (Fig. 1). Aquatic biotopes were identified and a semi-quantitative method was employed to sample each of them. Hand nets were used to collect larval

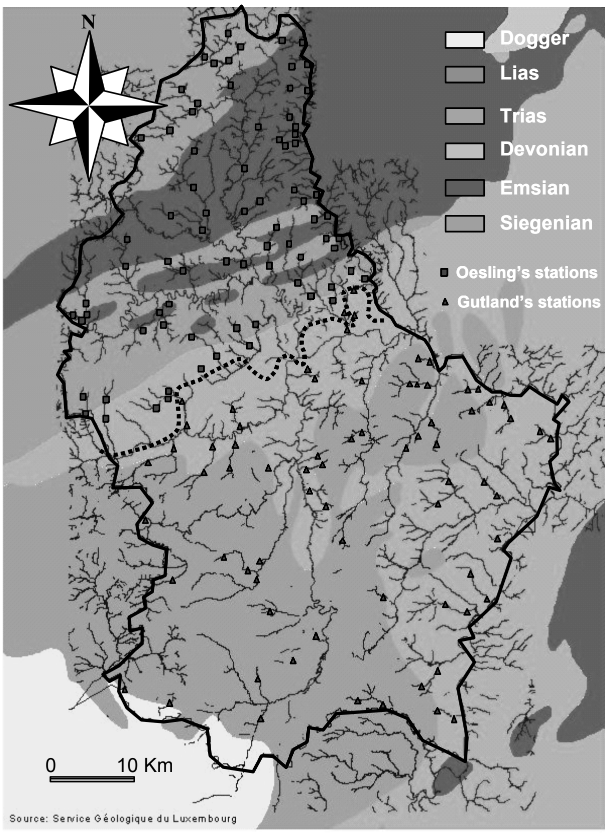

Fig. 1 - Map depicting the hydrological network of Luxembourg and showing the stations chosen. The dotted line separates the Oesling area (square symbol) from the Gutland area (triangle symbol).

stages twice a year (between spring 1994 and autumn 1998). Water samples were collected and analysed following standard procedures in the laboratory of the Environment Administration of Luxembourg, respectively the laboratory of CRP-GL, for the following variables: chlorides, sulphates, total phosphorus, ortho-phosphates, nitrates, nitrites, ammonium, sodium, potassium, total hardness and BOD5. To assess organic pollution, a multimetric index "IPO" (Leclercq and Maquet, 1987) based on four parameters (BOD5, NH4, NO2 and PO4) was calculated. The values of the IPO are based on four parameters: NH4+, NO2-, PO4--- and BOD5. The scale ranges from 1 (low organic pollution) to 5 (high organic pollution). Different physical and biological variables (stream width, stream depth, stream length, substrate number, bottom substrate type, aquatic vegetation) of the collecting sites were noted in the field and geographic information on the location (latitude, longitude, L*l, distance from the spring source, stream order, altitude, slope) was derived from 1/20.000 topographical maps. For the CCA analysis, the substrate types were summarized in three categories: stones (bedrock, cobbles), sediment (coarse and fine gravels, sand, silt) and vegetation (litter, roots, submerged and emergent aquatic vegetation, moose). The range values (min., max., 25-75% quartiles, median) of 22 environmental variables for each site were summarized in Table 2.

Table 1 - List of species code and full species name used in CCA.

