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Typology of large European rivers according to their Chironomidae communities (Insecta : Diptera)

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The Chironomidae fauna of ten large European rivers (Rhine, Elbe, Oder, Danube, Loire, Pripjat, Po, Maas, Garonne and Rhône) were investigated by analysing their ecological traits (longitudinal zonation pattern, saprobiological affinities, feeding types) using one-dimensional and multivariate methods. The results confirm the geomorphological differentiation of these rivers in two main types, i.e. gravel-type and sand-type rivers. The analyses of the Chironomidae traits also showed that transition zones separate the two main types of rivers.

Keywords : chironomidae, typology, biodiversity, large rivers, Europe.

Introduction

An essential prerequisite for the implementation of the EU Water Framework Directive is the classification of waters according to biocoenotic types. In Germany, 23 different macrozoobethos types of running waters are distinguished according to geomorphologic (Briem 2003, Schmedtje et al. 2001). The larger watercourses are divided into « gravel-type rivers » (Type 10) and « sand-type rivers » (Type 20). However, the individual character of the large rivers is often emphasized and expressed in an individual (geomorphologic) typification, as it was done, for instance, for the Rhine and the Danube by the international river-basin commissions, ICPR (International Commission for the Protection of the Rhine) and ICPDR (International Commission for the Protection of the Danube River), respectively. Moreover in comparision to small to medium-sized watercourses, the ecological situation of large rivers is often not as clearly defined because they integrate all environmental impacts over a much larger catchment. Additionally, the habitats in rivers of the same type may differ significantly in terms of their biocoenoses, e.g. the potamon-typical rheophile macrofauna and still-water zoocoenoses.

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The ecological typification of large rivers in Central Europe is more difficult than elsewhere, because of lack of knowledge about reference biocoenoses. Although there are some examples of a successful fossil reconstruction of single species (best known *Margaritifera auricularia* for the rivers Rhine, Elbe or Thames (Araujo & Ramos 2001)) the reconstruction of the full potamal biocoenosis even of a single river is far from beeing complete. In general these biocoenoses have been destroyed since the mid-19th century through anthropogenic activities like waste water and river training. Moreover, the invasion of alien species has changed the aquatic life community irreversibly (Tittizer et al. 2000). An actual zonation of e.g. the Rhine, is not or only roughly visible by reference to the macrozoobenthos (without chironomids and oligochaetes) (IKSR 2002).

The following analysis is an attempt at typifying large European rivers by means of the chironomid zoocoenosis. Non-biting midges are qualitative and quantitative one of the most important taxonomic groups of the macrozoobenthos, and as far as we know there are no aliens among them (Thienemann 1950, Tittizer et al. 2000). Because of the good knowledge about their autecological requirements, chironomids are suitable for the ecological characterization of watercourses (Dommermuth 1996, Janzen 2003, Orendt 2003).

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Material and methods

The data about chironomids in the large European rivers were taken from the literature (see references below for species lists) and supplemented by unpublished surveys of the German Federal Institute of Hydrology (BfG). Altogether ten rivers were considered (Rhine: Becker (1995); Elbe: Schöll & Balzer (1998); Oder: Balzer (1998); Danube: Balzer (1997); Loire: Garcia & Laville (2001); Rhône: Franquet & Pont (1996); Maas: Evrard (1996); Pripjat: Jonge et. al (1999); Po: Battegazzore et al. (1992)). An overview of the survey sites as well as comments on taxonomic consistency across the studies are given in Fig. 1 and Table 1. An impression of the sizes of these rivers can be gained from the distances of the survey sites from the sources and the long-term mean streamflows. The ecological traits based on the classification of species by Moog (1995) (longitudinal valencies, feeding types, saprobic valencies). As different methods had been used in surveying the chironomid fauna regarding the developmental stages (pupal exuviae, larvae, imagines), sampling duration and intensity, the data were interpreted only qualitatively with regard to the occurrence (only presence) of species, but not quantitatively for their abundances. The respective ecological subvalencies of the species were added up and normalized against a percentage scale. The crenal portion was added to the rhithral and the profundal portion to the littoral.

