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Characterisation of pristine Polish river systems and their use as reference conditions for Dutch river systems

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Characterisation of pristine Polish river systems and their use as reference conditions for Dutch river systems

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ABSTRACT

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A central feature of the European Water Framework Directive are the reference conditions. The ecological quality status is determined by calculating the distance between the present situation and the reference conditions. To describe reference conditions the natural variation of biota in pristine water bodies should be measured. Because pristine water bodies are not present in the Netherlands anymore, water bodies (springs, streams, rivers and oxbow lakes) in central Poland were investigated. Macrophytes and macroinvertebrates were sampled and environmental variables were measured. The water bodies appeared to have a high biodiversity and a good ecological quality. They contain a high number of rare macroinvertebrate species. There are only few species that can not occur in the Netherlands, but their abundances were low. The Polish water bodies are suitable to describe reference conditions for similar Dutch water types. The data resulting from this project can be used to update the descriptions of reference conditions in the 'Handboek Natuurdoeltypen'or to develop the descriptions for the Water Framework Directive types.

Keywords: macroinvertebrate, macrophyte, Poland, water bodies, reference conditions, Water Framework Directive

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Preface

The project ‘Ecological description of natural water bodies in central Poland’ was carried out together with the group ‘Invertebrate Zoology and Hydrobiology’, University of Łódź. The goal of the project was to describe the natural state of Polish fresh water bodies in terms of aquatic communities and related environmental conditions and to test whether the results can be used to describe reference conditions for Dutch water bodies.

Results of this investigation can be used to:

1. Record the natural state (reference conditions) of Polish waters;
2. Develop a monitoring, assessment and management system for Polish fresh water bodies;
3. Investigate ecosystem structures and functioning of natural water bodies;
4. Describe reference conditions for similar Dutch water bodies.

We thank everybody who has helped with the fieldwork, the water analyses, and the identification of macroinvertebrates and macrophytes. Special thanks go to Barbara Bis and Janusz Majecki for their support and effort within this research.

Summary

For the Water Framework Directive, European Member States are required to identify reference conditions for aquatic ecosystem types. Reference conditions are used as upper anchor for setting class boundaries which are used for the calculation of ecological quality ratios.

In the Netherlands, most water bodies are influenced by human impact. Eutrophication and hydromorphological degradation are the major threats to freshwater ecosystems. Because reference conditions are scarce for most water types in the Netherlands alternatives should be used to describe reference conditions. Nijboer et al. (2004) showed that the use of data from other geographical regions appeared to be useful as long as sampling methods were comparable and the same water types were used.

Polish data from natural sites can be useful for establishing the Dutch reference conditions, because similar water types occur and the majority of species overlap with the Dutch flora and fauna.

The goal of this study was:

1. To describe the reference conditions (environmental variables, macroinvertebrate and macrophyte composition) of pristine Polish stream and river systems;
2. To test whether Polish biological data can be used to describe reference conditions of similar Dutch water bodies.

From 1998-2000 35 sites in the area around Łódź (central Poland) were sampled. Sites included rivers, streams, springs, oxbow lakes and one isolated lake. The sites that were selected for this research were the ones with the highest expected ecological quality. The selected sites are located in the catchments of the rivers Grabia, Czarna, Gać, Rawka, and Pilica.

Environmental variables were measured, macroinvertebrates were sampled and vegetation surveys were carried out. The data were analysed using ordination and clustering techniques. The site groups (clusters) were characterised by their species composition: dominant taxa, abundant taxa, and indicator taxa.

The Polish water bodies appeared to be very diverse, including high numbers of macroinvertebrate species. Water plants were less abundant because many water bodies were situated in forested areas. The water bodies were still natural, chemical variables did not explain differences between sites. Variables that were important were shading, substrate, connection to the river (in the case of oxbow lakes), and dimensions (for streams and rivers). There was seasonal variation, which, in some cases, resulted in smaller differences between sites than between two seasons at one site.

The clustering of samples provided insight in which streams, springs, rivers and oxbow lakes were similar, and by which species they were characterised (dominant, abundant and indicative species). This can be valuable in describing reference conditions for these and similar water bodies.

Water bodies within a type showed different species compositions, which implies there is natural variation. To make an accurate description of reference conditions enough water bodies within a type should be sampled and included in the description. Data of new water bodies should be added to types which were only represented by one or two water bodies. Finally, the reference descriptions can be used to develop an assessment system, with which the ecological quality of water bodies can be determined.

The selected Polish water bodies are still pristine. Many alterations that took place in other European countries did not take place in Poland. The chemical variables showed that in relation to the Netherlands chloride and potassium concentrations were low. The nutrient levels varied. The ammonium level was in many cases within the range given for the Nature Target Types, but the nitrate and phosphate levels often exceeded these ranges, probably because of a large amount

of organic material in a number of water bodies. Compared to other near natural streams, the Polish streams seemed to have a good chemical quality.

Most of the samples of springs, streams and rivers were assigned to the best stream types in the Dutch stream typology (classes 3-4 and 4). With the AQEM assessment system almost all of the springs scored high ecological quality (reference conditions). For streams the results were a little worse, although with the German method in most cases class 4 was assigned. The Dutch method was less stable, because it gave different values between seasons.

In general, the samples all contained high numbers of rare taxa. There are thus many taxa present in these water bodies, that are rare in the Netherlands,. Many of the indicator species from the Nature Target Types were found in the Polish data (about 40 %). For short, the Polish systems can be used as reference conditions, they are natural and have a good chemical and ecological quality.

The Polish data are comparable with the Dutch data. The number of taxa per sample is higher in Poland, except for the numbers in springs. Mean numbers of individuals differ and therefore, it is recommended to use percentages of species abundances instead of absolute abundances. Only 32 taxa found in the data can not occur in the Netherlands because this country is outside their biogeographical region. Most of these taxa have only low abundances and are not relevant to the community.

In conclusion, the Polish data are suitable for describing reference conditions for similar Dutch water bodies. The ecological quality is good to high and the data are comparable.

To develop descriptions for reference conditions, using the Polish data, the following steps should be taken:

- Determine the reference target type;
- Select sites using environmental variables, sample or collect biological data, analyse the species composition;
- Determine ecological quality with the WFD assessment system as soon as it is finished;
- Compare the species found with the species described theoretically for this type;
- Compare the species found with species lists of best available sites in the Netherlands (to get more insight in species composition and which species are lacking or rare in the Netherlands);
- Add characteristic species and rare species;
- Add ratio's of abundances for species.

1 Introduction

1.1 The European Water Framework Directive

A central feature of the European Water Framework Directive (WFD, European Commission 2000) is that deviations in ecological quality are to be established as the difference between expected and observed conditions in five ecological quality classes (from 1: bad to 5 high ecological quality or reference conditions). In brief, European Member States are required to identify reference conditions for ecosystem types (typologies): (1) for defining a reference biological community, (2) for establishing the upper anchor for setting class boundaries, and (3) subsequently for identifying departures from expected that may be caused by anthropogenic stress. Hence, the identification of reference conditions plays a pivotal role in calculating ecological quality ratios and determining the deleterious effects of human-generated stress. According to the WFD, the reference condition is defined as "*Expected background (i.e. reference) conditions with no or minimal anthropogenic stress and satisfying the following criteria: (1) they should reflect totally, or nearly, undisturbed conditions for hydromorphological elements, general physico-chemical elements, and biological quality elements, (2) concentrations of specific synthetic pollutants should be close to zero or below the limit of detection of the most advanced analytical techniques in general use, and (3) concentrations of specific non-synthetic pollutants, should remain within the range normally associated with background levels*" (European Commission 2000).

For the purposes of the WFD, "undisturbed conditions" may be interpreted as being those existing before the onset of intensive agriculture or forestry and before large-scale industrial disturbances. In many areas in northern Europe this would correspond to a time period around the mid-1800s. However, since selection of an appropriate time period is often constrained by the lack of reliable information of pre-impact conditions, a more pragmatic approach is often used based on establishing the most optimal situation. For example, Reynoldson et al. (1997) recently defined the reference condition as the condition that is representative of a group of minimally disturbed sites defined by selected physical, chemical and biological attributes.

If minimally impacted sites are not available within the geographical region of interest, e.g., a country, it may be possible to survey comparable waters (i.e. same stream type) from another geographical area (Nijboer et al. 2004).

1.2 Reference conditions in the Netherlands

In the Netherlands, most water bodies are influenced by human impact. Eutrophication and hydromorphological degradation are the major threats to freshwater ecosystems. Both are caused by intensive agriculture asking for fertilisation and drainage of the area. Most of the streams are normalised, regulated, and canalised. Hydrology, morphology and chemical composition are all altered by human activities.

Many Dutch water types have already been described, e.g. in the EKOO assessment system and the national stream and channel typologies (Verdonschot 1990, Verdonschot & Nijboer 2004, Nijboer & Verdonschot 2003, respectively). From these typologies, for which large datasets were analysed, it appeared that natural waters, i.e. reference conditions were scarce. There are only few pristine water bodies left to serve as an example for reference conditions and target stages. The best available surface waters in the Netherlands have a good ecological quality status (class 4), but are not reference conditions (class 5) (Vlek et al. 2004).

Reference conditions of water types are needed, not only for Water Framework Directive purposes but also for use in restoration projects. Water managers need to know what they can expect when a water body is restored. Which species composition should become present? If the reference conditions are known it is possible to monitor the success of restoration measures by determining the distance to the reference conditions, e.g. the number of target species present or using an index.

Because reference conditions are scarce for most water types in the Netherlands alternatives should be used to describe reference conditions. Nijboer et al. (2004) tried the use of historical data and data from other countries for describing reference conditions. Historical data are not quantitative and never complete because representative sampling did not occur. Therefore, they can only be used to add special species (e.g. species that are rare nowadays) to the description of reference conditions. Data from other geographical regions appeared to be more useful as long as sampling methods were comparable and the same water types were used.

1.3 Reference conditions in Poland

Polish data from reference sites can be useful for establishing the Dutch reference conditions. The landscape of central Poland is comparable to that of the Netherlands. It is flat, in some parts are low hills comparable to the Dutch province of Limburg. Therefore, the streams and rivers have a slope that is similar to the slope of Dutch streams and rivers. Data from Polish water bodies can thus be useful to describe reference conditions for Dutch water bodies.

Since the descriptions of Polish water bodies will be used for describing reference conditions, the water bodies that were selected had to be as natural as possible. This means that they should not have been influenced by human activities. Ideal sampling sites are not regulated nor normalised or eutrophied. They are hydrological and morphological in a pristine state. This means there is no drainage from the surrounding area which influences the hydrology of the catchment area. Bank protection must be absent. The water quality should be good. This means a water body may not be toxically polluted or eutrophied. This implicates that only rivers and streams which are free of discharge from a village or town nor influenced by a high amount of nutrients running of from agricultural area, are suited for this study. In central Poland more or less pristine water bodies do still exist, mainly in nature reserves and in agricultural areas which are not often fertilised. At least hydrology and morphology of these systems are still intact.

Describing reference conditions of Polish water bodies is important for use within Poland as well. Since agriculture is developing very fast in Poland nowadays, it is important to describe the natural waters before they get disturbed by drainage or pollution with nutrients and toxicants. Probably, in the near future, Poland will also implement the Water Framework Directive and therefore, a description of the reference conditions of the surface waters is needed as a basis for an ecological assessment system. Furthermore, descriptions of reference conditions can be used to monitor the surface waters and to be able to detect degradation in an early stage by a change in species composition. Measures can than be used to prevent the system from further degradation.

1.4 Water types

Water bodies can be divided into running waters and stagnant waters. In central Poland stream and river systems, including oxbow lakes, are the most common water types. Therefore, it is important to describe the reference conditions of these water types for the use in Poland. In the Netherlands, most of the natural waters are streams or rivers. Standing waters are often artificial, dug for drainage of agricultural land, i.e., channels or dug for exploiting peat areas. Still the diversity and ecological quality of these stagnant waters can be high. For the Water Framework Directive they will be considered as artificial and therefore a maximal ecological potential should be described instead of a reference condition. However, the data used for this description are similar to data used for describing reference conditions.

In this study we focussed on springs, streams and rivers and their oxbow lakes, thus including running and standing waters. Springs, streams and rivers in different sizes can be used for describing reference conditions for the Dutch springs, streams and rivers and oxbow lakes can be compared with the Dutch oxbow lakes but also to a lesser extent also with the peat pits and channels.

The soil type of the water bodies partly determines the species composition. In the stream and river systems in the Netherlands the main soil type is sand. In the standing waters the soil can consist of sand, peat or clay. In central Poland most streams have a sandy bottom comparable to the Dutch streams. Peat, clay and sand bottom do all occur in the oxbow lakes in old river beds.

1.5 Goal of the study

The goal of this study was:

3. To describe the reference conditions (environmental variables, macroinvertebrate and macrophyte composition) of pristine Polish stream and river systems;
4. To test whether Polish biological data can be used to describe reference conditions of similar Dutch water bodies.

This report was divided in two parts, each of them including one of the main goals. Part one describes the reference conditions of the Polish water bodies. The following research questions were answered:

  a. Which ecological types (groups of samples with comparable species composition) can be distinguished in the Polish data using the macrophyte data?
  b. Which ecological types can be distinguished in the Polish data using the macro-invertebrate data?
  c. Which environmental variables play a major role in the biological variation between ecological types?
  d. Which are the dominant and abundant species in the ecological types?
  e. Which are the indicator species of the ecological types?

In the second part of this report the question whether the data can be used for describing reference conditions of Dutch water bodies is answered, using the following research questions:

  a. Are the Polish water bodies really undisturbed and do they meet the requirements for reference conditions as stated in the AQEM project?
  b. Are values of chemical variables comparable to those of other pristine waters or to target ranges?
  c. Are the samples from the Polish water bodies comparable to the Dutch samples within the AQEM procedure and the standard method used by Dutch water district managers?
  d. Are the species found in Poland also present in Dutch recent or historical data?
  e. How are the Polish water bodies related to the WFD typology?
  f. To which ecological types are samples assigned to and which ecological quality classes do the Polish water bodies get using the Dutch EKOO and stream typology?
  g. Which ecological quality classes do the Polish water bodies get using the Dutch or German AQEM assessment system?
  h. How many of the target species of the Dutch Nature Target Types occur in the Polish data?
  i. How many of the indicator species of the Dutch Nature Target Types occur in the Polish data?
  j. How does the number of rare species in Polish waters relate to this number in Dutch water bodies?

code	site
S1	Dobieszków – spring
S2	Dobieszków - spring’s outflow
S3	Dobieszków II – spring
S4	Imielnik – spring
S5	Imielnik spring’s outflow
S6	Janinów – spring
S7	Janinów - spring outflow
S8	Rochna – spring
S9	Grotniki – spring
S10	Grotniki - spring’s outflow
S11	Acid spring (near Ldzań)
S12	Acid spring' s outflow (near Ldzań)
R1	Jeżówka River
R2	Czarna river
R3	Stobnica stream
R4	Gać River (swamp stream)
R5	Gać River (near Spała)
R6	Sulejów stream
R7	Grabia river
R8	Brodnia river
R9	Rawka - temporair stream
R10	Pilica river (Sulejów)
R11	Pilica river (Maluszyn)
R12	Natural stream in the forest (near Gać)
L1	Lake near Paskrzyn
O1	Rawka oxbow I (connection with river)
O2	Rawka oxbow II
O3	Rawka oxbow III
O4	Grabia oxbow I (Zimne Wody)
O5	Grabia oxbow II
O6	Grabia oxbow III (with culvert)
O7	Pilica small oxbow
O8	Pilica large oxbow, site 3, far from river
O9	Pilica large oxbow, site 2, middle
O10	Pilica large oxbow, site 1, near river

Part A: Characterisation of Polish stream and river systems

2 Methods

2.1 Sampling sites

In May 1998 potential sampling sites (rivers, streams and oxbow lakes) were visited and evaluated concerning their naturalness. The sites that were selected for this research were the ones with the highest expected ecological quality. They are listed in Appendix 1. The selected sites are situated in the catchments of the rivers Grabia, Czarna, Gać, Rawka and Pilica. All sites are located south of Łódź in central Poland (figure 2.1, map of the area). One isolated lake (not an oxbow lake) was selected (L1). Because this lake was the only one in its type, it was not included in all analyses. In Appendix 5 the macroinvertebrate composition is given, and Appendix 13 includes the environmental variables.

Figure 2.1 Sampling area.

2.2 Sampling strategy

Each sampling site was visited twice (1998-2000), once in spring and once in autumn, to get a representative picture of the macro-invertebrate community. In spring, April and May were preferred as these months are the most ideal sampling months; in autumn, September and October were preferred. Most samples were taken in these months, however it was not possible to visit all sites during these months. Sampling dates are included in Appendix 1 for each sampling site. One vegetation survey was carried out at each of the sampling sites in spring 1999.
At each site first a drawing was made of the site, including the exact sampling points and the main structures and substrates. Then, a macroinvertebrate sample, a water sample and a water bottom sample were taken. The field form (Appendix 2) was completed.

2.3 Macroinvertebrate sampling

Macro-invertebrate samples were taken according to the standard Dutch method, to make data between the two countries comparable. Before samples were taken, 25-50 m stretches along linear waters or banks of lakes, or the total circumferences of small lakes and ponds area were studied concerning the distribution of the different habitats/substrates present. This careful pre-sampling procedure was necessary for obtaining a representative sample. This approach resulted in a schematic picture of the major habitats present, e.g., stands of macrophytes, leaf packets, and bare sandy bottoms et cetera (for an example see Appendix 2). At each sampling site it was attempted to compose the sample by combining sub-samples which were taken in proportion to the various habitats present as estimated from the schematic picture. A subsample was taken in each habitat to collect as many species as possible. So, the total sample represented the observed environment. In the large Pilica oxbow 3 sampling sites were chosen and sampled separately, O8, O9, and O10.