ALA MUT	*Alainites muticus* (Linne, 1758)
BAE ALP	*Baetis alpinus* (Pictet, 1843)
BAE FUS	*Baetis fuscatus* (Linne, 1761)
BAE LUT	*Baetis lutheri* Müller-Liebenau, 1967
BAE MEL	*Baetis melanonyx* (Pictet, 1843)
BAE RHO	*Baetis rhodani* (Pictet, 1843)
BAE SCA	*Baetis scambus* Eaton, 1870
BAE SP	*Baetis* sp. Leach, 1815
BAE VAR	*Baetis vardarensis* Ikonomov, 1962
BAE VER	*Baetis vernus* Curtis, 1834
CAE BES	*Caenis beskidensis* Sowa, 1973
CAE HOR	*Caenis horaria* (Linné, 1758)
CEN LUT	*Centroptilum luteolum* (Müller, 1776)
CLO DIP	*Cloeon gr-dipterum* (Linné, 1761)
ECD DIS	*Ecdyonurus dispar* (Curtis, 1834)
ECD SP	*Ecdyonurus* sp. Eaton, 1865
ECD SUB	*Ecdyonurus submontanus* Landa, 1869
ECD TOR	*Ecdyonurus torrentis* Kimmins, 1942
ECD VEN	*Ecdyonurus venosus* (Fabricius, 1775)
ELE LAT	*Electrogena lateralis* (Curtis, 1834)
ELE UJH	*Electrogena ujhelyii* (Sowa, 1981)
ELE SP	*Electrogena* sp. Zurwerra & Tomka, 1985
EPE SYL	*Epeorus sylvicolus* (Pictet, 1865)
EPH DAN	*Ephemera danica* Müller, 1764
EPH MUC	*Ephemerella mucronata* (Bengtsson, 1909)
HAB CON	*Habroleptoides confusa* Sartori & Jacob, 1986
HAB FUS	*Habrophlebia fusca* (Curtis, 1834)
HAB LAU	*Habrophlebia lauta* Eaton, 1884
HEP SP	*Heptageniidae*
LEP MAR	*Leptophlebia marginata* (Linné, 1767)
MET BAL	*Metreletus balcanicus* (Ulmer, 1920)
NIG NIG	*Nigrobaetis niger* (Linné, 1761)
PAR SUB	*Paraleptophlebia submarginata* (Stephens, 1835)
PRO BIF	*Procloeon bifidum* (Bengtsson, 1912)
RHI HER	*Rhithrogena hercynia* Landa, 1969
RHI HYB-GR	*Rhithrogena hybrida-Gr*
RHI PIC	*Rhithrogena picteti* (Sowa, 1971)
RHI PUY	*Rhithrogena puytoraci* Sowa & Degrange, 1987
RHI SEM	*Rhithrogena semicolorata* (Curtis, 1834)
RHI SEM-GR	*Rhithrogena semicolorata-Gr*
SER IGN	*Serratella ignita* (Poda, 1761)
SIP AES	*Siphlonurus aestivalis* (Eaton, 1903)
SIP LAC	*Siphlonurus lacustris* (Eaton, 1870)
TOR MAJ	*Torleya major* (Klapalek, 1905)

Multivariate analysis Ordination

Environmental variables that may affect the distribution of mayflies were investigated by Canonical Correspondance Analysis (CCA) using the CANOCO program of ter Braak and Smilauer (1998). A log-transformation was made to reduce the effect of a highly abundant species (Jackson 1993, Cao *et al.*, 1997). The mayflies were sampled in two different seasons (spring and autumn). This seasonal variation being not the prime objective of the present paper, a partial canonical correspondance analysis (partial CCA) in which the two class variables representing seasons were treated as covariables was used (ter Braak and Verdonschot, 1995). Partial CCA was conducted using the data set containing 59.645 specimens belonging to 45 taxa in 296 samples. Environmental variables were recorded for the same samples. Species and samples were ordinated along axes produced by linear combinations of environmental variables. Environmental variables are shown on plots as arrows: the longer the arrow and the closer it is to an axis, the more important it is in defining that axis. Significance of the relation between the species and the environmental variables were tested using a Monte Carlo Random Re-sampling Test using 199 random permutations. Results of CCA were plotted for the first two canonical axes using the computer program Canodraw (ter Braak, Smilauer, 1998)

Results

The results of the CCA ordination show that 9.8 % of the variance in species occurrences are accounted by the first two axes and 73.1 % of the variation could be explained by the environmental variables (Table 3).

Only the six environmental variables most strongly correlated to the species data are shown in the ordination diagram (Fig. 2).

Table 2 - Different range values (min-max, 75%-25% quartiles, median) of environmental variables from autumn 94 to spring 98. Abbreviations are: IPO: index of organic pollution, Alt.: altitude, SD: source distance, TH: total hardness (French degree), THCa: carbonate hardness (French degree).