Results

General information

The study determined altogether 261 species (higher taxa, genera and uncertain species, as well as «counting names» as *Parachironomus* sp. Pe Langton etc. were omitted), of which 164 were categorized for their longitudinal zonal valencies, 143 for their feeding types and 130 for the saprobic valencies according to Moog (1995) (Fig. 2a). The highest number of species was counted in the River Garonne, the lowest one in the River Po. The species numbers reflect essentially the intensity and the surveying method. For instance, on the River Po, the species inventory was determined

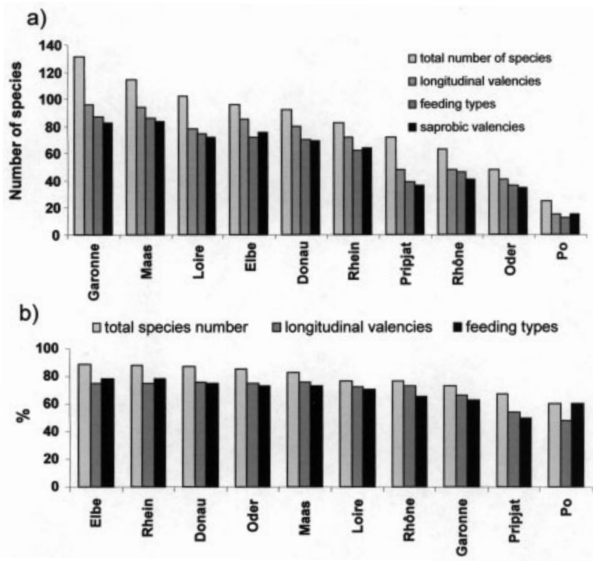

Fig. 2. Numbers of species and categorized species (a), and percentages of the categorized species (b).

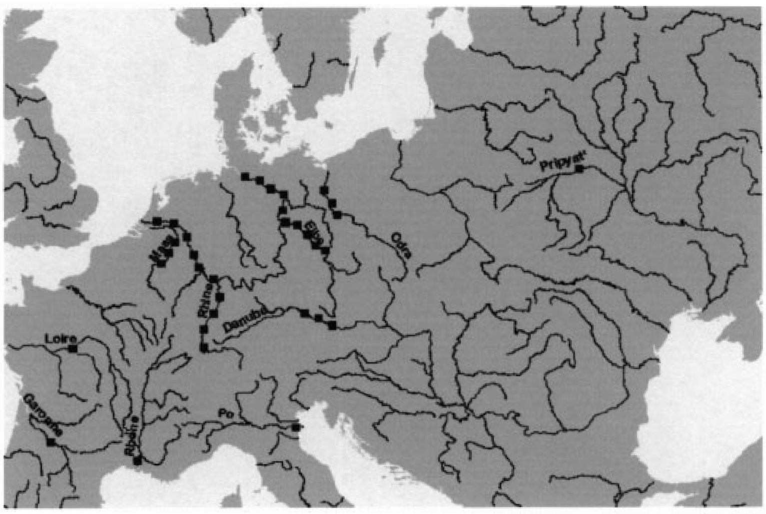

Fig. 1. Location of the survey sites

Table 1. Overview of the rivers under study. The distances from the sources (except Garonne and Loire) and the discharges were identified by the author. The quoted gauging stations are located in the immediate vicinity of the surveyed river reaches (except Pripjat).