A macroinvertebrate bottom sub-sample was obtained by placing the pond net (mesh size 0.5 mm, frame height 20 cm, and frame width 25 cm) on the bottom and, facing upstream in running waters, sampling the substratum (sometimes including some of the standing lower parts of the vegetation) direct in front. The pond net was pushed, with short quick movements, through the upper centimetres of the substratum and then swept back immediately above the sampled area.

Sub-samples from bank, emergent, floating and/or submerged vegetation were obtained by sweeping the pond net several times through that part of the vegetation. At each sampling site all major habitats were sampled in this way. A stretch of about 0.5-1 m was sampled in every major habitat, so the total combined sample comprised about 1.25 m^2. In small waters, the sample could not be composed of separate vegetation and bottom sub-samples, so only one combined sample was taken.

In the deeper parts (depths of more than 1 to 2 m) of large waters an Ekman-Birge sampler was used, with which two grab samples were taken at each site. In deep waters the grabs substituted one 0.5 m length of a pondnet bottom sub-sample.

In helocrene springs the pond net could not be used and here the micro-macrofauna shovel was used (Tolkamp 1980). This shovel is 10 cm wide and 15 cm long, which makes it possible to sample small-scale mosaic substrate patterns. Subsamples were taken to a sediment depth of 3 cm.

All samples were washed in a bucket, taken to the laboratory and stored in a refrigerator (at 8^{o}C) while they were aerated. In the next few days the samples were carefully processed in the laboratory, while most of the animals were still alive. A sample was first sieved using three sieves (4.0, 1.0, and 0.2 mm mesh sizes) and then placed in white, flat-bottomed trays from which the animals were sorted by eye. If a taxon was present in large numbers, a representative part (large and small individuals) was removed and the remaining part was estimated.

The collected individuals were conserved in ethanol (70 %) except for oligochaetes and water mites which were conserved in formalin (4 %) and Koenike-fluid, respectively.

Macroinvertebrates were mostly identified to species level, however this was not possible for all groups (table 2.1), because taxonomical knowledge for some groups is still not well developed. Other problems concerned individuals that were too small to identify. These were also identified on a higher taxonomic level.

Table 2.1 Identification level for macroinvertebrate groups.

taxonomic group	identification level			taxonomic group	identification level		
	species	genus	family		species	genus	family
Porifera	*			Psychodidae		*	
Coelenterata		*		Ptychopteridae		*	
Bryozoa	*			Chaoboridae			
Tricladida				Dixidae			
Oligochaeta	*			Culicidae			
Gastropoda	*			Simuliidae	*		
Bivalvia	*			Chironomidae: Tanypodinae	*		
Crustacea	*			Chironomidae: Diamesinae	*		
Odonata	*			Chironomidae: Orthocladiinae		*	
Hydracarina		*		Chironomidae: Chironomini	*		
Hirudinea	*			Ceratopogonidae			
Crustacea	*			Thaumaleidae			
Arachnidae	*			Stratiomyidae			

taxonomic group	identification level			taxonomic group	identification level		
	species	genus	family		species	genus	family
Heteroptera	*			Empididae			
Plecoptera	*			Tabanidae			
Ephemeroptera	*			Athericidae			
Trichoptera	*			Rhagionidae			
Megaloptera	*			Syrphidae		*	
Neuroptera	*			Ephydridae			
Coleoptera	*			Sciomyzidae			
Lepidoptera		*		Scatophagidae			
Tipulidae		*		Muscidae		*	
Limoniidae	*						

2.4 Vegetation survey

A vegetation survey was done once at each sampling site. Hydrophytes and helophytes were included. Bank vegetation was also included. This is especially important for determining the different succession stages of the oxbow lakes and the naturalness of the stream banks. Inventories were made along a stream stretch or along a few transects of an oxbow lake (by crossing it by boat). The abundances of the species were estimated using Tansley classes and later transformed into numerical classes (Table 2.2). In each water body, the different patches (combinations of plants) were investigated by selecting several stretches or transects. The number of stretches or transects depended on the homogeneity of the vegetation. One species list of the stretches was made using the maximum abundance class of the species listed.

Table 2.2 Translation of Tansley classes into numerical abundance classes.

abundance class	Tansley-class	
1	r	rare (some individuals)
2	o	occasionally (few individuals)
3	lf	locally frequent (locally many individuals, low coverage)
4	f	frequent (many individuals, low coverage)
5	la	locally abundant (locally many individuals, < 50% coverage)
6	a	abundant (many individuals, < 50% coverage)
7	ld	locally dominant (locally > 50% coverage)
8	cd	co-dominant (together with one or more species > 50% coverage)
9	d	dominant (> 50% coverage)

2.5 Environmental variables

A drawing was made of each sampling site. All visible habitats and physical structures were drawn as well as all sampling points (macroinvertebrates as well as water and bottom samples) (Appendix 2).

Table 2.3 Variables measured or classified in the field.

physical/chemical data	unit	water body and surroundings	unit
water temperature	°C	profile - length natural	0/1
air temperature	°C	profile - transversal natural	0/1

width	m	shading - left bank	0/1
depth	cm	shading - right bank	0/1
current velocity	m/s	forest	0/1
pH		grassland	0/1
electric conductivity	microS/cm	wooded bank	0/1
dissolved oxygen	mg/l	weir	0/1
oxygen saturation	%	cleaning	0/1
sapropelium thickness	cm	bank consolidation	0/1
		dredging	0/1
		no anthropogenic influence	0/1
		permanent	0/1
		seepage	0/1
		transparency clear	0/1

Some chemical and physical environmental variables were measured directly in the field together with the macroinvertebrate sampling (Table 2.3). Field recorders were used to measure oxygen content and saturation, electrical conductivity, current velocity and pH. A standard data form was used to note these variables in the field (Appendix 2). Additionally, the % coverage of the different substrata and vegetation types (Table 2.4) was noted on the field form.

Table 2.4 Habitat (substrate and vegetation) types (for each type the % coverage was given and the sampled area (m^2) and sampling method (pond net, Ekman-Birge grab or micro-macrofauna shovel) were noted).

substrate types	vegetation types
gravel	floating vegetation
sand	submerse vegetation
peat	emergent vegetation
clay	bank vegetation
silt	algae
detritus	
branches	
twigs	
roots	
leaves	
tree	
fine detritus	
sand with silt	
sand and stones	
stones	

Water samples were taken at the same time as the macroinvertebrate sample. The water sample was taken in the middle of the oxbow lake/stream and in the middle of the water column. The bottle was filled and closed under water if possible. The water samples were fixed immediately in the field by adding $HgCl_2$ and were frozen later. Analyses were conducted by generally following the prescriptions of the Dutch Normalisation Institute. Chemical variables measured are included in Table 2.5.

Table 2.5 Chemical variables analysed in the water samples.

variable	unit
ammonium	mg $N(NH_4)$/l
nitrate	mg $N(NO_3)$/l
chloride	mg Cl/l
sulphate	mg SO_4/l
iron	mg Fe/l
calcium	mg Ca/l
magnesium	mg Mg/l
potassium	ppm K/l
natrium	ppm Na/l
alkalinity	mval/l

bicarbonate	mg HCO_3/l
ortho-phosphate	mg o-PO_4/l
total phosphates	mg PO_4/l
BOD_5	mg O_2/l

At each sampling site a bottom sample was taken for grain size analysis. In streams, springs and rivers a sample was taken from each bottom habitat. In oxbow lakes the soil in the Ekman-Birge sampler was described, e.g., sand, black mud, et cetera.

2.6 Clustering and ordination

To analyse similarity in species composition between sites, clustering and ordination were carried out. The goal of clustering is to divide samples in groups with samples of similar species composition. Clustering gives insight in the structure of the community and the extent of similarity between sites. Clustering of macrophyte and macroinvertebrate data was done with the program FLEXCLUS (Van Tongeren 1986), using similarity ratio's. Of each clustering a table of cluster characteristics is given. These tables include:

- The average resemblance: This is the similarity between the samples within a cluster;
- Most similar to cluster: Gives the cluster that is most similar to the cluster;
- Resemblance: The similarity of the cluster with the most similar cluster;
- Isolation: Average resemblance divided by the resemblance to the most similar cluster. The higher this value, the more distinct the cluster is.

To analyse the relation between the macroinvertebrate assemblage and environmental variables an ordination analysis was carried out. Ordination was not carried out for the vegetation data. Ordination situates samples in a multidimensional space. The first two axes of this space are most important and can be illustrated in an ordination diagram. Samples that are similar are close to each other, samples that are different are far from each other in the diagram. Using direct gradient analysis environmental variables can be linked to the species composition of the samples. The most important environmental variables are given as arrows in the ordination diagram. The direction in which the arrow of a variable points is the direction in which the environmental variable has the highest value. The length of the arrow determines the extent to which the environmental variable explains the variation in the species data. To get a better insight in the data the ordination can be repeated by excluding the most different samples (these are situated at the edges of the ordination diagram). Then, the differences between the samples that are more similar become more explicit. Ordination was done with the program CANOCO, using Canonical Correspondence Analysis (Ter Braak & Šmilauer 2002).

To be able to unambiguously analyse the macroinvertebrate data taxonomic adjustment was needed to avoid overlap of taxa of different taxonomic levels. For vegetation, taxonomic adjustment was not necessary because almost all plants were identified to species.

Additionally, further selection of environmental variables was carried out.

2.6.1 Taxonomic adjustment

To adjust the macroinvertebrate data taxonomically, two matrices were made: one with taxa in streams/springs/rivers and their average abundance of two samples at one site, and one with taxa in oxbow lakes and their average abundance of two samples per site.

The data were ordered to taxonomy. To avoid overlapping taxa in the data (for example a genus and two species within the genus) taxa were changed in a taxon at a higher level or the higher level taxon was deleted. There were some basic rules:

- A genus and one species within the genus at a site: the species level was changed into the genus level;

- The higher level was found at the same site as several taxa at a lower level: the higher level was excluded;
- The higher level was found at other sites than the lower level: (1) if the higher level was found at only one or two sites, than the higher level was excluded, (2) if the higher level was found at many sites, the taxa of the lower level were added to higher level (depended also on the number and abundances of the species and their ecological relevance);
- Species and groups/aggregates were added;
- Larvae/nymphae and adults were added to one taxon.

The results of taxonomic adjustment are included in Appendices 3, 4, and 5 for springs, streams and rivers, and oxbow lakes, respectively.

2.6.2 Environmental variables

Some environmental variables were adjusted because they were not expressed as one value but in a range or by more than one value. In these cases the average was taken.

Some variables were excluded from the data before ordination analysis because they contained no information (there were no differences between sites) (Tables 2.6 and 2.7 for oxbow lakes and springs/streams/rivers, respectively). It mainly concerned substrate classes which did not occur and human influences (which were not present at most sites).

With the environmental variables left, a first ordination analysis was carried out. In this analysis the correlation between variables was studied. Variables that correlated with others were excluded from the next analyses (Table 2.6 and 2.7). This was necessary because the number of variables was larger than the number of samples, which negatively influences the further analyses.

Table 2.6 Deleted variables from oxbow data (The samples from the lake were excluded).

variable	reason for exclusion
detritus	always 0
gravel	always 0
peat	always 0
clay	always 0
branches	always 0
twigs	1% at one site
roots	always 0
leaves	always 0
tree	always 0
fine detritus	always 0
sand with silt	always 0
sand & stones	always 0
wet soil	always 0
stones	always 0
silt & stones	always 0
current velocity	always 0
seepage	always 0
weir	always 0
cleaning	always 0
bank consolidation	always 0
dredging	always 0
length profile natural	always 1
transversal profile natural	always 1
non anthropogenic influence	always 1
transparency clear	always 1, except for one sample
shade left, shade right	added in one category: shade
permanent	always 1
Ca	correlation with HCO_3 and alkalinity (0.81 and 0.80 respectively)
HCO_3	correlation with alkalinity (0.99)

o-PO_4	correlation with PO_4 (0.99)
O_2 %	correlation with O_2 concentration (0.96)
minimum depth	correlation with maximum depth (1.00)
minimum width	correlation with maximum width (0.97)
grassland	correlation with pH and forest (0.83 and 0.77 respectively)

Table 2.7 Environmental variables deleted from the running water data set.

variable	reason for exclusion
maximal depth	= minimal depth
peat	always 0
clay	always 0
algae	1% in one sample
silt & stones	1% in one sample
gravel, stones	added in one category: gravel/stones
roots, twigs, branches, tree	added in one category: roots/twigs/branches/tree
fine detritus	only in one sample, added with detritus, R3 October
wet soil	only in one sample, 40 %, half with sand and half with silt, R12 May
floating vegetation	only 1% in two samples
dredging	always 0
weir	always 0
cleaning	always 0
sand & stones	one sample 5 %, R7 June, half with sand, half with stones
bank consolidation	only one site, R1
profile length natural	always 1, except for R1
profile transversal natural	always 1, except for R1
non anthropogenic influence	always 1, except for R1
permanent	always 1, except for R9
shade left, shade right	are added together in one category: shade
HCO_3	correlation with Ca (0.90), alkalinity (0.90), EC (0.85), pH (0.89)
Ca	correlation with HCO_3 (0.90), alkalinity (0.81), pH (0.85), EC (0.90)
EC	correlation with HCO_3 (0.85), Ca (0.90), O_2 % (0.93), O_2 concentration (0.89), pH (0.82)
O_2%	correlation with O_2 concentration (0.95)

2.7 Characterisation of the clusters

The site groups (clusters) were characterised by the species composition. Three aspects were analysed: the dominant taxa, the abundant taxa and the indicator taxa in each cluster.

Dominant taxa are those taxa that have an abundance of more than 10% of all individuals in the sample and abundant species have an abundance of more than 5 % of all individuals in the sample.

Indicator species were determined by calculating an indicator weight for each taxon for a cluster using constancy, fidelity and concentration of abundance (Boesch 1977; Verdonschot 1984). Constancy is defined as the number of occurrences of a taxon in a community type divided by the number of sites in the community type. Fidelity is the degree to which a taxon prefers a community type, defined as the ratio of the relative frequency of a taxon in a community type and its overall relative frequency. Concentration of abundance is the average abundance of a taxon in a community type divided by its average overall abundance. Constancy, fidelity and concentration of abundance were combined to assign an indicator weight to a taxon per community type according to the values given in Table 2.8. The indicator weight related to the combination of the three characteristics was extracted from this table by checking, in order of occurrence, whether each characteristic was in accordance with the limits indicated. For example, if constancy is 0.29, fidelity 5.6 and concentration of abundance 6.2, the indicator weight is 10 (third row in Table 2.8). The indicator weights vary from one to 12 (Verdonschot 1990).

Table 2.8 Indicator weights and categories used. An indicator weight is assigned to a taxon when, in accordance to occurrence from top to bottom in the table, constancy, fidelity and concentration of abundance are all higher than the boundary indicated.

constancy	fidelity	concentration of abundance	indicator weight
> 0.50	> 3	> 5	12
> 0.40	> 4	> 4	11
> 0.25	> 5	> 5	10
> 0.50	> 2	> 4	9
> 0.40	> 3	> 3	8
> 0.25	> 4	> 4	7
> 0.50	> 1	> 3	6
> 0.40	> 2	> 2	5
> 0.25	> 3	> 3	4
> 0.50	> 1	> 1	3
> 0.25	> 1	> 1	2
> 0.00	-	-	1

3 Results

3.1 Springs, streams and rivers

3.1.1 Vegetation clusters

Vegetation data from springs and rivers were clustered together because a high number of species overlapped between these water types. Clustering of the vegetation data from streams and springs resulted in 7 clusters (Table 3.1 and Appendix 6). R1, R10 and R7 were not clustered with other sites. The Grabia (R7) is the only stream that has a high abundance of *Nuphar lutea*. That is why this stream is not clustered with other streams. The other species in the Grabia were also found at other sites. R1 Jeżówka stream has a high density of water plants (*Elodea canadensis*, *Berula erecta* and *Ranunculus circinatus*), which occur in large patches in the stream (Table 3.3). The stream is situated in open grassland and sunlight can easily reach the stream bottom. R10, the Pilica river near Sulejów, a large river has *Potamogeton pectinatus* as the most occurring macrophyte. This species often occurs in large rivers. There were only few water plant species in this river. *Potamogeton crispus,* a species often occurring in large rivers as well was also found in the Czarna river (R2). Because R2 was shallower, more plant species were found. This river was clustered together with some streams and springs in cluster 3, because of the high abundances of *Glyceria fluitans* at all these sites. The other species occurring at these sites vary strongly between the sites and therefore, the average resemblance is relatively low (Table 3.2). This also goes for cluster 4, in which four streams situated in forest area were clustered together. Abundant and indicator species in these streams mainly are bank species, occurring along the streams.