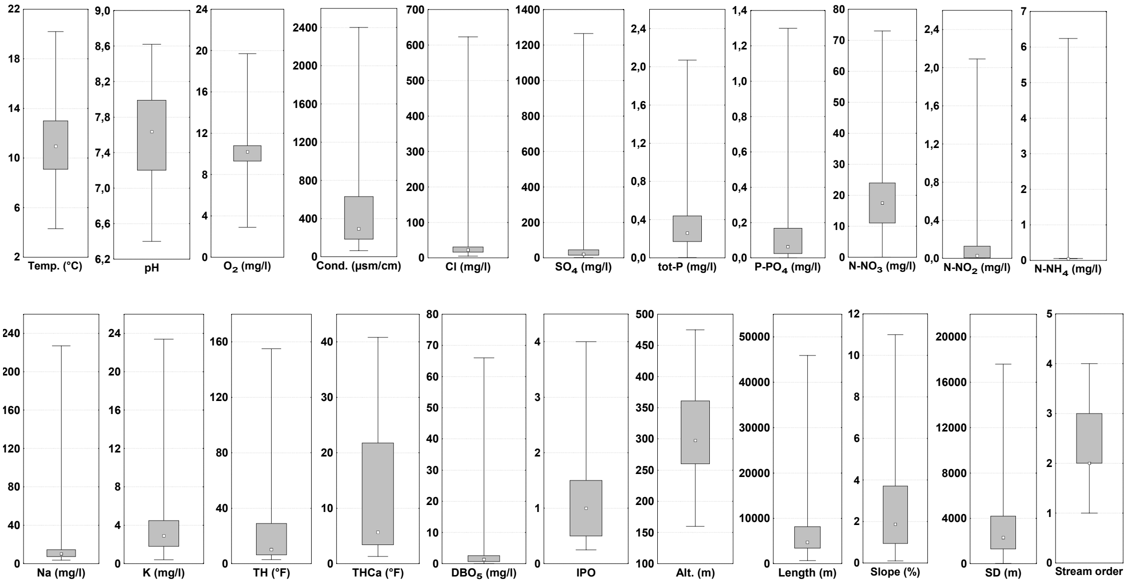

Table 3 - Results of canonical correspondance analysis (CCA) using environmental variables obtained by forward selection procedure for four axes of the CCA and the significance of the Monte Carlo test for the first axis. Weighed intraset correlations between axes 1 to 4 and the 6 environmental variables forwarded.

Axes	1	2	3	4	Total inertia
Eigenvalues:	.189	.104	.054	.028	3.054
Species-environment correlations:	.715	.706	.552	.368	
Cumulative percentage variance					
of species data:	6.3	9.8	11.6	12.6	
of species-environment relation:	47.1	73.1	86.4	93.4	
Sum of all unconstrained eigenvalues = 2.979					
Sum of all canonical eigenvalues = 0.401					
Monte Carlo permutation test F=18.525 (p<0.005)					
Conductivity	0.537	0.306	–0.170	0.005	
Slope	-0.368	0.490	0.177	0.010	
Organic Pollution Index (IPO)	0.489	-0.067	0.281	-0.094	
Stream Order (SO)	-0.013	-0.542	0.093	-0.123	
Carbonate hardness (THCA)	0.052	0.306	-0.215	-0.023	
T°	0.053	-0.226	0.144	0.296	

They are in decreasing order of importance: conductivity, slope, organic pollution (IPO), stream order, carbonate hardness and temperature. The first axis is positively correlated with the conductivity (0.537), organic pollution (0.489), carbonate hardness (0.052) and negatively correlated with slope (-0.368). The second axis indicates a negative correlation mainly with stream order (-0.542) and temperature (-0.226).

The stations are clearly distributed along the gradient of mineralisation. The high values of water mineralisation indicated by the conductivity and total carbonate hardness (THCa) attest of the different geological nature of the two regions prospected: Oesling (square symbol) and Gutland (triangle symbol).

Ephemeroptera are well dispersed over the whole CCA ordination diagram, but it can be noted that most of them are positioned in the lower left quarter. Those species occured in streams characterized by low mineralisation and high-order stream. It can be noted that Ephemeroptera are also well distributed along the stream order gradient and therefore constitute a very interesting group for studying longitudinal zonation. Species of fast flowing water and low anthropogenic disturbance occurred in the upper left quarter. Species of high mineralisation and low-order stream occurred in the upper right one. Species in the lower right quarter were characterized by moderate anthropogenic disturbance and high-order stream. The multimetric index that characterizes organic pollution (IPO) confirms the relatively good water quality in the investigated stations. Most values are ranging between 0.4 and 1.5 on a scale of 1 to 5.