	Rhône	Garonne	Loire	Po	Maas	Rhine	Danube	Elbe	Oder	Pripjat
Survey sites	11 km downstream of Arles	45 km downstream of Toulouse	near Tours	Pontelagoscuro	Belgian Maas	Basel - Kampen	Weltenburg - Jochenstein	Schmilka - Geeshacht	Ratzdorf - Merschin	Turov
Distances from the source (km)	ca. 800	290	794	587	ca. 480 - 620	488 - 1320	ca. 430 - 650	ca. 370 - 950	ca. 650 - 800	ca. 370
Surveyed reaches	Main channel and groyne field, some km	Main channel and side arms, some km	Main channel, 40 km	Main channel, some metres	Main channel, ca. 140 km, 14 sites	Main channel, German Rhine: ca. 600 km, 17 sites; Dutch Rhine: 88 km, 4 sites	Main channel, 224 km, sites at regular intervals	Main channel, 580 km, sites at regular intervals	Main channel, 162 km, sites at regular intervals	Main channel, side arms, and oxbows, some km
Long-term mean streamflow (m^3/s)	Beaucaire: 1694	Verdun sur G.: 254	La Chapelle: 464	Pontelagoscuro: 1516	Borgharen (near Maastricht): 272	Basel: 1013 Mainz: 1608 Emmerich: 2260	Regensburg: 440 Achleiten (below Inn): 1418	Dresden: 318 Neudarchau (above Hamburg): 709	Niederfinow: 525	Mozyr (ca. 100 km below Turov): 555
Prevailing substrates	Gravel, silt	Gravel, molasse	Gravel, sand	No data, probably gravel	Gravel, sand (?)	Upper Rhine: coarse/fine gravel Middle Rhine: coarse gravel and bedrock Lower Rhine: fine gravel and sand Rhine Delta: sand	Gravel	Upper Elbe: coarse/fine gravel Middle Elbe: sand	Sand	Sand, silt
Survey years	1993 - 1994	1996 - 1997	1994 - 1996	1988 - 1990	1991 - 1992	German Rhine: 1990-1991, Dutch Rhine: 2000	1997	1995 - 1996	1998	1998
Methods	Traps, exuvia	Exuviae, pupae	Exuviae, pupae	Larvae (?) on artificial substrates	Exuviae	German Rhine: rearing, Dutch Rhine: larvae	Exuviae	Rearing and exuviae	Exuviae	Larvae, exuviae
Authors	Franquet & Pont (1996)	Garcia & Laville (2001)	Garcia & Laville (2000)	Battegazzore et al. (1992)	Evrard (1996)	Becker (1994) IKSR (2002)	Balzer (1997)	Schöll & Balzer (1998)	Balzer (1998)	Jonge et al. (1999)

with artificial substrates, so that in reality a considerably higher number of species has to be expected.

The percentage of the categorized species was between 48 and 88, with the highest values were detected from the German rivers Elbe, Rhine, Danube and Oder, while the lowest ones were those from the rivers Pripjat and Po. The results from the River Po have limited representativity for the chironomid fauna, because of the selective study method used there (see above), and the species inventory of the River Pripjat includes increasingly representatives of the eastern continental fauna which are not listed in the «Fauna Austriaca». The category of the longitudinal valencies was generally best represented (60 to 88 %), while the saprobic valencies were as a rule the poorest (60 to 78 %).

Longitudinal valencies

An analysis of the longitudinal valencies in the potamal of the rivers Elbe and Rhine shows generally a similar distribution (Figs 3a and 3b). In the River Type 10 «gravel-type river» (i.e. the Elbe between Schmilka and Pirna or the Rhine at Basel) the rhithral portion is around 45 %, the potamal one between 35 and 40 %, and the littoral one below 20 %. Further downstream, the longitudinal valencies shift continuously towards Type 20 «sand-type river» (the Elbe from Magdeburg to Geesthacht or the Rhine in the Netherlands), where potamal and littoral valencies prevail. As a consequence of impoundment, the Danube differs distinctly in its structure from the Rhine and the Elbe. The low portion of still-water species observed at Weltenburg increases significantly in the impoundment Geisling, to become replaced again in the free-flowing reach between Straubing and Vilshofen by species of the potamal and the rhithral (Fig. 3c). The River Rhône near Arles shows a longitudinal distribution of zonal valencies according to the River Type 20. The rivers Oder and Pripjat in Eastern Europe reach the potamal character after shorter distances from their sources than the Elbe and the Rhine, locally this character is even much more pronounced (Fig. 3d). The River Po, the Belgian Maas, and the Loire have intermediate positions between Type 10 and Type 20 (Fig. 3e). The distribution of the zonal valencies depends not only on the distance from the source, but also on the hydrological regime. For instance, the main channel of the Garonne near Saint Cassian would come into the category of River Type 10 according to the longitudinal zoning of the chironomid zoocoenosis (Fig. 3f). However, the zonal valencies shift distinctly from the rhithral to the potamal in the side arms of the Garonne that are regularly or only once a year connected to the main stream. A side arm that is permanently connected shows no differences against the main channel.