There were two clusters including springs, clusters 6 and 7. Both clusters have a relatively high average resemblance, thus the species composition of the sites within the clusters is comparable. The spring sites in these clusters were very species poor, on average including 3 species per site. Cluster 6 is characterised by the high abundance of *Cardamine amara* and *Berula erecta.* In cluster 7 *Cardamine amara* is lacking. *Berula erecta* is accompanied by *Glyceria fluitans* and *Veronica beccabunga.*

Table 3.1 Springs, streams and rivers included in the vegetation clusters and their species richness.

cluster	sites	total no. of species	mean no. species/sample
1	R1	17	17
2	R10	5	5
3	R2, R6, R8, S2, S4	28	9
4	R3, R4, R5, R9	36	16
5	R7	7	7
6	S10, S3, S8	6	3
7	S5, S6, S7	6	4

Table 3.2 Clusters of vegetation samples from springs, streams and rivers: cluster characteristics (for explanation see paragraph 2.6).

cluster	average resemblance	most similar to cluster	resemblance	isolation
1	1	7	0.223	4.4836
2	1	3	0.0961	10.4038
3	0.4851	7	0.2942	1.6485
4	0.4708	5	0.2447	1.9236
5	1	7	0.3553	2.8143
6	0.6743	4	0.194	3.4752

7	0.703	5	0.3553	1.9785

Table 3.3 Dominant, abundant and indicator taxa in the vegetation clusters of springs, streams and rivers. The numbers that are in brackets are the indicator weights (only indicator taxa with low weights 4-6, moderate weights 7-9 and high weights 10-12 were included). For explanation see paragraph 2.7.

cluster	dominant taxa	abundant taxa	indicator taxa
1	*Elodea canadensis* *Ranunculus circinatus*	*Glyceria maxima* *Phragmites australis*	*Rumex hydrolapathum (6), Galium palustre (5), Sparganium erectum (5), Veronica beccabunga (5)*
2	*Potamogeton crispus* *Potamogeton pectinatus* *Sagittaria sagittifolia* *Sparganium erectum*	*Alisma lanceolatum*	*Sparganium erectum (9)*
3	*Glyceria fluitans* *Myosotis palustres*	*Berula erecta* *Potamogeton crispus* *Sparganium erectum*	
4	*Myosotis palustris*	*Calla palustris* *Caltha palustris* *Cardamine amara* *Galium palustre* *Lemna minor* *Peucedanum palustre*	*Peucedanum palustre (11), Lemna minor (9), Galium palustre (8), Lycopus europaeus (8), Caltha palustris (5)*
5	*Nuphar lutea* *Berula erecta* *Myosotis palustris*	*Caltha palustris*	*Nuphar lutea (12), Caltha palustris (5)*
6	*Berula erecta* *Cardamine amara*	*Carex acutiformis* *Cirsium oleraceum* *Myosotis palustris*	*Cardamine armara (9)*
7	*Berula erecta* *Glyceria fluitans* *Veronica beccabunga*	-	*Veronica beccabunga (8), Berula erecta (6)*

3.1.2 Ordination of macroinvertebrates and environmental variables

First, the total running water dataset, including springs, streams and rivers was used as input in the ordination program. Figure 3.1 shows that springs (S-types) are together in the right site of the diagram and streams and rivers (R-types) in the left part of the diagram. Figure 3.2 shows that the position of the springs is related to the presence of seepage water, shade, detritus, emergent vegetation and twigs. Nitrate concentrations are higher in springs than in streams and rivers. Streams and rivers are deeper and wider, have higher ammonium content, more submerse vegetation and higher current velocity. Because the difference between springs on the one hand and streams and rivers on the other hand is large both datasets were further analysed separately.

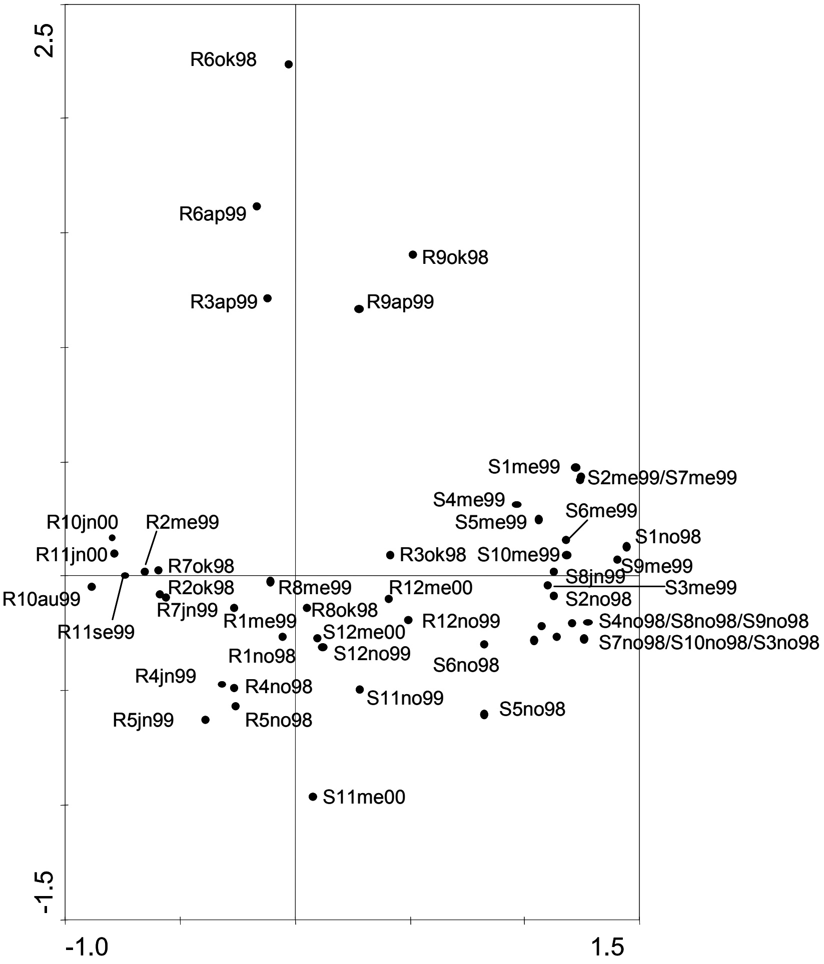

Figure 3.1 Ordination diagram of the macroinvertebrate samples of the total spring, stream and river dataset. For explanation see paragraph 2.6.

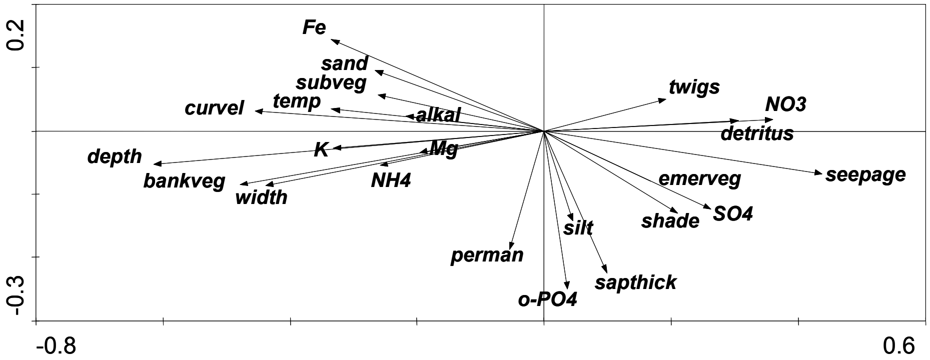

Figure 3.2 Ordination diagram of the environmental variables of the total spring, stream and river dataset (subveg = submerse vegetation, temp = temperature, curvel = current velocity, bankveg = bank vegetation, alkal = alkalinity, perman = permanent, sapthick = sapropelium thickness, emerveg = emergent vegetation).

3.2 Springs

3.2.1 Ordination of macroinvertebrates and environmental variables

Figure 3.3 shows the ordination diagram of the ordination of all spring samples. All samples are close together, their boundaries are drawn in the left of the diagram. S11 and S12, the acid spring near Ldzań and its outflow are outliers. That pH is the main variable is shown by the large pH arrow in the opposite direction indicating a low value for S11. In S12 pH was is higher but this sample differed from the other spring samples because of the relatively high current velocity (Appendix 8). The wooded bank can not alone explain the difference in species composition compared to the other springs, because they were almost all in forested area. Because S11 and S12 were outliers, both sites were removed from the dataset and an additional ordination was carried out.

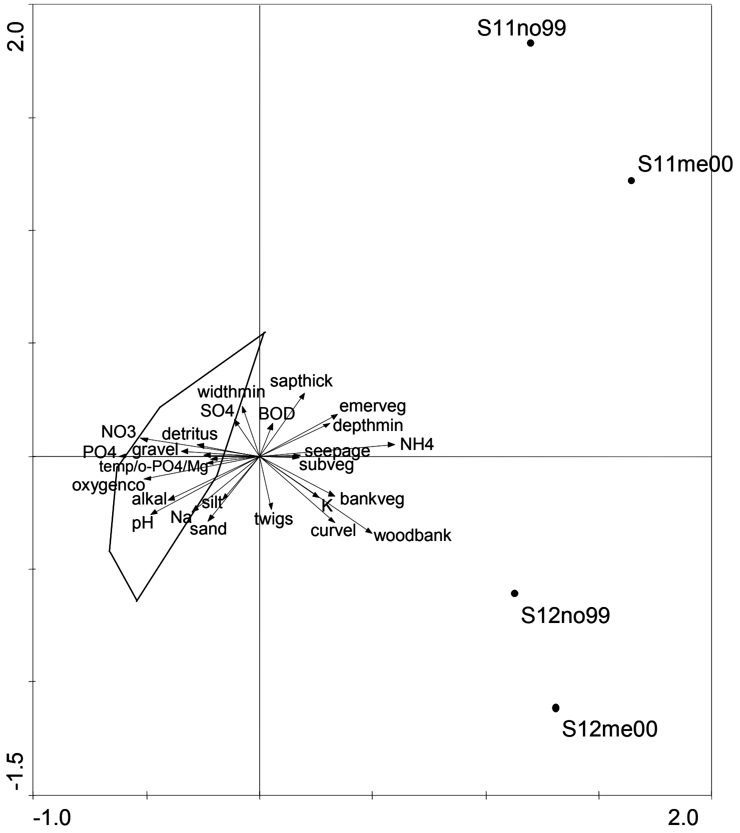

Figure 3.3 Ordination diagram of the total spring dataset: First diagram with all spring samples, without variables Fe, forest, leaves, Cl, and grassland (<0.25 interset correlations, thus not explaining the variation in species data). S11 and S12 are outliers. The other samples are located in the area indicated left in the diagram. (widthmin = minimum width, temp = temperature, oxygenco = oxygen concentration, alkal = alkalinity, curvel = current velocity, woodbank = wooded bank, bankveg = bank vegetation, subveg = submerse vegetation, depthmin = minimum depth, emerveg = emergent vegetation, sapthick = sapropelium thickness. BOD = biotic oxygen demand)

Without S11 and S12 the remaining spring samples were better separated in the ordination diagram (figure 3.4). Remarkable is the separation of spring samples (at the right in the diagram) and autumn samples (in the left of the diagram). This difference in seasons is caused by the environmental variable leaves, which is indicated by the large arrow. Because all but one spring are situated in the forest, leaves accumulate in autumn in the springs and in spring they are flushed away or decayed. Due to the presence of leaves in autumn the macroinvertebrate community differed between both seasons. S4 and S5, Imielnik spring and its outflow are situated in grassland and were therefore projected in the upper part of the diagram. They were characterised by a higher temperature in spring and the presence of emergent and submerse vegetation. The spring samples of S3, S6 and S8 were characterised by silt and a relatively high temperature.

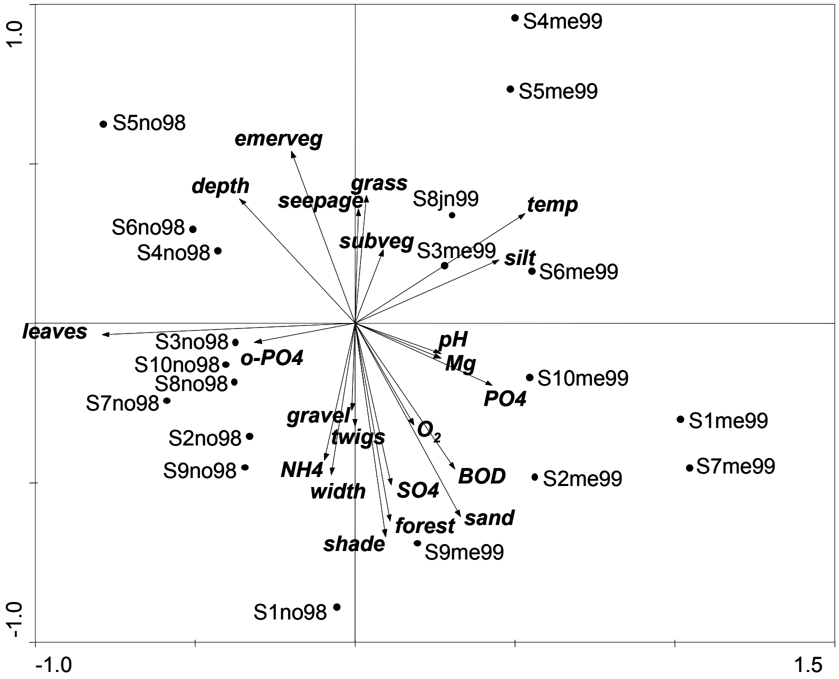

Figure 3.4 Ordination diagram of the spring dataset without sites S11 and S12. The variables Na, Cl, alkalinity, Fe, current velocity, NO3, K, detritus and sapthick were excluded because their interset correlations with both axes were <0.25. (emerveg = emergent vegetation, subveg = submerse vegetation, temp = temperature, BOD = biotic oxygen demand).

The spring samples of S1, S2, S7 and S10 were close to each other in the ordination diagram. They showed high Mg and PO_4 contents. S9, at the same site of the diagram, was characterised by sand, a high SO_4 concentration and a high BOD.

In autumn S1 was projected far from the other samples in the diagram, because of the high width. S2, S3, S7, S8, S9 and S10 are close together, all having accumulation of leaves.

3.2.2 Macroinvertebrate clusters

Six clusters of macroinvertebrate samples of springs and spring outflows were made (Table 3.4, 3.5, Appendix 7). The acid spring (S11) with its outflow (S12) were two separate clusters. Their specific conditions also resulted from the ordination. S11 was characterised by species tolerating acid conditions, e.g. *Lumbriculus variegatus*, an indicator species for this cluster and *Micropsectra sp.*, which were dominant. Larvae of the beetle *Cyphon sp.* are dominant as well. Other common species, which are dominant or abundant in other clusters but lacking in S11 are, for example *Gammarus fossarum, Prodiamesa olivacea* and *Brillia modesta* (Table 3.6).

S12, the outflow of the acid spring was circum neutral and contained a very high number of taxa (Table 3.4) as well as a high number of indicator taxa, probably because of the relatively high current velocity compared to the other spring outflows. Some common species that occur in other clusters were lacking, such as *Dugesia gonocephala*, *Nemurella pictetii* and *Plectrocnemia conspersa* but on the other hand, there were many species only occurring in this cluster, including species of water mites, snails, bivalves and oligochaetes. Remarkable in this cluster is the dominance of *Asellus aquaticus* and *Nemoura sp*. *Gammarus fossarum* which is lacking from the acid spring, was abundant in the springs outflow (Table 3.6).

For S11 and S12, the spring sample was similar to the autumn sample. This is not the case for the other sites, which are mainly divided in one cluster containing the autumn samples (cluster 5) and two clusters containing the spring samples (clusters 1 and 2). In the ordination diagram is also illustrated that in autumn the samples were more similar to each other than the samples taken in springtime. In general, seasonal differences play a major role. Some taxa were only observed in the autumn samples others only in the spring samples. This is due to the life cycles of the taxa. They can for example hide far down in the bottom during winter or be absent from late spring because they are terrestrial in the adult stage. Seasonal differences were less important at the sites S3 and S9, of which spring and autumn samples were together in the same cluster.

Cluster 5, including the autumn samples, had no indicator species which means that the taxa in this cluster are also common in the other clusters and not specific. *Gammarus fossarum* was dominant in clusters 1, 2 and 5 but accompanied by different abundant taxa in the different clusters (Table 3.6). Cluster 2 had more taxa than cluster 1. There were also more indicator taxa, including snails, bivalves, chironomids and a water mite. The autumn sample of S5 (Imielnik spring outflow) was clustered separately (cluster 6). This sample was in the upper left corner of the ordination diagram. This outflow differed from the spring, S4. The number of indicative species is high. This site was the only one with abundant emergent vegetation, which provides a habitat for a high number of species. Characteristic was the high abundance of *Nemurella pictetii* (Table 3.7)

Table 3.4 Clusters of macroinvertebrate samples from springs.

cluster	samples	total no. taxa	mean no. taxa	mean no. individuals
1	S1me99, S2me99, S7me99, S10me99	41	21	529
2	S4me99, S5me99, S6me99, S8jn99	62	33	719
3	S11me00, S11no99	52	31	672
4	S12me00, S12no99	80	57	1719
5	S1no98, S2no98, S3me99, S3no98, S4no98, S6no98, S7no98, S8no98, S9me99, S9no98, S10no98	81	25	1251
6	S5no98	33	33	754

Table 3.5 Clusters of macroinvertebrate samples from the springs: cluster characteristics.

cluster	average resemblance	most similar to	resemblance	isolation
1	0.5525	5	0.5219	1.0586
2	0.6005	5	0.5782	1.0384
3	0.3422	6	0.2025	1.6899
4	0.5997	6	0.2731	2.1963
5	0.5919	2	0.5782	1.0236
6	1	5	0.4902	2.04

Table 3.6 Dominant and abundant taxa in the macroinvertebrate spring clusters.

cluster	dominant	abundant
1	*Gammarus fossarum, Metriocnemus sp*	*Sericostoma sp*
2	*Gammarus fossarum*	*Micropsectra sp, Pisidium personatum*
3	*Cyphon sp larva, Micropsectra sp*	*Chironomus sp, Dixidae, Lumbriculus variegatus*
4	*Asellus aquaticus, Micropsectra sp, Nemoura sp*	*Gammarus fossarum, Microtendipes sp, Pisidium subtruncatum*

5	*Gammarus fossarum, Micropsectra sp*	-
6	*Gammarus fossarum, Microtendipes sp, Nemurella pictetii*	*Brillia modesta, Micropsectra sp*

Table 3.7 Indicator taxa in macroinvertebrate spring clusters.

cluster	indicator
1	*Heleniella ornaticollis (9), Beraea maura (8), Metriocnemus sp (6), Scleroprocta sp (6)*
2	*Anisus spirorbis (12), Galba truncatula (11), Pisidium personatum (9), Rheocricotopus sp (9), Lebertia stigmatifera (8), Heterotrissocladius marcidus (6), Prodiamesa olivacea (6)*
3	*Chironomus sp (12), Dixidae (12), Lumbricidae (12), Ilybius sp larva (9), Enchytraeidae (8)*
4	*Apsectrotanypus trifascipennis (12), Asellus aquaticus (12), Empididae (12), Lype sp (12), Nemoura sp (12), Pisidium milium (12), Pisidium subtruncatum (12), Procladius sp (12), Sperchon squamosus (12), Potamothrix hammoniensis (11), Tonnoiriella sp (9), Ilybius sp larva (8), Tubifex tubifex (8), Chaetopteryx sp (6), Microtendipes sp (6), Trissopelopia sp (6), Zavrelimyia sp (6), Galba truncatula (5), Heterotrissocladius marcidus (5)*
5	-
6	*Athericidae (12), Eukiefferiella sp (12), Tonnoiriella sp (11), Corynoneura sp (8), Sialis fuliginosa (8), Simulium angustitarse (8), Sperchon glandulosus (8), Brillia modesta (6), Dugesia gonocephala (6), Microtendipes sp (6), Nemurella pictetii (6), Ilybius sp larva (5), Prionocyphon serricornis larva (5), Procladius sp (5)*

3.2.3 Biotic characterisation

In most springs the majority of the taxa are rheobionts (Table 3.8). Probably these animals need good oxygen conditions or a low temperature, rather than a high current velocity. In most of the springs current velocity was low. Second were the ubiquistic species, which are not strictly bound to a certain environment. In Imielnik spring and its outflow (S4 and S5) ubiquists were found in relatively high numbers in springtime, in the Janinów spring (S6 and S7) in autumn.