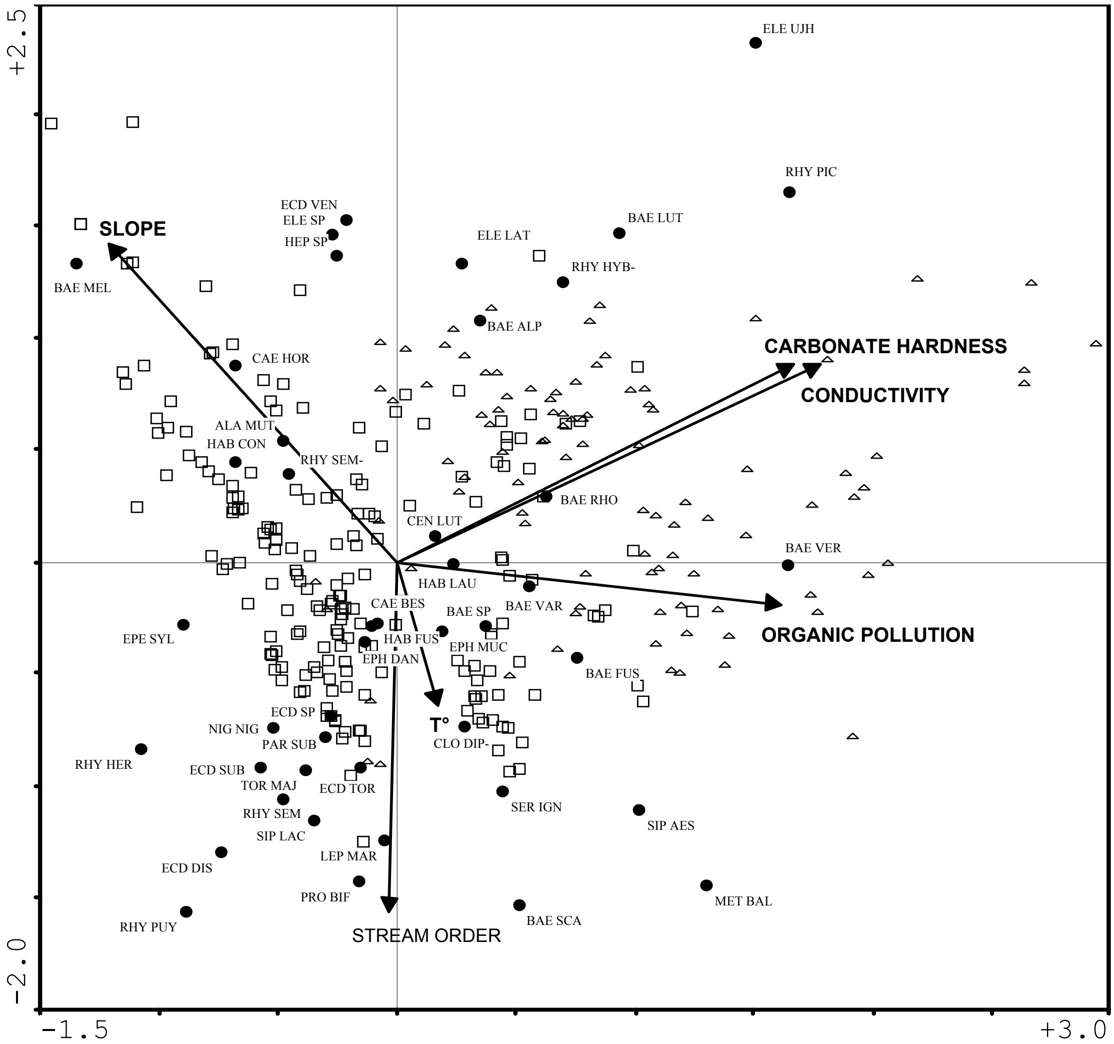

Fig. 2 - CCA Ordination diagram of taxa (circle symbol), stations from Oesling (square symbol) and stations from Gutland (triangle symbol). Eigenvalues and percent variance of species data are listed for the first four axes of CCA. F-ratio statistics (Monte Carlo permutation test) are listed for the first axis and all axes combined.

Considering the organic pollution gradient, Ephemeroptera species can be considered as sensitive, moderately sensitive or even pollution resistant. This is particularly obvious in the Baetidae family which shows a very large range of sensitivities to organic pollution. This family is represented by 13 different species which are very useful to point out the difference of sensibility between the different species. *Baetis melanonyx*, *Alainites muticus* are very sensitive, on the contrary, *Baetis vernus*, *Baetis fuscatus*, *Baetis scambus* and *Baetis vardarensis* are more tolerant (Fig. 2).

Discussion

Our results show that Ephemeroptera are well distributed over the whole diagram of the CCA and that they cover all environmental conditions investigated in this study. This group is particularily sensitive to the mineralisation of the substrat. This is clearly demonstrated by the conductivity and the carbonate hardness gradient. This confirms the importance of water alkalinity in determining mayflies community composition. Another important gradient is represented by the organic pollution gradient which shows a change in mayflies composition. In rapid bio-assessment based on a family level of identifications as the IBGN (AFNOR 1992), the Baetidae family is usually considered as tolerant to organic pollution. As we have seen the example of the Baetidae family it is important to work with species-level identifications to show the difference of sensibility induced by anthropogenic disturbances. The mayflies community seems to respond to physiogeographical features as the slope, the stream order and the temperature. The slope is the second most important gradient and is also an important variable in explaining differences in species composition. The stream order and the temperature affect also mayfly distribution. This result can be understood as a confirmation of the high significance of the longitudinal zonation.

In conclusion, we can say that Ephemeroptera show many features making them a useful group for assessing aquatic biodiversity and quality in rivers. The knowledge of the distribution of the Ephemeroptera is essential in order to assess more accurately the conservation status and biodiversity of many aquatic ecosystems.

Acknowledgements

This study was organized and financed by the Centre de Recherche Public-Gabriel Lippmann and the Musée National d'Histoire Naturelle in Luxembourg. Chemical analyses were provided by the Administration of Environment. I would like to thank Dr. A. Haybach for his help in the identification of the larva. My gratitude is also addressed to Dr. L. Hoffmann for his involvement during this study.

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