Feeding types

In terms of nutrition physiology, the chironomid zoocoenoses of large rivers are dominated by detritivorous and grazing species. Active and passive filter-feeders and predators occur also in smaller numbers. The differences along the river courses of the Elbe and the Rhine and between the individual rivers are not large in a one-dimensional analysis and are difficult to explain, (Fig. 4, Table 2). An evaluation of quantitative data would probably yield more differentiated results. However, such an evaluation would have much higher requirements on the comparability of the data, than the available data set could offer.

Table 2. Percentage distributions of the chironomid fauna in their zonal and saprobic valencies and the trophic types (L/P = littoral/profundal valencies, K/R = crenal/rhithral valencies, P = potamal valencies, WEI = grazers, AFIL = active filter-feeders, PFIL = passive filter-Feeders, DET = detritivor, RÄU = predators, x, o, β, a, p = = saprobic valencies)

	K/R	P	L/P	WEID	AFIL	PFIL	DET	RÄU	x	o	ß	a	p
Elbe /Schmilka	45.5	37	17	37	5.2	4.3	40	8.9	2.5	19.4	46.8	28	2.9
Elbe/Riesa	37.6	39	24	33.1	7	3.4	43.8	7.8	2	16	47.3	30.4	4.2
Elbe/Magdeburg	20	39	41	29.7	11.9	4.4	36.9	10.8	0.2	15.1	45.7	33.4	5.4
Danube/Weltenburg	36	45	18	42	5.8	5.5	36.5	6.2	3	17.3	48	28.6	2.6
Danube /Geisling	21	34	45	26.2	10.8	2.2	44	13.4	2	15.2	43.5	33.2	5.8
Danube /Straubing	29	37	34	32.3	8.8	2.6	39.7	11.4	2	15.5	46.8	30.25	5.5
Rhine/Basel	45	39	17	33	4.4	4.7	39	15.8	3	18.8	47	28	2
Rhine /Altrip	35	43	22	35.4	7.5	4.8	36.3	8.7	2.2	18.1	48.1	29	2.5
Rhine /Orsoy	31	45	24	36.5	8.8	6.1	33	8.8	1	14.5	48	33	3.3
Rhine /NL	22	33	45	31	11	0	45	5	0	13.3	48.3	33.3	5
Garonne/StCassianHS	40	35	25	50	5	2	36	7	2	20	48	27	2.5
Garonne/StCassianNB_I	38	33	29	40.1	5.5	2	39.4	10.5	2.8	20.8	46.8	27.1	2.3
Garonne/StCassianNB_II	33.8	32	34	38.4	6.1	1.8	43.4	8.9	2.6	19.4	47.1	27.5	3.1
Garonne/StCassianOxbo	26	30	44	33.5	12.2	1.8	42.5	7.4	2.1	16	46.2	30.3	5.1
Maas/Belgium	37.5	31	31	30.5	9	3.1	40	13	2.4	19	44.8	29.2	4.4
Oder/Ratzdorf	19	36	44	26	10	6	37	12	1.7	15.7	42	32	7.7
Loire/Tours	35	30	35	33	8.9	2.1	46.6	5.6	2.3	18.6	47.2	28.3	3.4
Po/Pontelagoscuro	35	36	28	31.6	8.3	0	43.3	14.1	1	14	42	31	12
Pripjat/HS	16	32	52	29.3	18.2	0	33.6	14.3	0	12.3	43	33.8	10.8
Rhone/ArlesHS	24	35	40	31.4	9.4	4.4	38	6.9	2.4	19.3	45.8	29.3	3.1