Table 3.8 Number of taxa in each current velocity class for springs (for each sample, the class with the highest number is shaded).

sample	no. taxa in each current velocity preference class					
	limnobiont	limnophilous	ubiquist	rheophilous	rheobiont	unknown
S1me99	0	1	2	0	8	11
S1no98	1	0	1	1	5	11
S2me99	0	0	5	0	10	9
S2no98	0	3	3	4	9	13
S3me99	0	0	5	0	7	9
S3no98	0	1	5	3	9	15
S4me99	0	1	6	1	3	13
S4no98	0	1	3	1	7	6
S5me99	0	1	9	1	9	9
S5no98	0	1	5	3	13	12
S6me99	0	1	5	2	12	13
S6no98	0	2	10	3	7	5
S7me99	0	0	4	1	7	7
S7no98	0	1	9	3	8	13
S8jn99	2	4	7	3	14	23
S8no98	0	1	6	3	14	17
S9me99	1	0	3	2	8	6
S9no98	0	2	2	2	7	16
S10me99	1	1	2	2	7	7
S10no98	0	0	2	3	6	6
S11me00	15	9	7	3	2	16

S11no99	4	2	4	0	2	6
S12me00	2	8	13	3	7	29
S12no99	3	7	16	4	6	31

S11 and S12 (acid spring near Ldzań and its outflow) had few rheobionts, they were characterised by limnobionts and ubiquists respectively, probably caused by the acid conditions in S11. S12 had a relatively high current velocity and although the number of rheobionts was higher than in S11 it is much lower than in other springs with lower current velocity, e.g. S8 (Rochna spring).

Remarkable is that omnivores were the main part of the macroinvertebrate community in springs (Table 3.9). In autumn the percentage of omnivores was larger than in spring. The high percentage of omnivores was caused by the dominance of *Gammarus fossarum,* an omnivorous species. In S5, Imielnik springs outflow, herbivores occurred in high numbers, probably this is linked to the high coverage of emergent and submerse vegetation. In S6, Janinów spring, the highest percentage was reached by detriti-herbivores in autumn. Detriti-herbivores were also dominant in S11 (autumn) and S12 (acid spring and outflow). Carnivores were dominant in one sample, the spring sample of S11. This was probably caused by the beetle *Cyphon sp*., which occurs in high abundance.

Table 3.9 Percentage of individuals in each trophic class for spring samples (the highest value for each sample is shaded).

	% individuals						
	carnivore	detritivore	detriti-herbivore	herbivore	omnivore	predator	unknown
S1me99	3	17	1	z	66	0	12
S1no98	0	0	1	0	97	0	2
S2me99	23	27	3	2	32	0	13
S2no98	10	11	14	3	45	0	17
S3me99	10	12	12	7	48	0	12
S3no98	4	14	16	2	50	0	14
S4me99	1	1	6	12	68	0	12
S4no98	15	0	5	1	73	0	7
S5me99	7	7	12	42	26	0	6
S5no98	6	6	24	15	44	0	6
S6me99	11	7	16	13	42	0	11
S6no98	3	1	56	0	40	0	1
S7me99	1	3	0	1	70	0	25
S7no98	9	25	9	7	41	0	9
S8jn99	6	6	29	12	31	0	16
S8no98	2	4	32	0	55	0	7
S9me99	2	43	2	1	49	0	3
S9no98	4	21	5	5	46	0	20
S10me99	3	17	7	1	58	0	14
S10no98	16	6	17	4	32	0	25
S11me00	40	11	36	0	0	0	13
S11no99	5	15	56	0	0	0	23
S12me00	13	19	40	10	8	0	10
S12no99	13	13	42	12	10	0	11

The saprobic class preference of most species in the spring samples is unknown (Table 3.10). Therefore, no valid conclusions could be drawn only an indication is given. In most springs the highest percentage of individuals indicated an oligo-saprobic or oligo-β-saprobic environment. A more saprobic environment was only present in S11 and S12, there the percentages of individuals indicating a more saprobic environment were higher, probably because of the presence of acidity tolerant species and ubiquists, which are often also tolerant for more saprobic conditions.

Table 3.10 Percentage of individuals in each saprobic class for spring samples (the highest value for each sample is shaded).

	% individuals in each saprobic class						
sample	poly-saprobic	α-saprobic	β-saprobic	meso-saprobic	oligo-β-saprobic	oligo-saprobic	unknown
S1me99	0	0	1	0	6	17	77
S1no98	0	0	0	0	0	0	100
S2me99	0	1	0	0	5	39	55
S2no98	0	0	8	0	7	10	75
S3me99	0	5	1	1	7	13	73
S3no98	0	0	0	1	3	5	90
S4me99	0	0	0	4	2	1	93
S4no98	0	0	0	3	1	15	80
S5me99	0	2	1	1	6	15	75
S5no98	0	0	2	13	10	26	49
S6me99	0	1	2	0	6	17	75
S6no98	0	0	3	0	51	1	45
S7me99	0	0	0	0	22	3	75
S7no98	2	0	0	3	5	15	74
S8jn99	0	1	5	0	19	8	66
S8no98	0	0	1	0	31	3	65
S9me99	0	0	0	0	0	14	85
S9no98	0	0	0	0	2	8	90
S10me99	1	0	1	0	1	18	77
S10no98	0	0	9	0	5	5	81
S11me00	12	12	0	1	26	0	48
S11no99	6	7	0	0	56	0	30
S12me00	0	15	17	12	18	3	35
S12no99	1	14	24	6	9	1	45

Taxa richness of the springs was low (Table 3.11) compared to streams, rivers and oxbow lakes Most of the springs had many Chironomidae taxa, followed by other Diptera and Trichoptera. Only S11 was different, there many Coleoptera taxa occur, probably they were tolerant for acid conditions.

Table 3.11 Number of taxa in each taxonomic group for stream and river samples (for each sample, the group with the highest number of taxa is shaded).

	total no. taxa	Acarina	Bivalvia	Chironomidae	Coleoptera	other Diptera	Ephemeroptera	Gastropoda	Heteroptera	Hirudinea	Lepidoptera	Malacostraca	Megaloptera	Odonata	Oligochaeta	Plecoptera	Trichoptera	Turbellaria	other
S1me99	21	0	1	4	2	4	0	0	0	0	0	1	0	0	2	1	5	1	0
S1no98	19	0	0	1	3	6	0	0	0	0	0	1	0	0	2	0	5	1	0
S2me99	24	3	1	5	0	5	0	0	0	0	0	2	0	0	2	1	5	0	0
S2no98	32	1	1	12	2	8	1	0	0	0	0	1	0	0	1	0	4	1	0
S3me99	20	0	3	5	1	3	0	0	0	0	0	1	1	0	0	1	5	0	0
S3no98	32	3	0	10	2	6	0	0	0	0	0	2	1	0	1	1	5	1	0
S4me99	24	1	3	8	1	3	0	2	0	0	0	1	0	0	0	1	4	0	0
S4no98	18	1	0	8	2	1	0	0	0	0	0	1	0	0	0	2	2	1	0
S5me99	29	1	3	10	1	4	0	2	0	0	0	1	0	0	0	1	4	2	0
S5no98	34	3	0	15	3	5	2	0	0	1	0	1	1	0	0	1	1	1	0
S6me99	33	3	1	13	0	7	0	1	0	0	0	1	0	0	0	1	5	1	0
S6no98	27	3	0	8	1	4	0	0	0	0	0	1	0	0	3	1	3	3	0
S7me99	19	0	1	7	0	6	0	0	0	0	0	1	0	0	0	0	4	0	0
S7no98	34	1	0	10	2	8	0	0	0	0	0	2	1	0	5	1	4	0	0
S8jn99	51	4	2	15	1	15	0	3	0	0	0	1	0	0	1	1	7	1	0
S8no98	41	3	0	11	1	11	0	0	0	0	0	1	1	0	3	2	7	1	0
S9me99	20	0	0	7	1	4	0	0	0	0	0	1	0	0	0	1	5	1	0

S9no98	28	1	0	8	4	7	2	0	0	0	0	1	0	0	0	1	3	1	0
S10me99	19	0	1	7	1	4	0	0	0	0	0	1	0	0	0	0	4	1	0
S10no98	17	1	0	5	0	4	0	0	0	0	0	1	0	0	1	2	3	0	0
S11me00	50	1	0	10	23	4	0	0	4	0	0	1	0	2	3	0	1	1	0
S11no99	18	0	0	5	5	3	0	0	0	0	0	0	0	0	3	1	0	1	0
S12me00	59	4	5	14	4	7	0	1	2	1	0	2	1	0	5	1	11	0	1
S12no99	65	6	2	18	5	7	2	3	0	4	0	2	1	0	5	3	6	1	0

3.3 Streams and rivers

3.3.1 Ordination of macroinvertebrates and environmental variables

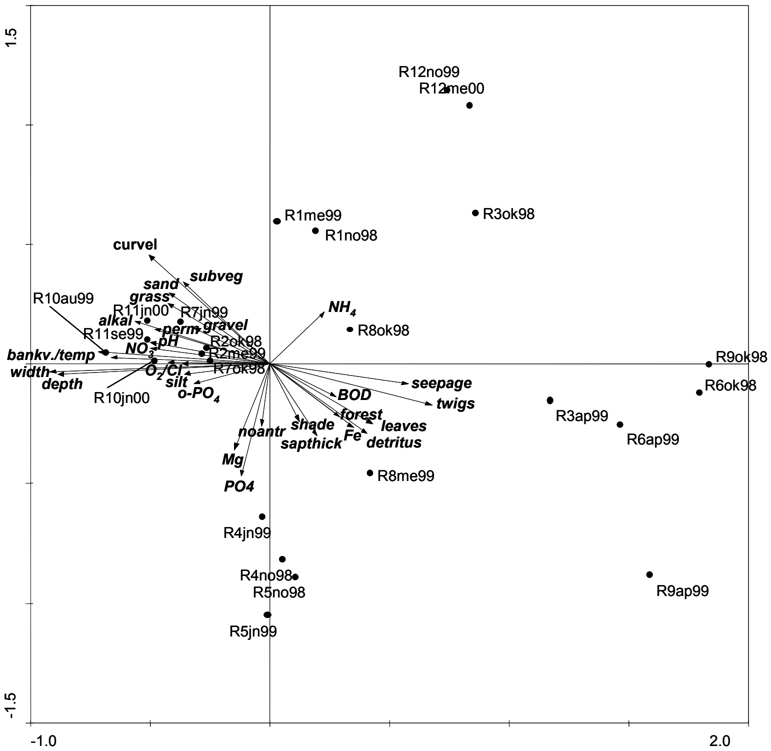

Figure 3.5 Ordination diagram of the total stream dataset. First diagram with all stream samples, without variables SO4, Na, wooded bank, clear, K, emergent vegetation. (curvel = current velocity, BOD = biological oxygen demand, sapthick = sapropelium thickness, noantr = no anthropogenic influence, bankv = bank vegetation, perm = permanent, subveg = submerse vegetation, alkal = alkalinity).

Ordination of the stream and river data was done in two steps. First all data were included. The results are shown in figure 3.5. It appeared that the streams R3, R6, R9 and R12, which are all small streams in forested area, are most right in the diagram. Environmental variables that explained the different species composition at these sites were the presence of seepage, twigs, leaves and detritus. Because R6 and R9 were situated far from the other sites in the diagram an additional analyses was carried out without these sites to be able to better explain the differences between the other sites. R9 is a small stream in the forest near the river Rawka. The stream is intermittent and falls dry in summer. Therefore, the species composition differed from all other streams. R6 is a small stream near the Pilica river. This stream has a characteristic environment as well, because it is very small and had an almost complete coverage with leaves.

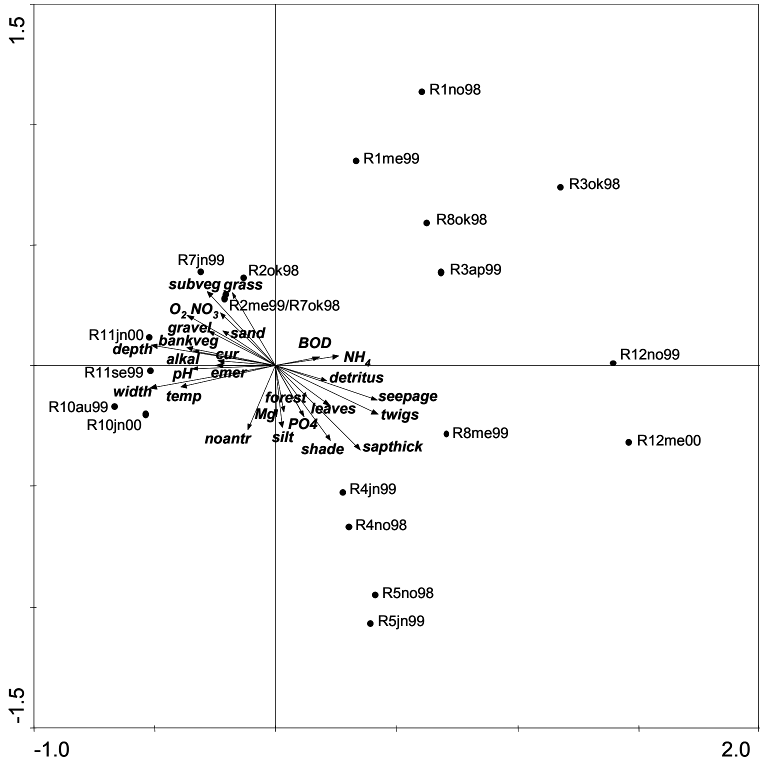

Figure 3.6 Ordination diagram of the stream dataset, R6 and R9 excluded. Second diagram without R6 and R9 (outliers) and variables clear, Na, SO4, K, Fe, wooded bank, permanent, Cl excluded (<0.25 interset correlations). (cur = current velocity, BOD = biological oxygen demand, sapthick = sapropelium thickness, noantr = no anthropogenic influence, bankveg = bank vegetation, subveg = submerse vegetation, alkal = alkalinity, emer = emergent vegetation)).

The second ordination diagram (Figure 3.6) shows that in general, the two samples from one site are positioned together, meaning that differences between two seasons at one site were smaller than the differences between sites in one season.

Both sites in the Gać river are close to each other (R4 and R5). They were characterized by a relatively thick sapropelium layer, silt and shade. Both sites had a low current velocity and were in forested area. The phosphate concentration was high.

Also, sites R10 and R11, both in the Pilica river are similar. This river is wide and deep and had a high pH and alkalinity. The Czarna river and the Grabia river (R2 and R7, respectively) are also large rivers but they had a lower pH and alkalinity than the Pilica river.

R1, the Jeżówka river was clearly separated from the others. This small river is situated in an open grassland area and contained abundant submerse vegetation. R12, the forest stream near the Gać river was also different from the others, characterised by a high coverage of leaves and detritus. This stream had a high current velocity (Appendix 10) but this is not visible in the ordination diagram. R3 is also a small forested stream, similar to R12. Only, R3 is much deeper and had a low current velocity compared to R12.

R8, the Brodnia river is a grassland river with a wooded bank. The difference between the two samples from this stream was highest, although differences in environmental variables between seasons were small, even the water temperature (Appendix 10).

3.3.2 Macroinvertebrate clusters

In general, the clusters relate to the ordination diagram. Sites that were close together in the diagram are clustered together. R8 falls apart in two clusters, but the differences between two seasons were large, as was already mentioned.

Six clusters could be described from the macroinvertebrate samples of streams and rivers (Tables 3.12 and 3.13, Appendix 9). The largest cluster (no. 1) includes the large streams and rivers: Grabia, Pilica, Czarna and the spring sample of the Jeżówka stream. The autumn sample of the Jeżówka is in cluster 2, together with the forest stream near the Gać river and the autumn samples of Stobnica stream and Brodnia river. Probably, the presence of leaves and detritus in these streams in autumn causes the clustering with the forest stream. The third cluster includes both samples of the Sulejów stream, a very small forest stream in the Pilica catchment and the spring samples of the Stobnica stream and the Rawka forest stream. Both sites of the Gać river, a wide river with many side channels and islands are clustered together in cluster 5. Two samples were not grouped with others: the autumn sample of the Rawka forest stream and the spring sample of the Brodnia river. Both samples are characterised by a small number of taxa (the mean value is only half of the value in other samples, Table 3.12) and only few indicator taxa (Table 3.15).

Table 3.12 Clusters of macroinvertebrate samples from streams and rivers.

cluster	samples	total no. taxa	mean no. taxa	mean no. individuals
1	R1me99, R2me99, R2ok98, R7jn99, R7ok98, R10au99, R10jn00, R11jn00, R11se99	351	115	9584
2	R1no98, R3ok98, R8ok98, R12me00, R12no99	130	47	3299
3	R3ap99, R6ap99, R6ok98, R9ap99	97	46	845
4	R9ok98	22	22	1127
5	R4jn99, R4no98, R5jn99, R5no98	140	66	2364
6	R8me99	23	23	596

Table 3.13 Clusters of macroinvertebrate samples from streams and rivers: cluster characteristics.

cluster	average resemblance	most similar to	resemblance	isolation
1	0.4247	5	0.4033	1.0531
2	0.3985	5	0.3366	1.1838
3	0.4102	2	0.2912	1.4089
4	1	3	0.2427	4.12
5	0.5358	1	0.4033	1.3286
6	1	2	0.2949	3.3904

The large streams and rivers of cluster 1 were characterised by a high density of *Simulium erythrocephalum* and *S. morsitans*. Cluster 5, the Gać river cluster, *Aulodrilus pluriseta* was the dominant species (Table 3.14). This is probably due to the slow flow and the presence of much soft sediment in which this species lives. In all other clusters *Gammarus fossarum* was the dominant species, sometimes co-dominant with other species, in most cases Chironomidae or *Pisidium sp.* In cluster 3, the stonefly *Nemoura sp.* was dominant and in cluster 5 the mayfly *Caenis rivulorum* was an abundant taxon.

Table 3.14 Dominant and abundant taxa in the macroinvertebrate stream and river clusters.

cluster	dominant taxa	abundant taxa
1	*Simulium erythrocephalum, Simulium morsitans*	-
2	*Gammarus fossarum*	*Micropsectra sp, Polypedilum sp*
3	*Gammarus fossarum, Nemoura sp, Pisidium personatum*	-
4	*Gammarus fossarum, Pisidium personatum*	-

5	*Aulodrilus pluriseta*	*Caenis rivulorum, Microtendipes sp, Pisidium*
6	*Gammarus fossarum, Odontomesa fulva, Tanytarsus sp*	*Apsectrotanypus trifascipennis, Paratendipes sp*

Table 3.15 Indicator taxa in macroinvertebrate stream and river clusters.

cluster	indicator taxa
1	*Ablabesmyia monilis (5), Agabus sp larva (5), Albia stationis (5), Anabolia furcata (5), Ancylus fluviatilis (5), Aphelocheirus aestivalis (5), Athericidae (5), Atractides nodipalpis (5), Baetis buceratus (5), Baetis gr fuscatus (5), Baetis rhodani (5), Brachycentrus subnubilus (5), Brachycercus harrisella (5), Caenis pseudorivulorum (5), Calopteryx splendens (5), Calopteryx virgo (5), Ephemerella ignita (5), Gomphus vulgatissimus (5), Gyraulus albus (5), Gyrinus sp larva (5), Heptagenia flava (5), Heptagenia sulphurea (5), Hydraena riparia (5), Hydropsyche pellucidula (5), Hygrobates calliger (5), Laccophilus sp larva (5), Lebertia inaequalis (5), Lebertia insignis (5), Limnodrilus udekemianus (5), Micronecta sp nymph (5), Mideopsis orbicularis (5), Mideopsis roztoczensis (5), Nais pardalis (5), Ophiogomphus cecilia (5), Orthocladius sp (5), Pisidium supinum (5), Polycentropus flavomaculatus (5), Psectrocladius sp (5), Radix peregra (5), Rheotanytarsus sp (5), Robackia demeijerei (5), Simulium equinum (5), Simulium erythrocephalum (5), Simulium morsitans (5), Simulium ornatum (5), Simulium reptans (5), Sperchonopsis verrucosa (5), Stylaria lacustris (5), Synorthocladius semivirens (5), Thienemanniella sp (5), Torrenticola amplexa (5), Triaenodes bicolor (5), Tubifex ignotus (5)*
2	*Pericoma sp (9), Plectrocnemia conspersa (9), Potamophylax sp (9), Elodes sp (8), Sericostoma sp (8), Dendrocoelum lacteum (6), Dicranota sp (6), Gammarus fossarum (6), Micropsectra sp (6), Pisidium milium (6), Chaetopteryx sp (5), Psychoda sp (5)*
3	*Bathyomphalus contortus (12), Planorbis planorbis (12), Anisus leucostomus (11), Thyas rivalis (11), Valvata cristata (11), Anisus vortex (9), Stylodrilus heringianus (9), Limnephilus rhombicus (6), Nemoura sp (6), Bithynia tentaculata (5), Glyphotaelius pellucidus (5), Pisidium personatum (5), Rhyacodrilus coccineus (5)*
4	*Anisus leucostomus (12), Pisidium personatum (12), Sericostoma sp (11), Pisidium casertanum (6), Galba truncatula (5), Lumbricidae (5), Valvata cristata (5)*
5	*Caenis rivulorum (12), Epoicocladius flavens (12), Forelia variegator (12), Paratanytarsus sp (12), Acroloxus lacustris (9), Beraeodes minutus (9), Chaetocladius sp (9), Ephemera danica (9), Habrophlebia sp (9), Hygrobates longipalpis (9), Monodiamesa bathyphila (9), Pisidium amnicum (9), Pisidium henslowanum (9), Sialis lutaria (9), Zavrelimyia sp (9), Chironomus sp (8), Molanna angustata (8), Apsectrotanypus trifascipennis (6), Aulodrilus pluriseta (6), Centroptilum luteolum (6), Galba truncatula (6), Hydrodroma despiciens (6), Lype sp (6), Microtendipes sp (6), Nais communis (6), Odontomesa fulva (6), Paratendipes sp (6), Procladius sp (6), Prodiamesa olivacea (6), Tanytarsus sp (6), Brillia longifurca (5), Glyphotaelius pellucidus (5), Specaria josinae (5)*
6	*Apsectrotanypus trifascipennis (12), Stictochironomus sp (12), Odontomesa fulva (9), Tanytarsus sp (9), Chaetopteryx sp (8)*

3.3.3 Biotic characterisation

In contrast to the oxbow lake samples the stream and river samples included few limnobionts and limnophils (Table 3.16). The number of taxa that prefer running water was much higher, as was expected. However, taxa indicating standing water did still occur, even in the fast flowing rivers (R10, R11 and R12). Probably these taxa live in the quiet habitats at sites where current velocity is low. In all streams and rivers ubiquists concerning current velocity preference did occur. At some sites their numbers were highest, e.g. in the Gać river (R4 and R5). Rheobionts had highest numbers in the Pilica river R10 and R11. These sites also had the highest current velocities.

Table 3.16 Number of taxa in each current velocity class for stream and river samples (for each sample, the class with the highest number is shaded).

sample	no. taxa in each current velocity preference class					
	limnobiont	limnophilous	ubiquist	rheophilous	rheobiont	unknown
R1me99	2	5	10	5	18	41
R1no98	2	4	8	3	12	31
R2me99	2	14	9	4	14	26
R2ok98	2	22	13	11	17	42
R3ap99	8	9	14	3	4	23
R3ok98	0	4	10	2	12	21
R4jn99	3	9	22	10	10	33
R4no98	10	13	26	12	12	54
R5jn99	0	6	9	4	2	18
R5no98	2	6	19	5	4	17
R6ap99	7	9	10	4	3	18
R6ok98	10	7	11	0	1	17
R7jn99	0	10	17	14	21	65
R7ok98	7	13	17	11	17	47
R8me99	0	2	7	2	3	10
R8ok98	0	2	6	4	12	19
R9ap99	3	7	8	2	2	20
R9ok98	2	1	4	1	4	13
R10au99	13	21	31	10	20	84
R10jn00	15	33	33	13	20	81
R11jn00	9	21	22	15	27	70
R11se99	9	23	20	13	24	67
R12me00	4	13	10	4	10	29
R12no99	0	10	9	3	8	17

Table 3.17 Percentage of individuals in each trophic class for stream and river samples (the highest value for each sample is shaded).

	% individuals in each trophic class					
	carnivore	detritivore	detriti-herbivore	herbivore	omnivore	unknown
R1me99	2	2	50	2	24	20
R1no98	0	1	22	1	52	23
R2me99	8	11	33	11	7	30
R2ok98	3	17	7	2	10	61
R3ap99	3	13	10	13	55	6
R3ok98	2	1	5	1	90	2
R4jn99	6	19	50	8	5	11
R4no98	12	22	25	15	5	20
R5jn99	17	34	33	2	4	12
R5no98	9	47	18	20	5	1
R6ap99	10	30	33	19	0	9
R6ok98	10	24	1	54	0	12
R7jn99	2	4	43	3	18	30
R7ok98	6	7	18	17	30	23
R8me99	6	9	48	1	29	7
R8ok98	2	3	20	12	24	39
R9ap99	5	13	3	70	0	9
R9ok98	3	2	0	75	17	2
R10au99	1	1	61	10	1	26
R10jn00	8	21	32	11	0	28
R11jn00	1	14	8	2	1	75
R11se99	4	20	20	3	4	49
R12me00	3	21	20	11	33	12
R12no99	1	9	14	6	60	10

In streams and rivers detriti-herbivores were more common than detritivores (Table 3.17). Carnivores occurred always in low numbers in the streams and rivers. On the other hand, some streams and rivers had high numbers of omnivores, a group that was strongly under represented in the oxbow lakes. It is difficult to explain the differences in trophic structure between streams, because there seems to be no relation with the surrounding land use as was expected. Probably other variables play an important role to determine the species composition, and the trophic structure follows and is therefore 'coincidental'.

The numbers of taxa for which the saprobic class preference is unknown is high (Table 3.18). In most streams and rivers most of the taxa from which the preference is known indicate that the environment is β-saprobic. Only R12, the stream near the Gać river seemed to be oligo-saprobic considering the relatively high number of taxa in this class. However, the number of taxa indicating oligo-saprobic water was also high in R10 and R11, the Pilica river, where also many taxa indicating β-saprobic circumstances occurred. Probably none of the sites was α- or poly-saprobic, because the numbers of taxa indicating such an environment were low. It is common that these taxa are present, also in less saprobic waters.

Table 3.18 Percentage of individuals in each saprobic class for stream and river samples (the highest value for each sample is shaded).

	% individuals in each saprobic class						
sample	poly-saprobic	α-saprobic	β-saprobic	meso-saprobic	oligo-β-saprobic	oligo-saprobic	unknown
R1me99	3	2	11	1	3	8	53
R1no98	1	1	3	0	4	4	47
R2me99	3	2	9	2	3	5	45
R2ok98	2	2	20	2	4	6	71
R3ap99	3	3	11	2	1	3	38
R3ok98	0	3	6	1	2	4	33
R4jn99	2	2	12	3	5	3	60
R4no98	3	4	24	2	5	7	82
R5jn99	2	3	3	1	1	1	28
R5no98	3	5	9	2	3	0	31
R6ap99	2	2	9	1	1	3	33
R6ok98	0	2	9	3	2	2	28
R7jn99	1	2	15	3	7	9	90
R7ok98	2	5	21	3	2	8	71
R8me99	2	2	3	1	0	3	13
R8ok98	1	2	8	0	1	4	27
R9ap99	2	5	3	1	1	2	28
R9ok98	1	1	4	0	2	2	15
R10au99	1	2	30	4	6	14	122
R10jn00	4	7	30	5	8	10	131
R11jn00	5	5	25	2	9	12	106
R11se99	4	4	27	2	9	13	97
R12me00	3	3	4	1	3	8	48
R12no99	3	1	3	2	1	6	31

In general, the total number of taxa in streams and rivers was smaller than in oxbow lakes. The larger rivers (R2 Czarna river, R7 Grabia river, R10 and R11 Pilica river) reached a higher number of taxa than the smaller ones. Of the smaller streams only the Gać swamp stream (R4) had a high number of taxa in autumn. Chironomidae were the most diverse group in almost all streams and rivers. In the larger rivers after Chironomidae the number of Ephemeroptera was high as well as other Diptera, Trichoptera and Acarina (Table 3.19).

The smaller streams differed from each other. R1, Jeżówka stream had low similar numbers of taxa in a high number of groups. R3, Stobnica stream was characterised by high numbers of Oligochaeta and Gastropoda taxa in spring and Trichoptera in autumn. Also in R5, Gać river Oligochaeta had a relatively high number of taxa after Chironomidae. In R6, Sulejów stream, Gastropoda and Oligochaeta played a major role. R8, Brodnia river and R9, Rawka temporary stream were both species poor. In R9 the number of Oligochaeta was high in spring and the number of Gastropoda highest in autumn, probably because it fell dry in autumn.

Table 3.19 Number of taxa in each taxonomic group for stream and river samples (for each sample, the group with the highest number of taxa is shaded).

sample	total no. taxa	Acarina	Bivalvia	Chironomidae	Coleoptera	other Diptera	Ephemeroptera	Gastropoda	Heteroptera	Hirudinea	Lepidoptera	Malacostraca	Megaloptera	Odonata	Oligochaeta	Plecoptera	Trichoptera	Turbellaria	others
R1me99	79	9	5	19	6	8	7	3	0	2	0	2	0	1	6	1	8	2	0
R1no98	58	2	6	15	6	7	3	0	5	1	0	1	0	0	3	2	6	1	0
R2me99	65	2	4	20	1	5	9	1	2	0	0	1	0	4	11	1	3	1	0
R2ok98	103	9	0	20	4	10	15	0	4	0	1	1	0	6	18	2	11	2	0
R3ap99	61	7	6	8	2	4	3	9	0	4	0	2	0	0	9	2	3	2	0
R3ok98	46	2	3	5	2	4	6	0	0	2	0	2	0	0	5	2	11	2	0
R4jn99	85	7	10	28	2	5	13	1	0	1	0	3	1	0	5	0	9	0	0
R4no98	124	9	10	28	5	7	18	11	3	2	0	3	1	3	11	1	12	0	0
R5jn99	38	2	3	18	0	2	3	0	0	0	0	1	1	0	8	0	0	0	0
R5no98	53	1	5	20	1	2	2	3	1	3	0	2	1	0	8	0	4	0	0
R6ap99	51	4	2	11	2	2	3	7	0	4	0	1	0	0	7	1	4	3	0
R6ok98	46	5	6	2	2	7	0	10	0	3	0	0	0	0	8	0	1	2	0
R7jn99	119	15	8	23	11	13	16	1	2	3	0	2	0	3	8	0	12	2	0
R7ok98	107	9	7	20	4	10	17	7	3	3	0	2	1	3	12	1	6	1	1
R8me99	22	1	1	10	0	1	1	0	0	0	0	1	0	0	5	0	2	0	0
R8ok98	42	1	3	14	2	4	9	0	0	2	0	1	0	0	2	1	3	0	0
R9ap99	42	0	2	10	1	3	2	6	0	0	0	1	0	0	14	1	2	0	0
R9ok98	25	2	3	1	1	1	2	6	0	0	0	2	0	0	2	1	3	1	0
R10au99	167	18	9	35	11	13	19	12	5	6	2	1	0	8	11	0	16	0	1
R10jn00	186	21	8	37	9	15	25	12	9	7	0	2	1	4	18	2	14	1	1
R11jn00	157	13	10	33	15	13	18	7	6	7	0	2	1	3	17	2	10	0	0
R11se99	148	9	7	27	15	15	17	10	7	4	1	2	1	5	13	1	12	1	1
R12me00	67	7	6	12	1	17	1	1	1	3	0	2	0	0	6	1	6	3	0
R12no99	46	4	5	10	1	9	0	1	0	0	0	2	0	0	5	1	5	3	0

3.4 Oxbow lakes

3.4.1 Vegetation clusters

Vegetation data of oxbow lakes were clustered apart from the streams and springs. Both sites that had a connection with the river, O1 (Rawka, oxbow 1) and O10 (Pilica, large oxbow, site near river) were clustered together in cluster 1 (Table 3.20). Conversely to the macroinvertebrate samples the open connection with the river determined the plant composition at these sites. *Glyceria maxima* and *Potamogeton natans* were dominant species at these sites. *Carex elata* was the only indicator species. The sites were characterised not only by this species but also by the absence of many other species such as *Stratiotes aloides*, which is for example present at the two other sites of the Pilica large oxbow (Appendix 11).

That there was similarity between the Pilica and the Rawka oxbow lakes appeared also from the fact that two other sites from the Pilica oxbow lakes (O7, the small oxbow and O9 the middle site of the large oxbow) were in one cluster with the two other Rawka oxbow lakes, O2 and O3. Moreover this cluster 2 was the one that is most similar to cluster 1 (Table 3.21). In this cluster the diversity of plant species was high. There were many water and bank species. *Carex acuta* and

Elodea canadensis were dominant (Table 3.22). They occurred together with *Nuphar lutea* which was abundant. There were no indicator species in this cluster, which means that the species occurring in this cluster were not specific and occurred in the other clusters as well.