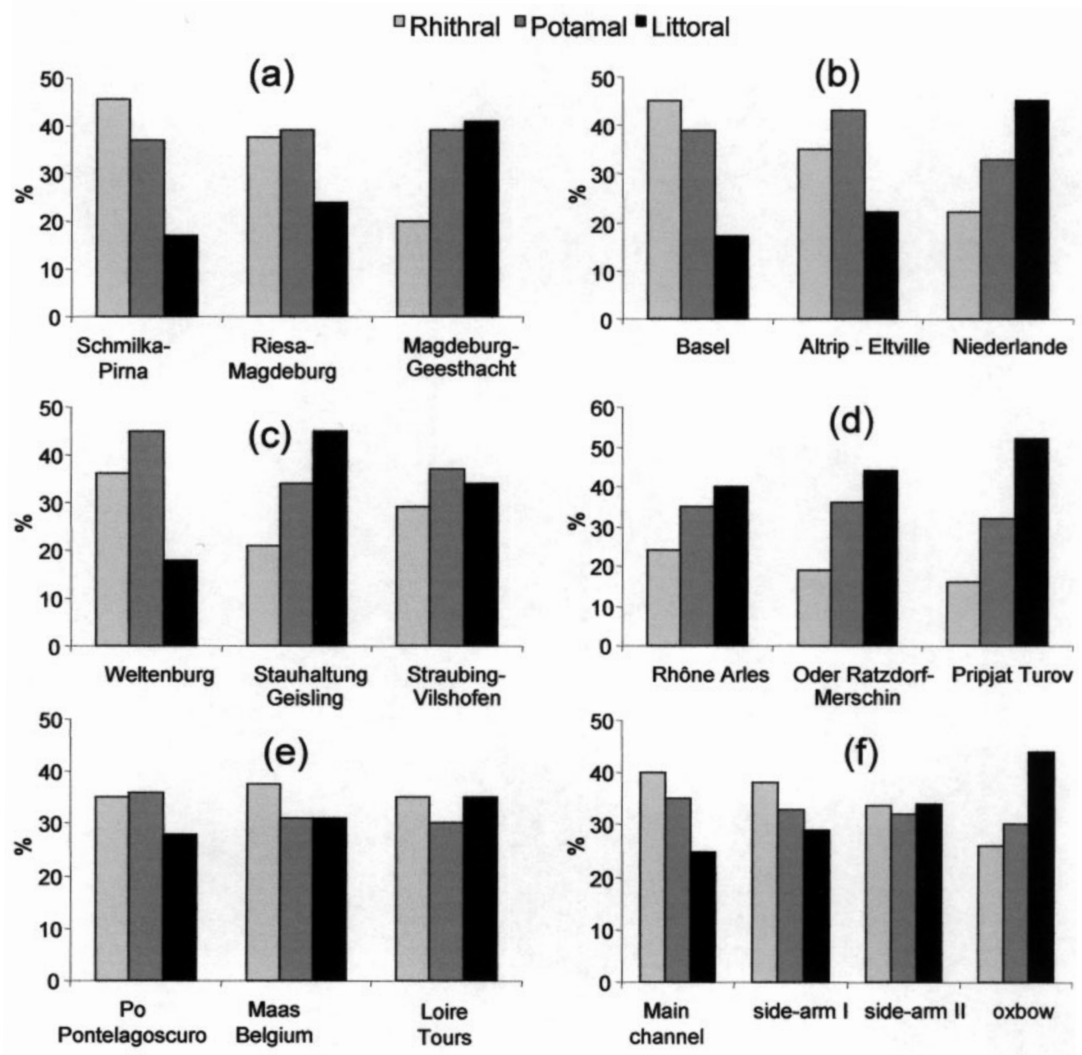

Fig. 3. Zonal valencies in the longitudinal profile of : (a) River Elbe, (b) River Rhine, (c) River Danube, (d) Rivers Rhône (main channel), Oder, and Pripjat (main channel), (e) Rivers Po, Maas, and Loire, and (f) River Garonne at St. Cassian (main channel, side-arm I = permanently connected, side-arm II = temporarily connected, oxbow = connected once a year).

Saprobic valencies

The saprobic valencies of the rivers considered in this study are very similar. In the longitudinal course, an increase of the a-mesosaprobic portion along with a decrease of the oligosaprobic portion can be generally noted (Fig. 4). Here too, the lacking qualitative consideration probably prevents more precise distinctions.

Multivariate analysis

A multidimensional analysis is used for an evaluation or validation of the results presented in Chapter 3. The classification procedure used was the cluster analysis (Ward method), the ordination procedures were the primary-component analysis (PCA) and the redundance analysis (RDA). The computations were made with the statistical software ADE 4 (Chessel & Dolédec 1992, Thioulouse et al. 1997) and the RDA with CANOCO 4.5 (ter Braak & Smilauer 2002). The data sets used were the computed percentage distributions of the chironomid fauna in their zonal and saprobic valencies and the trophic types. The cluster analysis (Fig. 5) categorizes the rivers or study areas, respectively, between the vertices Rhine/Basel and Pripjat in two distinct main groups. This grouping according to traits is practically identical with the typological grouping of

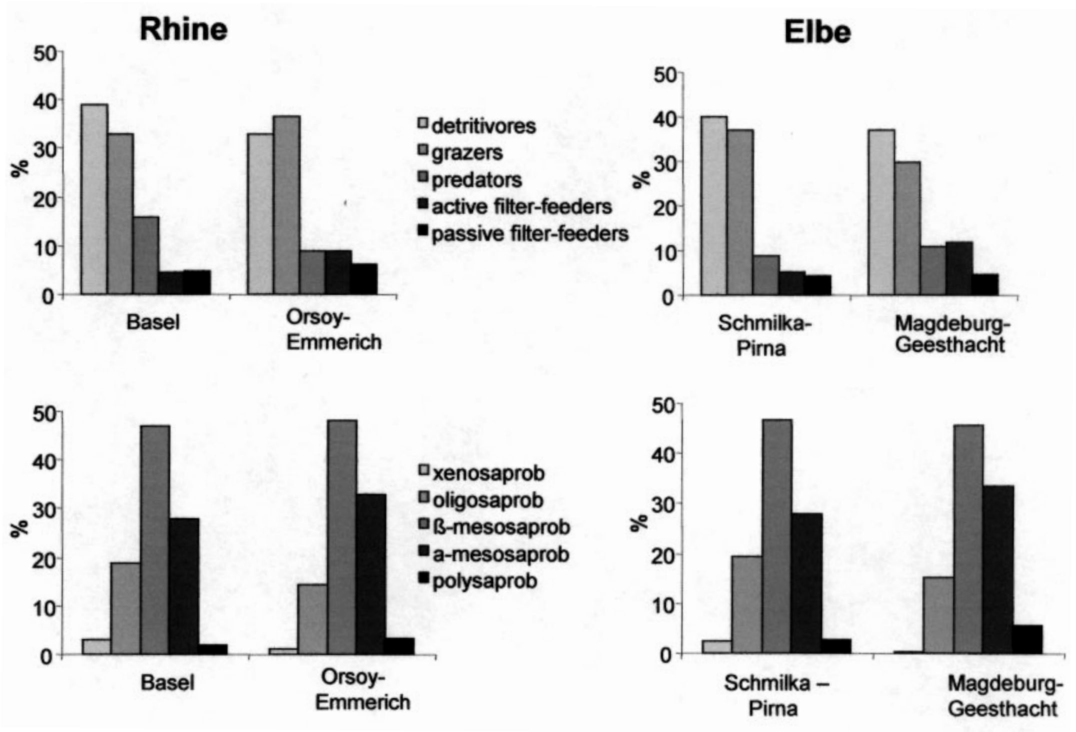

Fig. 4. Top : Distribution of trophic types in the longitudinal profile of Rivers Rhine and Elbe. Bottom : Saprobic valencies in the longitudinal profile of Rivers Rhine and Elbe.