One site of the large Pilica oxbow, O8, the site that is furthest from the river was clustered separately in cluster 5. The cluster was most similar to cluster 2, in which O7 and O9, the other Pilica oxbow sites which are more isolated from the river are. O8 was probably clustered as a separate site because many species that were present at the banks of the other sites were lacking here. O8 was characterised by a forested bank without a large gradient of bank species as is the case at the other sites. That is why the total number of species was low at this site. O8 was dominated by *Elodea canadensis*, a plant that is abundant at the other Pilica sites. At O8 there was seepage water from the banks. This was indicated by species such as *Hottonia palustris* (Appendix 11).

Table 3.20 Oxbow lakes included in the vegetation clusters and their species richness.

cluster no.	oxbow lake sites	total no. of taxa	mean no. taxa/sample
1	O1, O10	29	21
2	O2, O3, O7, O9	45	27
3	O4	25	25
4	O6	26	26
5	O8	16	16

Table 3.21 Clusters of vegetation samples from the oxbow lakes: cluster characteristics.

cluster	average resemblance	most similar to cluster	resemblance	isolation
1	0.5846	2	0.4242	1.3784
2	0.6825	5	0.5204	1.3116
3	1	2	0.5183	1.9294
4	1	2	0.4299	2.3264
5	1	2	0.5204	1.9216

Table 3.22 Dominant, abundant and indicator taxa in the vegetation clusters of oxbow lakes. The numbers that are in brackets are the indicator weights (only indicator taxa with low weights 4-6, moderate weights 7-9 and high weights 10-12 were included).

cluster	dominant	abundant	indicator
1	*Glyceria maxima* *Potamogeton natans*	*Carex acuta* *Hydrocharis morsus-ranae*	*Carex elata (5)*
2	*Carex acuta* *Elodea canadensis*	*Nuphar lutea*	-
3	*Carex pseudocyperus*	*Carex acuta* *Elodea canadensis* *Equisetum fluviatile* *Hydrocharis morsus-ranae* *Lemna minor* *Lemna trisulca* *Nuphar lutea* *Spirodela polyrhiza*	*Carex pseudocyperus (6)* *Carex vesicaria (5)* *Myosotis palustris (5)* *Sparganium erectum (5)*
4		*Carex acuta* *Carex elongata* *Stratiotes aloides*	*Sparganium erectum (9)* *Stratiotes aloides (6)* *Ceratophyllum demersum (5)* *Myosotis palustris (5)*
5	*Elodea canadensis*	*Caltha palustris* *Hydrocharis morsus-ranae* *Nuphar lutea* *Sium latifolium*	*Glyceria fluitans (5)*

The two Grabia oxbow lakes O4 and O6 were clustered separately as well. Both had a high species diversity, comparable to cluster 2. Both clusters were most similar to cluster 2, more than to each other. This means the difference between both Grabia oxbow lakes was larger than the difference between these and the Pilica and Rawka oxbow lakes. But it can also be a result of the fact that cluster 2 included more samples and therefore had more variation in species composition than a cluster with a single sample.

In cluster 3 (O4) *Carex pseudocyperus* was dominant and occurred along the oxbow banks. Remarkable were the high abundances of duckweeds, which indicate eutrophic conditions. The indicator species had all low indicator weights and are all bank species.

In cluster 4 there was no dominant species. Abundant were *Stratiotes aloides* and some sedge species. *Stratiotes aloides* was also an indicator species along *Sparganium erectum*, *Myosotis palustris* and *Ceratophyllum demersum* (Table 3.22).

3.4.2 Ordination with macroinvertebrates and environmental variables

The ordination diagram (Figure 3.7) shows that in general oxbow lakes from one river are close to each other. The Rawka oxbow lakes (O1, 2, 3) were clustered together, one group with the springtime samples and one group with the autumn samples. Temperature of the water appeared to be an important environmental variable in explaining the species composition. During springtime the EC and BOD were also higher than during autumn in these oxbow lakes. The oxbow lakes of the Pilica river (O7, O8, O9, and O10) were characterized by the presence of forest and shading in both seasons. In autumn the values of some substances, e.g., chloride, potassium, and sulphate were higher (Appendix 13). Site O10, close to the river Pilica was more separate from the other Pilica sites, probably because of the river influence. The Grabia oxbow lakes were characterized by a high coverage of algae and floating vegetation, especially in autumn (Appendix 13).

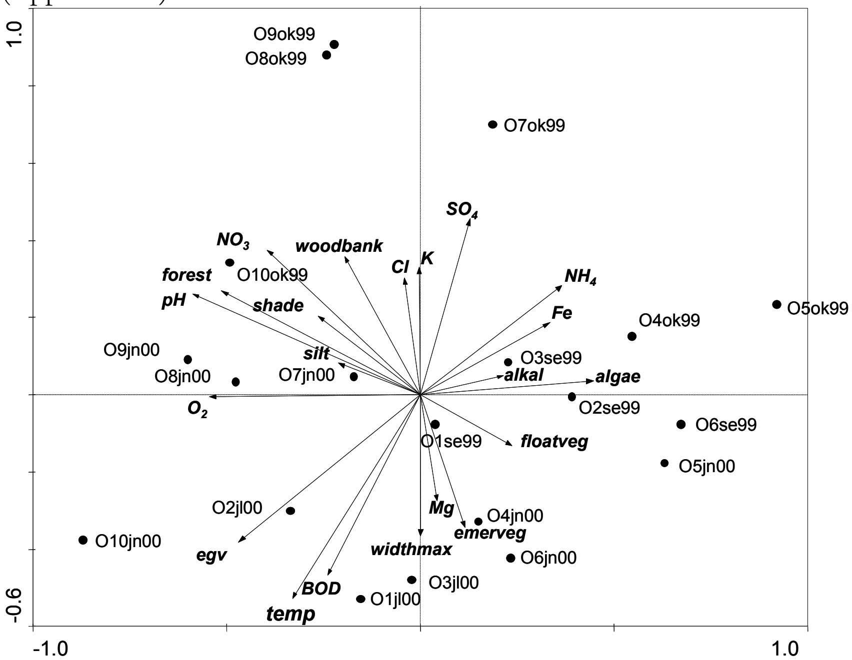

Figure 3.7 Ordination diagram of the macroinvertebrate samples from oxbow lakes. The variables sand, maximal depth, sapropelium thickness, submerse vegetation, bank vegetation, PO_4, Na were not included in the diagram because their interset correlation with axes 1 and 2 were lower than 0.25. (woodbank = wooded bank, alkal = alkalinity, floatveg = floating vegetation, emerveg = emergent vegetation, widthmax = maximum width, BOD = biological oxygen demand, temp = temperature, egv = electric conductivity).

3.4.3 Macroinvertebrate clusters

Seven clusters of oxbow lake samples resulted from the cluster analysis (Tables 3.23 and 3.24, Appendix 12). The clustering partly followed the ordination diagram, although the influence of the temperature (season) was more important in the ordination splitting up spring and autumn samples.

Cluster 1 included both samples from the site near the river in the large open Pilica oxbow (O10). It is remarkable that this site was different from the other 2 sites in the same oxbow (O8 and O9). However, the cluster of the two O10 samples was most similar to cluster 6, including the autumn samples of the other sites in this oxbow (Table 3.24). Conversely, the more isolated sites of the large Pilica oxbow (O8 and O9) were clustered together with O7 (the small Pilica oxbow) in clusters 6 and 7, including the spring and autumn samples, respectively. This implies that the differences between seasons were larger than the differences between these sites. Probably, the site near the river in the large oxbow was quite different from the other sites because the water was deeper and there was less vegetation at that site. Also river water quality could influence the species composition. Looking at the clustering diagram (Appendix 12) it appears that in O10 mainly species were lacking compared to O9 and O8. Table 3.23 shows that also the total and mean number of taxa and the mean number of individuals was smaller in O10.

In the other oxbow lakes, seasonal differences were less important. Samples from spring and autumn of one oxbow were clustered together for all other sites. The three Rawka oxbow lakes were clustered together in cluster 2, probably they did not differ much, although the inundation frequency was different (O1, has an open connection to the river, the two others haven't). However, it is not known how often the isolated oxbow lakes are inundated by the river Rawka. If this happens frequently, the species composition is influenced by river water and will look alike the species composition of the oxbow with the open connection to the river.

The three Grabia oxbow lakes were clustered separately. This means that the differences between these oxbow lakes were larger than between the three Rawka oxbow lakes. One of the Grabia oxbow lakes, O4 (cluster 3) was most similar to cluster 2, the cluster with the three Rawka oxbow lakes. This implies that the differences between this oxbow and the other two Grabia oxbow lakes is larger than between this oxbow and the Rawka oxbow lakes. The diversity in this oxbow was large (as is also the case in the Rawka oxbow lakes), there were many taxa and the highest number of individuals was collected from this oxbow.

Table 3.23 Clusters of macroinvertebrate samples from the oxbow lakes.

cluster	samples	total no. taxa	mean no. taxa	mean no. individuals
1	O10jn00, O10ok99	140	95	1851
2	O1jl00, O1se99, O2jl00, O2se99, O3jl00, O3se99	280	144	5076
3	O4jn00, O4ok99	192	140	6431
4	O5jn00, O5ok99	140	96	2950
5	O6jn00, O6se99	157	114	3463
6	O7jn00, O8jn00, O9jn00	222	132	5592
7	O7ok99, O8ok99, O9ok99	184	112	4252

Asellus aquaticus occurred in each oxbow as a dominant or abundant species, except for cluster 1 (O10) and cluster 3 (O4) (Table 3.25). *Cloeon gr. dipterum* was another taxon that occurred in high abundances in all oxbow lakes but not in cluster 6 (O7, 8 and 9 in June). But in the autumn samples in these oxbow lakes the species was present in high numbers.

Each cluster had a high number of indicative taxa of different taxonomic groups, of which some were even highly indicative (Table 3.26). Only cluster 2 had no highly indicative taxa.

Table 3.24 Clusters of macroinvertebrate samples from the oxbow lakes: cluster characteristics.

cluster	average resemblance	most similar to cluster	resemblance	isolation
1	0.52	6	0.5939	0.8755
2	0.7131	3	0.7504	0.9503
3	0.5789	2	0.7504	0.7714
4	0.5322	3	0.5154	1.0325
5	0.5796	3	0.5977	0.9698
6	0.6526	2	0.7055	0.9251
7	0.6068	6	0.6232	0.9736

Table 3.25 Dominant and abundant taxa in the clusters of oxbow lakes.

cluster	dominant taxa	abundant taxa
1	*Cloeon gr dipterum, Cricotopus sp*	*Ceratopogonidae, Dicrotendipes sp, Erpobdella nigricollis, Micropsectra sp, Polypedilum sp*
2	*Asellus aquaticus, Cloeon gr dipterum*	*Dicrotendipes sp*
3	*Dicrotendipes sp, Erpobdella octoculata*	*Cloeon gr dipterum, Polypedilum sp*
4	*Asellus aquaticus, Cloeon gr dipterum*	*Physa fontinalis, Stylaria lacustris*
5	*Cloeon gr dipterum, Polypedilum sp*	*Asellus aquaticus, Dicrotendipes sp, Endochironomus sp, Stylaria lacustris*
6	*Asellus aquaticus*	*Dicrotendipes sp*
7	*Asellus aquaticus, Cloeon gr dipterum*	*Limnephilus rhombicus*

Table 3.26 Indicator taxa in oxbow clusters.

cluster	indicator taxa
1	*Arrenurus tubulator (12), Pisidium supinum (11), Ablabesmyia sp (9), Anabolia furcata (9), Limnephilus lunatus (9), Ephydridae (6), Lype sp (6), Micropsectra sp (6), Nais pardalis (6), Radix auricularia (6), Arrenurus albator (5), Arrenurus crassicaudatus (5), Coelostoma sp larva (5), Sisyra fuscata (5)*
2	*Arrenurus tetracyphus (8), Arrenurus tricuspidator (8), Arrenurus bicuspidator (6), Gyrinus aeratus (6), Marstoniopsis scholtzi (6), Nanocladius sp (6), Ophidonais serpentina (6), Piona longipalpis (6), Piona stjoerdalensis (6), Aeshna cyanea (5), Aeshna grandis (5), Cordulia aenea (5), Microvelia reticulata (5), Piscicola geometra (5), Ranatra linearis (5), Sinurella ambulans (5), Tipulidae (5), Zavreliella marmorata (5)*
3	*Arrenurus neumani (12), Cercyon sp larva (12), Hygrotus decoratus (12), Segmentina nitida (12), Ablabesmyia longistyla (9), Agraylea multipunctata (9), Donacia sp (9), Limnephilus nigriceps (9), Myxas glutinosa (9), Paratendipes sp (9), Peloscolex ferox (9), Anisus vortex (6), Arrenurus batillifer (6), Arrenurus virens (6), Clinotanypus nervosus (6), Coelambus impressopunctatus (6), Coenagrion lunulatum (6), Dero digitata (6), Elophila nymphaeata (6), Enallagma cyathigerum (6), Erpobdella octoculata (6), Haemonais waldvogeli (6), Leptophlebiidae (6), Lestes viridis (6), Limnebius truncatellus (6), Limnodrilus udekemianus (6), Neumania vernalis (6), Radix peregra (6), Tubifex ignotus (6), Aeshna mixta (5), Cymatia coleoptrata (5), Metriocnemus sp (5), Microvelia reticulata (5), Notonecta maculata (5)*
4	*Chaoborus crystallinus (12), Haemopis sanguisuga (12), Anisus vorticulus (9), Heptagenia fuscogrisea (9), Lestes viridis (9), Polycelis nigra (9), Sinurella ambulans (8), Argyroneta aquatica (6), Chaoborus flavicans (6), Coelambus impressopunctatus (6), Helophorus aquaticus (6), Helophorus nubilus (6), Hygrotus inaequalis (6), Lumbricidae (6), Orthocladius sp (6), Physa fontinalis (6), Cataclysta lemnata (5), Colymbetes sp larva (5), Coelostoma sp larva (5), Limnesia undulata (5), Planorbis planorbis (5), Sympetrum sanguineum (5)*
5	*Ischnura elegans (12), Leptocerus sp (12), Muscidae (11), Ablabesmyia longistyla (9), Anisus vorticulus (9), Cyphon sp larva (9), Mesovelia furcata (9), Parapoynx stratiotata (9), Ablabesmyia monilis (6), Cataclysta lemnata (6), Elophila nymphaeata (6), Haemonais waldvogeli (6), Holocentropus picicornis (6), Paratanytarsus sp (6), Psectrocladius sp (6), Sigara striata (6), Stratiomyidae (6), Xenopelopia falcigera (6), Aeshna cyanea (5), Armiger crista (5), Coenagrion pulchellum (5), Enallagma cyathigerum (5), Limnesia undulata (5), Parapoynx nivalis (5)*

6	*Mystacides sp (12), Aeshna mixta (9), Cladotanytarsus sp (9), Graptodytes pictus (9), Arrenurus crassicaudatus (8), Sympetrum sanguineum (8), Arrenurus virens (6), Bithynia tentaculata (6), Dero dorsalis (6), Enchytraeidae (6), Hyphydrus ovatus (6), Hydrachna globosa (6), Laccophilus sp larva (6), Muscidae (6), Nepa cinerea (6), Sialis lutaria (6), Cryptotendipes sp (5), Eylais sp (5), Galerucella nymphaeae (5), Helophorus aquaticus (5), Hygrobates longipalpis (5), Limnephilus lunatus (5), Limnesia undulata (5), Unionicola minor (5)*
7	*Glyphotaelius pellucidus (12), Pyrrhosoma nymphula (12), Hydroporus palustris (9), Limnephilus rhombicus (9), Notonecta glauca (9), Unionicola minor (9), Heptagenia fuscogrisea (8), Caenis horaria (6), Hygrobates longipalpis (6), Planorbis planorbis (6), Sphaerium corneum (6), Tubifex tubifex (6), Acilius canaliculatus (5), Haemopis sanguisuga (5), Lumbricidae (5), Pisidium hibernicum (5), Pisidium nitidum (5)*

3.4.4 Biotic characterisation

Most of the taxa found in the oxbow lakes are limnobiont or limnophilous, indicating that they prefer standing water (Table 3.27). Ubiquists, taxa that can survive in standing and in running water had highest numbers in half of the samples from the large Pilica oxbow. Probably there was some current in this oxbow due to the open connection with the river. Taxa commonly occurring in running water can easily enter the oxbow and survive there for a while. This was also indicated by the relatively high number of rheophilous and rheobiont taxa in comparison to the other oxbow lakes. However, this was not observed in the other lake with an open river connection, Rawka oxbow lake 1 (O1). This might be due to the fact that this is a smaller river and the connection to the river is much smaller.

Table 3.27 Number of taxa in each current velocity class for oxbow lake samples (for each sample, the class with the highest number is shaded).

	no. taxa in each current velocity preference class					
sample	limnobiont	limnophilous	ubiquist	rheophilous	rheobiont	unknown
O1jl00	49	48	42	3	3	56
O1se99	33	41	36	2	3	40
O2jl00	31	39	40	0	1	41
O2se99	40	41	36	1	3	38
O3jl00	39	36	35	3	1	47
O3se99	36	39	29	2	2	42
O4jn00	34	40	35	1	0	51
O4ok99	40	43	32	3	1	45
O5jn00	33	23	25	2	0	37
O5ok99	27	19	22	3	1	22
O6jn00	25	35	29	3	1	41
O6se99	26	32	27	2	1	32
O7jn00	33	25	33	2	1	37
O7ok99	31	25	28	2	3	25
O8jn00	27	34	30	3	2	33
O8ok99	16	22	32	4	3	30
O9jn00	39	32	50	5	5	59
O9ok99	31	38	34	6	6	34
O10jn00	13	26	37	4	5	39
O10ok99	14	25	22	5	1	21

The trophic structure of the macroinvertebrate communities of the oxbow lakes is presented in Table 3.28. Detritivores had high percentages in the Pilica oxbow lakes, probably because of the presence of forest, introducing much detritus into the lakes. Only at the site near the river (O10), the percentage of detritivores was similar to the percentages in other oxbow lakes, probably because this site was least shaded.