the large rivers, with the upper group representing the Type 20 (sand-type rivers) and the lower group standing for Type 10 (gravel-type rivers). A further differentiation into two groups is noticeable in the lower main group. The primary component analysis (Fig. 6) shows that the group of Figure 5 (10/20) represents a transitional type, because it is located along the F1 axis roughly between the main types. The redundance analysis determines and visualizes the influences of the environmental factors «river type», «distance from the source», and «streamflow regime» as well as the traits that are decisive for the separation of the biocoenoses (Fig. 7). The evaluations show at first what is already known: From right to left (i.e. from Type 10 to Type 20) the active filter-feeders increase and replace the grazers, the rhithral species are substituted by potamal species, and the alpha-mesosaprobic valencies increase (Fig. 7). It is noteworthy that the F1 axis corresponds exactly to the typology of the river, so that the latter provides already a substantial explanation (>50 %, see Eigenvalues in Fig. 6) of the main changes in the variance of the data sets.

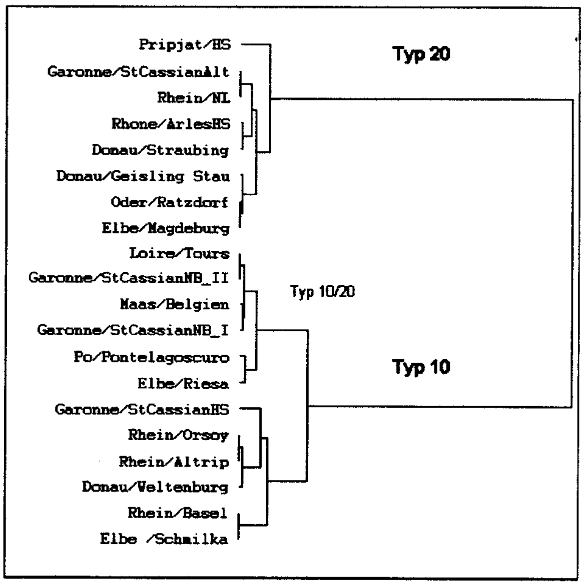

Fig. 5. Cluster analysis of the Chironomidae fauna on the basis of biological and ecological traits, according to Moog (1995), HS = main channel, NB - side-arm.

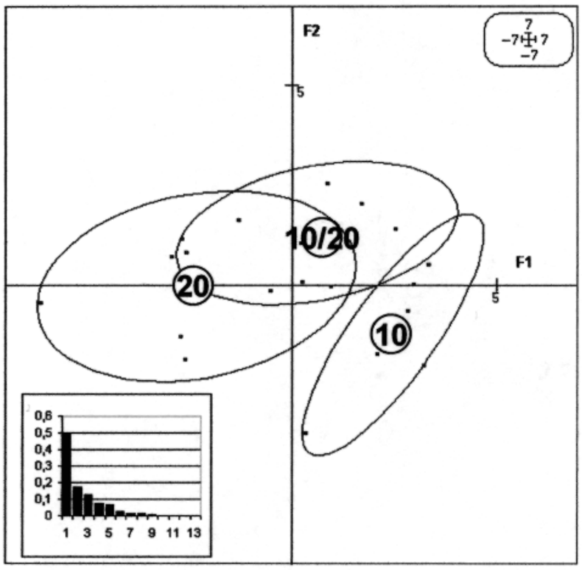

Fig. 6. Ordination diagram (PCA) of the Chironomidae fauna on the basis of biological and ecological species characteristics. 10, 20 = potamal types, 10/20 = transitional type. The left bottom inset shows the distribution of eigenvalues.