In the Rawka oxbow lakes (O1, 2, 3) the detritivores dominated in the autumn samples, carnivores and detriti-herbivores in the summer samples.

The Grabia oxbow lakes (O4, 5, 6) strongly differed from each other. O4 was dominated by carnivores, in particular in autumn with the high percentage of 52%. The community of O5 mainly existed of detritivores, in June accompanied by herbivores, in autumn by carnivores. In O6, carnivores and herbivores each included 17 % of the communities' individuals in summer. In autumn detriti-herbivores were dominant.

Table 3.28 Percentage of individuals in each trophic class for oxbow lake samples (the highest value for each sample is shaded).

	% individuals in each trophic class					
sample	carnivore	detritivore	detriti-herbivore	herbivore	omnivore	unknown
O1jl00	30	26	10	14	1	19
O1se99	20	27	11	14	0	28
O2jl00	19	19	21	10	2	30
O2se99	22	36	7	20	0	15
O3jl00	26	27	10	14	0	22
O3se99	15	29	16	8	1	31
O4jn00	15	9	10	15	2	49
O4ok99	52	12	7	11	0	18
O5jn00	13	35	2	33	0	17
O5ok99	17	32	1	14	0	37
O6jn00	17	14	12	17	0	41
O6se99	17	6	25	9	0	43
O7jn00	11	42	12	10	2	22
O7ok99	5	57	10	12	0	15
O8jn00	17	48	7	14	2	12
O8ok99	8	54	10	7	1	19
O9jn00	19	40	8	16	2	16
O9ok99	10	49	17	8	0	16
O10jn00	29	15	23	11	1	22
O10ok99	13	20	19	7	2	40

The majority of the taxa observed in the oxbow lake samples indicate a β-saprobic environment (Table 3.29). This might be due to the fact that in each oxbow lake there was a sapropelium layer of at least 20 cm on the bottom, containing deposited silt and organic material. On the other hand, there were also reasonable numbers of taxa that indicate oligo-β-saprobic water and oligo-saprobic water. This would mean that the water is oligo-saprobic, otherwise these taxa would not be able to survive. This is different for the taxa that indicate β-saprobic water, which can also survive in oligo saprobic conditions but in lower densities. There appeared to be no relation with the presence of forest surrounding the oxbow lakes. However, the numbers of taxa of which the saprobic class is unknown was high.

Table 3.29 Percentage of individuals in each saprobic class for oxbow lake samples (the highest value for each sample is shaded).

	% individuals in each saprobic class						
sample	poly-saprobic	α-saprobic	β-saprobic	meso-saprobic	oligo-β-saprobic	oligo-saprobic	unknown
O1jl00	4	7	32	5	12	8	133
O1se99	4	6	22	5	14	12	92
O2jl00	4	6	27	5	8	5	97
O2se99	5	6	25	3	12	10	98
O3jl00	4	4	28	5	8	8	104
O3se99	4	6	25	4	8	9	94
O4jn00	4	6	28	5	9	5	104
O4ok99	4	5	22	5	11	9	108
O5jn00	3	4	21	4	6	4	78
O5ok99	2	3	22	5	7	5	50
O6jn00	3	6	21	5	6	4	89
O6se99	1	3	23	4	6	6	77

O7jn00	3	6	22	5	10	5	80
O7ok99	4	5	24	4	7	8	62
O8jn00	4	7	28	5	8	4	73
O8ok99	3	5	22	4	8	3	62
O9jn00	4	6	33	4	13	5	125
O9ok99	4	7	32	6	9	6	85
O10jn00	3	6	23	4	7	4	77
O10ok99	3	4	20	3	7	3	48

Table 3.30 Number of taxa in each taxonomic group for oxbow lake samples (for each sample, the group with the highest number of taxa is shaded).

sample	total no. taxa	Acarina	Bivalvia	Chironomidae	Coleoptera	Other Diptera	Ephemeroptera	Gastropoda	Heteroptera	Hirudinea	Lepidoptera	Malacostraca	Megaloptera	Odonata	Oligochaeta	Plecoptera	Trichoptera	Turbellaria	Others
O1jl00	196	30	7	25	34	10	4	17	21	9	3	1	1	11	15	0	6	0	2
O1se99	154	21	6	17	16	11	5	14	9	10	3	1	1	8	21	0	7	2	2
O2jl00	149	24	5	25	12	9	3	14	9	8	1	2	1	10	19	0	4	1	2
O2se99	154	22	2	19	16	10	5	18	12	9	2	1	1	11	17	0	6	2	1
O3jl00	157	28	3	19	17	9	4	16	13	9	3	1	1	14	10	0	8	1	1
O3se99	148	20	2	18	16	9	6	15	10	8	3	1	0	9	17	0	11	2	1
O4jn00	158	22	5	21	22	4	4	16	9	10	3	1	1	11	18	0	9	1	1
O4ok99	161	16	6	18	24	10	8	20	10	6	3	1	1	10	17	0	7	3	1
O5jn00	117	15	1	12	15	9	2	15	9	9	2	1	0	6	13	0	5	2	1
O5ok99	92	12	2	6	15	5	6	14	2	10	2	1	1	4	4	0	4	3	1
O6jn00	132	20	3	25	8	9	4	12	9	5	3	1	0	9	13	1	9	0	1
O6se99	118	7	0	18	13	10	6	18	7	4	4	1	1	7	7	0	9	3	3
O7jn00	130	18	4	21	18	5	4	10	10	11	1	1	1	4	12	0	7	2	1
O7ok99	112	6	5	13	14	8	6	13	7	9	3	1	1	4	11	0	7	3	1
O8jn00	126	15	6	20	7	3	4	13	9	8	1	1	1	7	16	0	11	3	1
O8ok99	106	10	7	16	8	4	7	12	5	3	1	1	1	5	14	0	11	1	0
O9jn00	188	32	12	23	29	8	11	19	7	9	0	3	1	7	15	0	11	1	0
O9ok99	148	15	7	21	14	9	11	20	5	7	2	1	1	4	21	0	8	2	0
O10jn00	122	18	6	26	11	6	7	7	5	7	1	1	1	3	13	0	8	0	2
O10ok99	87	7	4	18	3	5	10	12	5	3	2	1	1	3	11	0	1	1	0

Total taxa richness in the oxbow lakes was high. In general, the highest number of taxa was found in the summer, probably because in autumn many animals were too small to identify them to species level. The highest number of taxa was found during springtime in O1, the Rawka oxbow lake with the open connection to the river and the lowest number of taxa during autumn in O10 the site close to the river in the large Pilica oxbow.

In most oxbow lakes the majority of the taxa found belong to the water mites (Acarina), water beetles (Coleoptera) and midges (Chironomidae). Also, the numbers of snails (Gastropoda) and worms (Oligochaeta) were high in all oxbow lakes (Table 3.30).

Differences between oxbow lakes were mainly found in numbers of water bugs (Heteroptera) and dragonflies and damselflies (Odonata), which were higher in the Rawka oxbow lakes (O1, O2 and O3) and one of the Grabia oxbow lakes (O4).

4 Conclusions

4.1 Vegetation

In springs, streams and rivers only few plant species occurred, mainly bank species. Water plants were scarce because many of the springs and streams are situated in the forest and have little light penetration. The larger rivers and the streams that are running trough grassland had more species of water plants. Because the three open waters, R1, R10 and R7 each contained different species of water plants, they were not clustered with other sites. The springs could be divided into two groups, one with *Cardamine armara* and one with *Berula erecta* as important species. Small forest streams were clustered together, because they only contained a few bank species. The other sites were grouped in one cluster, but their vegetation was diverse, as were the environmental conditions. The fact that springs and streams were clustered together and that large rivers were clustered together with small streams indicates that vegetation is not related to dimensions. It was difficult to relate the vegetation to environmental variables. More surveys are needed to carry out a proper ordination analysis. Because many species are living on the banks and not in the water, other environmental variables are needed to explain their distribution.

Vegetation in oxbow lakes consisted of more species and more real water species. Isolated oxbow lakes were clearly different from oxbow lakes with a connection to the river. O10 and O1 were clustered together, lacking e.g. *Lemna trisulca*, a species that occurred in all other types. The numbers of *Glyceria maxima* and *Potamogeton natans* were large in this cluster. The other two Rawka sites were clustered together with two Pilica sites. O8 was clustered separately, because many bank species were lacking. This site was in the darkest part of the forest. In general, connection with the river, and openness of the water were the main explaining environmental variables.

4.2 Macroinvertebrates

Macroinvertebrate communities differed between springs and streams. Stream and river communities were much more similar.

Springs were first divided in acid and pH neutral springs. The acid spring had a few good indicator species which are characteristic for these circumstances. Many common species were lacking. S12 was separated from the other springs and had a high number of indicative species, probably caused by the relatively high current velocity. In the other springs the season was more important than the differences between the springs. Autumn samples were clustered together and spring samples were clustered together. The differences caused by the accumulation of leaves are larger than the differences between the springs. In autumn many species were lacking and no indicator species occurred. In springtime the springs were divided in two groups, although the causes were not clear. Probably open springs were clustered together (S4, S5 and S6) with S8, which has frozen water in winter (very low discharge). Further interpretation is difficult, because the macroinvertebrate communities of the springs were quite similar. Clustering and ordination showed different results if looking in more detail. Springs and spring outflows were clustered together, which suggests dimension and current velocity were not important within these data. In most springs rheobionts occurred, although current velocity was very low. In the open springs the majority of the taxa were ubiquists (concerning current velocity preference) and omnivores. The springs were oligo- or oligo-β-saprobic. The majority of the taxa found, belong to the Chironomidae and other Diptera and Trichoptera.

For streams other conclusions can be drawn. In this water type season was far less important than in springs, probably because leaves are flushed away sooner by the higher current velocity.

In streams, dimensions played a major role. Large rivers (high width and depth, high current velocity, presence of vegetation) were clustered together as were small forested streams (much detritus and leaves, shade, a thick sapropelium layer). The larger forested streams were clustered with the autumn samples of the more open streams (still a little seasonal influence!). The autumn sample of R9 was clustered alone, probably as a result of the dry period during summer. All samples from the Gać river (R4 and R5) were clustered together, indicating that this is a special environment. This river is special because it flows through a swamp, it has many branches and islands and builds a very diverse landscape. The sapropelium thickness measured in this river was extremely high. This is the major explaining variable for the aberrant community, which was indicated by the high number of indicative taxa. In general, chemical variables played a minor role in streams and rivers, as was also the case in the analysis of spring samples.

The number of rheobionts was lower than in springs, although the current velocity was higher in the streams and rivers. Probably, rheobionts prefer a continuous flow of groundwater and good oxygen conditions instead of a high current velocity. There were many ubiquists and also a number of limnophilous species (probably living in the pools). The trophic classes showed much more differences between samples than was the case for the springs. These differences might be related to the availability of detritus (forested streams) or algae, however, direct relations with these variables could not be found in the data. The streams and rivers were more saprobic (β-saprobic) than the springs. Again, Chironomidae were the largest taxonomic group.

In oxbows the presence of a connection with the river was an important explaining variable which grouped O10 apart from all other oxbow lakes. O1, also with a river connection but a very small one, was clustered together with the other Rawka oxbows. In contrast with the vegetation results, the macroinvertebrate community was similar between these sites. This would suggest that there is few exchange of species between river and oxbow lake. The chemical constitution of the water is less important for macroinvertebrates than for vegetation.

The forested oxbows lakes of the Pilica river were clearly different from the others, caused by shading, much detritus and less vegetation.

The ordination showed a difference between seasons for the Rawka and Grabia oxbow lakes but this was not shown by the clustering, in which all Rawka oxbow lakes were put together and each Grabia oxbow lake composed one cluster (each with a spring and autumn sample). The differences between the Grabia sites were larger than between the Rawka sites, which are situated more close together and show less variation in environmental variables. The Grabia oxbow lakes had more floating vegetation and algae but this was not reflected in nutrient levels.

The clusters were all very different and included large numbers of indicative species. As was expected the oxbow lakes included mainly standing water species, in all trophic classes. The lakes were β-saprobic. Besides Chironomidae, water mites and beetles had high numbers of taxa.

4.3 How to use the results?

The diversity in the sampled water bodies was high. Each water type contained its own species. Constructing a strict typology is not possible nor needed. The ordinations and cluster analyses showed the major patterns and gave insight in the species composition and the main environmental variables. However, vegetation and macroinvertebrates did not give the same results and results form ordination and clustering differed, if looked at in detail. Therefore, they should be used as guidance, not as the 'truth'. It is important to know more about the autecology of the dominant, abundant and indicative species. They can give more information about their environment and why they occur there.

The clustering of samples provided insight in which streams, springs, rivers and oxbow lakes are similar, and by which species they are characterised (dominant, abundant and indicative species). This can be valuable in describing reference conditions for these and similar water bodies. The water bodies were of similar chemical quality, as chemical variables did not play a role in the ordination results. The waters were of good ecological quality which was illustrated by the saprobic characterisation. Other variables such as land use, shade, dimensions, connection to the river and substrate were the major ones. This means that these water bodies can be used as reference conditions and serve as waters of good ecological quality. To give a good description for reference types, enough water bodies of each type should be sampled. The number of water bodies per type differs strongly. It is recommended to search for more water bodies similar to those who formed a separate cluster on their own. There is always variation between waters, seasons, captured animals, et cetera, although environmental conditions are similar. This variation should be known as well to make a good reference description.

Finally, the reference descriptions can be used to develop an assessment system, with which the ecological quality of water bodies can be determined. The reference descriptions are the highest ecological quality class of the assessment system and the quality of new water bodies can be determined by using a typology, an index or multimetric (e.g., Hering et al., 2003, 2004).

Part B: The use of Polish river systems as reference conditions for Dutch river systems

5 Methods

5.1 Naturalness of Polish streams

To use the Polish water bodies as reference conditions for the Dutch water bodies it should be tested whether they are really natural and if they suffer from human influences how strong the effects are. The naturalness was described using the environmental data from the field inventory and using the chemical variables measured in the water samples. The land use and hydromorphological criteria were compared with the criteria used in the AQEM project (Hering et al. 2003).

Chemical variables at the Polish sampling sites were compared with the target ranges of the Nature Target Types given in the Aquatic Supplement (Nijboer et al. 2000: large rivers and oxbow lakes, Verdonschot 2000a: springs, Verdonschot 2000b: streams). To make a correct comparison, the sampling sites should first be assigned to the corresponding types. For streams this was done using the variables permanency, acidity, width and current velocity. One river was very wide (R10), therefore this site was assigned using the large river types.

The springs were assigned using electric conductivity and calcium concentration (to determine whether they are mineral poor or moderately mineral rich). The discharge was not known, therefore the springs could not be divided into low and moderate discharge (a high concentrated discharge did not occur). The spring outflows were assigned to the stream types.

The oxbow lakes were divided in oxbow lakes with or without a connection to the river. The frequency of inundation was not known. Therefore, the oxbow lakes could not be further assigned to a Nature Target Type.

5.2 Comparability of macroinvertebrate data

To be able to use the data and compare the results to the data of water bodies in the Netherlands the data should be similar concerning structure, numbers of individuals, et cetera. This means sampling and sorting should be carried out in similar ways. To test whether this was the case, the data structure is compared with the structure of two large Dutch data sets (EKOO data including running and standing waters in the province of Overijssel and stream typology data including data of streams all over the Netherlands). Numbers of taxa, individuals in total and per sample were compared.

5.3 Comparing taxa lists

Taxa from the Polish data are only useful in the Dutch reference condition descriptions if these taxa can occur in the Netherlands. Probably some of the taxa that do occur in Poland do not occur in the Netherlands, because their distribution is limited to the continental area. For the complete taxa list the possibility of occurrence in the Netherlands should be checked. Therefore, the dataset was divided in two parts: one dataset for running waters, including the taxa from springs, streams and rivers, and one dataset for standing waters, including the lake and the oxbow lakes.

From each dataset the taxa were extracted. After that, a few steps were carried out to make the taxa list more comparable with the Dutch taxa lists:

1. Taxa on higher level (groups, genera, families and higher) were removed if taxa on lower level belonging to the respective higher level were present;

2. Taxa lower than the species level, e.g., a form or variation were changed into the species name;
3. Taxon names including life stages were replaced by the plain taxon name.

After these adaptations had been made, the taxa lists of the running waters were compared with three datasets:

1. The stream typology dataset (containing 2243 samples taken in streams all over the Netherlands);
2. The AQEM dataset (containing 156 samples taken in streams all over the Netherlands);
3. Historical data of running waters (containing information on occurrences of species from reports before 1980 (Nijboer & Van den Hoorn 2003).

The taxa list of standing waters was compared with:

1. The channel dataset (with 5196 samples of small channels from all over the Netherlands);
2. The EKOO dataset (containing 664 samples of different water types from the Province of Overijssel).

For each taxon was indicated in which datasets it was found. If a taxon was not found in a database, but a taxon on higher level was available this was also indicated.

5.4 Assignment to Dutch WFD water types

All Polish water bodies were assigned to the Dutch Water Framework Directive typology to determine to which type the Polish water bodies are comparable. Elbersen et al. (2003) developed a decision tree to classify water bodies using the WFD typological criteria. This decision tree was used to classify the Polish water bodies. The R (rivers and streams) and S (springs) water bodies were classified using the scheme for rivers, the O (oxbow lakes) and L (lake) water bodies were classified using the scheme for lakes. Classification was done by comparing the abiotic data with the criteria given in the decision tree.