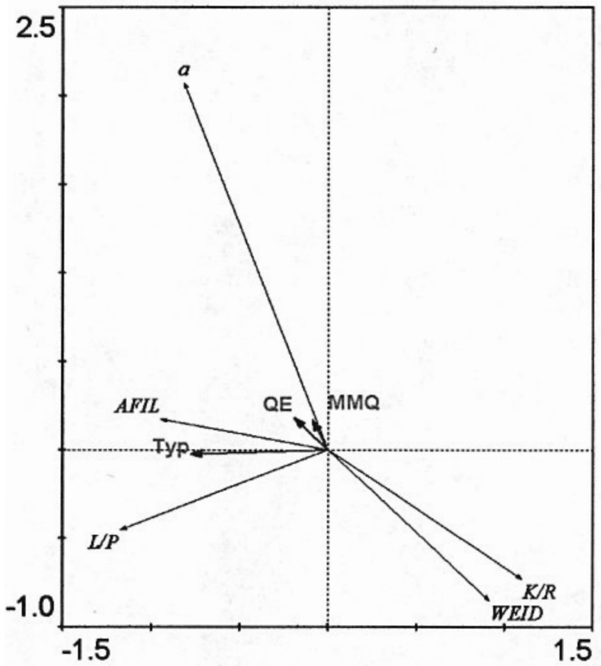

Fig. 7. Biplot (RDA) of the Chironomidae fauna on the basis of biological and ecological species characteristics. Type = river type, QE = distance from the source; NMQ = long-term mean streamflow, L/P = littoral/profundal valencies, K/R = crenal/rhithral valencies, WEI = grazers, AFIL = active filter-feeders, a = a-mesosaprobic valency.

This is an impressive proof of the suitability of non-biting midges for a typology of large rivers. The distance from the source and the mean streamflow play secondary roles in the analyses of all rivers, since the zoning is differently developed according to ecological region, climate, geomorphology, etc. For instance, the potamal state is reached in the River Oder after a considerably shorter flow distance than in the River Rhine.

Discussion

The present study shows that one-dimensional or multivariate analyses of the biological/ecological characteristics of the chironomid fauna are appropriate tools for a typology of large rivers in Europe. This method is suitable not only for small-scale analyses (Haybach et al. 2004), but also for the benthos biocoenosis of different ecological regions. It is particularly appropriate if an evaluation on the level of the species is not possible because of incomparable survey methods and intensity of sampling effort. Even with comparable sampling strategies, typological differences are not always apparent when exclusively species are used for the analysis (compare Becker 1995 and Caspers 1991). On the whole, the conventional German geomorphologically and hydrologically based differentiation of the large rivers in «gravel-type rivers» and «sand-type rivers» with transitions between them could be clearly confirmed by means of the chironomid data. This is particularly noteworthy, as the evaluation of the information from the literature followed purely the distinction between present or absent species data. Obviously, non-biting midges are very good indicators of the abiotic habitat conditions of large rivers, because of their species diversity and their differentiated ecological requirements. Although the family of non-biting midges plays no role in the German evaluation practice pursuant to the EU Water Framework Directive, they themselves or their species characteristics might well be used for the typology of rivers. Chironomid surveys with pupal exuviae could offer a low-cost method. This especially in comparison to much more expensive methods to evaluate benthos biocoenosis in large rivers by means of a ship (e.g. Tittizer & Schleuter 1986). Obviously, biologically relevant transitions exist between Type 10 and Type 20. In an ecological assessment with orientation at the reference state it is not always easy to find out under which type the river reach under consideration should be categorized. That is why an assessment method that takes account of the ecological diversity of the whole potamal as the reference state for the ecological evaluation of large rivers would be beneficial.

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