For rivers these criteria are based on: slope (current velocity), catchment geology, width, and permanency. Except for catchment geology, the values were directly present in the abiotic data. To determine whether the soil was calcareous or siliceous, the calcium concentration was used in combination with alkalinity. The soil type was classified as calcareous if the calcium concentration in the water was higher than 50 mg/l, or if the calcium concentration in the water was higher than 40 mg/l and alkalinity was higher than 2.0 mval/l. In all other cases the soil was considered to be siliceous. In two cases the width was exactly the width in between two classes. In these cases the water body was classified in the category with the smallest width range.

For lakes the criteria were: salinity, morphology, geology, water depth, surface area, river influence, and buffering capacity. Salinity was very low for all Polish (oxbow) lakes. Brackish waters were not included and therefore all water bodies were classified in the lowest chloride range (0-0.3 g/l). The morphology of all lakes was non-linear. Geology was again determined using the calcium concentration in combination with alkalinity as was explained for rivers. The water depth could be extracted from the data directly (using the minimum and maximum depth of two sampling seasons). The surface area was calculated using the maximum width and concerning each lake as a circle. All lakes appeared to be classified in the lowest surface area category. River influence was recorded only for the Rawka oxbow O1 and the three sites in the Pilica oxbow that is connected to the river (O8, O9 and O10), however for lakes smaller than 0.5 km^2 this is no option in the WFD decision tree. The buffering capacity was determined using alkalinity values.

5.5 Assignment to Dutch macroinvertebrate typologies

The samples of streams, springs, oxbow lakes and lakes were assigned to either the stream typology (springs, streams, and rivers) or the EKOO typology (oxbow lakes and the lake) using the macroinvertebrate data. The stream typology was built with a large dataset, including macroinvertebrate data of 2243 samples derived from water managers all over the Netherlands. Analysing these data resulted in 26 stream types. The typology includes near natural types as well as types which are disturbed by human impact (Verdonschot & Nijboer 2004). The EKOO typology was built by analysing 864 macroinvertebrate samples from the province of Overijssel (Verdonschot 1990). The main difference with the stream typology is that in the EKOO typology running as well as standing waters are included. The typology also includes degraded types. In both typologies an ecological quality class is available for each type.

To assign the Polish samples to the typologies the data had to be adjusted to the data in the typologies. Therefore:

1. The data were split in two data sets: (1)springs, streams and rivers (to be assigned to the stream typology) and (2) oxbow lakes and the lake (to be assigned to the EKOO typology);
2. A total list of taxa was made for each of the data sets;
3. Numbers indicating life history stages were removed from all taxa, except for Coleoptera and Heteroptera;
4. For each species the occurrence in the Netherlands was checked;
5. Coding of the taxa was adjusted to the coding system used for the stream typology and the EKOO typology;
6. The taxa from the oxbow lakes and the lake data were adjusted to the taxa used in the EKOO typology using an already existing 'taxonomical adjustment list'. The taxa from the springs, streams and rivers were adjusted to the taxa used in the stream typology using an already existing 'taxonomical adjustment list';
7. Taxa that did not occur in the existing translation lists were translated manually;
8. For the data of oxbow lakes and the lake: (1) species occurring in the data but not in the EKOO typology were kept if other species from the genus were present in the EKOO data, (2) if the species was not present in the EKOO data but the genus or a higher level was than the species was changed in the higher level taxon, (3) higher level (genus or family) taxa in the oxbow/lake data of which species were present in the EKOO data were removed, (4) larvae of Coleoptera and nymphae of Heteroptera were translated into the genus level taxon if this was present in the EKOO data, if not they were assigned to the adult taxon, (5) all other taxa were kept;
9. The adjustment of the taxa of springs, streams and rivers was similar to the translation of the taxa from oxbow lakes and the lake. The only difference was that larvae of Coleoptera and nymphae of Heteroptera were always assigned to the adult taxon;
10. The abundances of all taxa were transformed (${}^2\log(x+1)$) to make them comparable with the abundances in the stream and EKOO typology. Additionally, the transformed abundances in the Polish stream data >9 were changed into 9 because that was the maximum transformed abundance in the stream typology data.

The data including adjusted taxon codes and transformed abundances were assigned to the stream typology and the EKOO typology using the program ASSOCIA (Van Tongeren 2000, Verdonschot et al. 2003). This program assigns a sample to the type within a typology that is most similar. Within the program default values were used. For each sample the first and second type to which it was most similar were given as well as some measures to indicate the similarity: (1) combined index (the lower the number the more similar the sample is to the type), (2) incompleteness (the higher the number the more species that occur in the type are missing from the sample), and (3) weird species (the higher the number, the higher the number of species in the sample that do not occur in the type).

5.6 Assessment of the AQEM ecological quality class

To determine whether the data are useful as reference conditions, the ecological quality of the Polish spring and stream samples was assessed using the AQEM assessment system (Hering et al. 2004). In this program a multimetric is included for a number of European stream types. With the multimetric the ecological quality class (from 1=bad to 5=high) was calculated.

To use the system, the taxa in the data should be adjusted to the taxonomy used in the AQEM system. Therefore, samples were imported in the AQEM program. Automatically, all taxa that were not recognised by the program were listed and using a list of taxa within AQEM, for each taxon the most appropriate replacing taxon was selected. Taxa with different coding, different life history stages and taxa that were synonymous with AQEM taxa were all replaced by the code, synonym, or life history stage as it was present in the AQEM taxa list. Species that did not occur in the AQEM taxa list were replaced by the genus or by the family if the genus was not present in the AQEM taxa list. Finally, the adjusted taxa list was reduced by 25 taxa (because of assignment to a higher taxonomic level or because they were deleted from the analysis).

After importing the data and transforming the taxa list to the AQEM requirements, the ecological quality class was calculated. Two methods were used:

1. The Dutch system for small Dutch lowland streams, with the stressor 'general degradation';
2. The German system for 'Kies-, sand- und zum Teil organisch geprägte Bäche der Niederungsgebiete', with the stressor 'organic pollution';

Each system used different metrics to calculate the final ecological quality class. The quality classes resulting from the two methods were compared.

5.7 Similarity to Dutch Nature Target Types

In the Netherlands the reference conditions of a number of water types were described in the 'Handboek Natuurdoeltypen' (Bal et al. 2001). In the background documents target species and indicator species were listed for more detailed water types. Target species are species that are rare, have decreased in numbers or are of international importance (two out of these three criteria should be met). Indicator species are species that are specific for the water type. The lists include macrophytes, macroinvertebrates and fishes. The species lists were compiled using data from literature, especially literature of pristine waters in the Netherlands. It might be expected that the Polish water bodies include a large number of the species of the lists of target and indicator species, because they are considered to be suitable reference systems. Whether this is true is tested by counting the numbers of target and indicator macroinvertebrate species in the Polish water bodies. Therefore the lists of the most similar water types were used.

5.8 Dutch distribution classes

Additionally, for each sample the number of species in each of the six distribution classes was counted to determine the rarity of the species. Nijboer and Verdonschot (2004) assigned distribution classes to 1544 macroinvertebrate taxa in the Netherlands to identify their rarity. They defined six distribution classes based on the percentage of sites (in a database of samples of 7608 sites) in which a taxon occurred (very rare 0-0.15%, rare >0.15-0.5%, uncommon >0.5-1.5%, common >1.5-4%, very common >4-12%, and abundant >12% of the sites). The list of 1544 taxa and their distribution classes was used in our study to assign the distribution classes to all taxa in the Polish water bodies. It indicates whether species that are rare in the Netherlands occur often at the Polish sampling sites. In total, the data set with Polish data contained 943 taxa with a valid distribution class. Taxa of which the distribution in the Netherlands was unknown were not given a distribution class (it mainly concerned Diptera or taxa at genus or family level).

6 Results

6.1 Naturalness of Polish streams

6.1.1 Anthropogenic influences

All streams were permanent, except for R9 and R11. None of the streams was suffering anthropogenic influence, except for R1. Dredging and cleaning did not take place in any of the streams. Bank consolidation was only present in R1. There were no weirs in any of the streams. The length and transversal profile of all the streams except for R1 were natural. The vegetation was diverse. Some of the streams were surrounded by grassland, others by forest (Table 6.1). Assuming forest to be the natural vegetation, the streams in grassland were not surrounded by natural vegetation. The lack of shading has an effect on the stream temperature and the substrata in the stream (less leaves). The grassland was in most cases not intensively fertilised, therefore the effect of land use on the nutrient contents in the water will be low. Only in R2, the water of the stream was not clear.

Table 6.1 Land use in the surroundings of the springs, streams and rivers, and oxbow lakes and the presence of a wooded bank in the case of grassland.

surroundings	springs	streams and rivers	oxbow lakes
forest	S1, S2, S3, S6, S7, S8, S9, S10, S11, S12	R3, R4, R5, R6, R7, R9, R10, R12	O2, O8, O9, O10
grassland	S4, S5	R1, R2, R7, R8, R11	O1, O2, O3, O4, O5, O6, O7
wooded bank		R8	O4, O6, O7

The springs sampled were also not influenced by anthropogenic activities. All springs had natural profiles. They were not cleaned or dredged. All of them were permanent and there were no weirs in the spring brooks. In all springs the water was clear.

Reference conditions also apply to the oxbow lakes. All of the lakes had natural profiles, no cleaning or dredging took place. Therefore, some of the oxbow lakes had thick sapropelium layers at the bottom. The water in the oxbow lakes was clear, except for the water in O5 during the autumn 1999 sampling.

Compared to streams in other countries in Europe (Table 6.2) many of the criteria for reference conditions were being met in the Polish streams. Although at some sites there might have been point source pollution or other human influence, in general the water bodies chosen for this study were still natural.

Table 6.2. Criteria for the selection of reference sites for streams (modified after Hering et al. 2003) met for the reference sites of German, Italian, Dutch and Swedish stream types (white = criteria completely met, grey = criteria only partly met, and black = criteria not met) (Nijboer et al. 2004).

country	Germany					Italy				Netherlands		Sweden				
stream type	D01	D02	D03	D04	D05	I04	I02	I03	I01	N01	N02	S01	S02	S03	S04	S05
catchment size (km²)	10-100	10-100	>100-1000	10-100	>100-1000	10-100	10-100	100-1000	10-100	10-100	10-100	5-634	17-251	9-336	10-132	32-1005
ecoregion	lowlands	lowlands	lowlands	mountains	mountains	lowlands	highlands	highlands	mountains	lowlands	lowlands	lowlands	highlands	highlands	highlands	lowlands
floodplain not cultivated	■	▒	■		■	■	▒	■	▒	■	■					▒
presence of coarse woody debris	▒	▒	▒	▒	▒	▒		▒		■	▒	▒	▒	▒	▒	▒
presence of standing water bodies	■	▒	▒	▒	▒	▒		▒		■	■	▒	▒	▒	▒	▒
no bank fixation, no bed fixation												▒	▒			▒
no migration barriers	▒	▒	▒	▒	▒	■	■	■	▒			▒	▒			▒
no flood protection							■		▒	▒	▒					
presence of natural floodplain vegetation	▒	▒			▒	■	▒	▒		■	■			▒	▒	▒
natural discharge regime			■		■		■	■		▒	▒	▒	▒			▒
no sediment retention							▒	▒				▒	▒			▒
no water diversion					▒		▒	▒								
no point-source pollution			▒		▒					▒	▒					▒
no point-source eutrophication			▒		▒					▒	▒					▒
no diffuse impacts	■	▒	■	▒	■	▒		▒	▒	■	■	▒	▒	▒		▒
no acidification																
no liming																
natural thermal conditions	▒		■		■			▒								▒
natural salinity																
no introduced species						■	?	▒ ?	▒	■	■					

6.1.2 Chemical variables

Table 6.3 shows the Nature Target Types and the assignment of the Polish sampling sites to these types. The majority of the spring sites belongs to the springs with moderate mineral content and low or moderate discharge. Only S11 is mineral poor. This spring has a low pH and electric conductivity. The majority of the streams is slowly flowing except for R11 and R12. The slowly flowing streams vary in dimensions (from small upper courses to rivers). For fast flowing streams not all Nature Target Types were represented, only upper courses and small rivers.

The Pilica river, R10 is very wide (about 50 m) and therefore assigned to the large rivers. The major substrates are sand (70 %) and sand with silt (20 %), both habitat target types can be used for this river. Current velocity is high, but probably lower in the parts with sand and silt.

Table 6.3 Nature Target Types given in the Aquatisch Supplements (Nijboer 2000, Verdonschot 2000a and b), and the Polish sampling sites belonging to each Nature Target Type.

major type	detailed Nature Target Type (Aquatic Supplement)	Polish sampling sites
springs	concentrated high discharge	
springs	moderate mineral content, diffuse low discharge	S1, S3, S4, S6, S8, S9
springs	moderate mineral content, local moderate discharge	
springs	mineral poor, diffuse low discharge	S11
springs	mineral poor, local moderate discharge	
streams	(weakly) acid small upper courses	
streams	(weakly) acid upper courses	
streams	intermittent small upper courses	
streams	intermittent upper courses	R9
streams	slowly flowing small upper courses	R6, S2, S5, S10
streams	slowly flowing upper courses	R3, S7
streams	slowly flowing middle courses	R1, R8
streams	slowly flowing lower courses	R4, R5, R7
streams	slowly flowing small rivers	R2
streams	fast flowing small upper courses	
streams	fast flowing upper courses	R12
streams	fast flowing middle courses	
streams	fast flowing lower courses	
streams	fast flowing small rivers	R11
streams	(weakly) acid middle courses	
rivers	gravel and stones, slowly flowing	
rivers	gravel and stones, fast flowing	
rivers	clay and loam banks, fast flowing	
rivers	silt, slowly flowing/standing	
rivers	sand, slowly flowing	
rivers	sand, fast flowing	R10
rivers	sand with silt or detritus, slowly flowing	
oxbow lakes	shallow, isolated, moderately inundated water bodies	O2, O3, O4, O5, O6, O7
oxbow lakes	shallow, isolated, often inundated water bodies	
oxbow lakes	shallow, isolated, hardly inundated water bodies	
oxbow lakes	shallow water bodies with connection to the river	O1, O8, O9, O10
oxbow lakes	water bodies with tidal influence	
oxbow lakes	intermittent water bodies	
oxbow lakes	deep water bodies with connection to the river	
oxbow lakes	deep small isolated water bodies	
oxbow lakes	deep large isolated water bodies	

Many of the Nature Target Types were not represented. Probably they are less common. For example, the deep oxbow lake types are common for the Netherlands (they are sand or clay pits) but were not found in Poland.

6.1.2.1 Springs

S11 represents the mineral poor springs. Mineral concentrations were low and fell within the ranges given for the Nature Target Type (Table 6.4). The pH was very low (3.03) in one season, too low for this spring type actually. The oxygen saturation was too low as well during one of the sampling seasons. Nutrient contents were high in comparison to the ranges given. Only the ammonium concentration fell within the given range. Nitrate and phosphate concentrations were higher but still much lower than in many Dutch water systems.

The springs with moderate mineral content, represented by the sites S1, S3, S4, S6, S8 and S9, in general had higher mineral and nutrient contents. Only K and Mg concentrations were very low. The pH and chloride level only exceeded the given range for the 90th percentile. The ammonium content of these springs was extremely low, even fits within the range of the mineral poor springs. However, nitrate and phosphate concentrations were higher than the given ranges and much higher than in the mineral poor spring (Table 6.4).

Table 6.4 Ranges of chemical variables given for the Nature Target Types ‘mineral poor springs’ and ‘springs with moderate mineral content’. Average, 10th percentile and 90th percentile of the Polish sampling sites belonging to the respective Nature Target Type are given.

variable	springs mineral poor	S11	springs moderate mineral content	S1, S3, S4, S6, S8, S9		
		values of both samples		10th percentile	average	90th percentile
pH	4.5-5.5	3.03-5.43	6.5-7.5	7.1	7.4	7.8
ec µS/cm	<250	110-160	>250	312	357	419
O$_2$ %	>50	36.75-74.1	>50	74	80	86
Fe^{2+} mg/l	<0.2	0.07-0.12	<0.2	0.02	0.14	0.19
Ca mg/l	<30	19.55-14.36	>30	49.3	67.0	97.7
Na mg/l	<10	3.2-3.3	3-20	4.42	7.16	9.52
K mg/l	<4	1.13-1.26	4-30	0.96	1.24	1.53
Mg mg/l	<5	3.03-3.46	>5	2.40	4.61	6.25
Cl mg/l	<25	9.37-9.86	<25	3.63	13.07	26.48
NH$_4$ mgN/l	<0.4	0.19-0.2	<0.4	0.01	0.03	0.04
NO$_3$ mgN/l	0	0.14-0.28	<0.35	0.56	4.11	5.74
o-P mgP/l	<0.007	0.065-0.082	<0.034	0.091	0.133	0.193
t-P mgP/l	<0.015	0.023-0.026	<0.040	0.137	0.179	0.231

Table 6.5 Ranges of chemical variables given for the Nature Target Types described for streams. Average, 10th percentile and 90th percentile of the Polish sampling sites belonging to the respective Nature Target Type are given.

variable	large river, substrate sand (with silt)	R10	intermittent upper courses	R9	fast flowing upper courses	R12	fast flowing small rivers	R11	slowly flowing small upper courses - lower courses	S2, S5, S7, S10, R1, R3, R4, R5, R6, R7, R8			slowly flowing small rivers	R2
		2 values		2 values		2 values		2 values		10th percentile	average	90th percentile		
pH			5.5 – 7.5	7.79	6.5 – 8.5	7.5-7.9	6.5 – 7.5	8.1-8.2	5.5 – 7.5	7.2	7.5	7.9	6.5 – 8.5	7.3-8.1
ec mS/cm			< 250	387	250 - 500	270-310	250 – 500	453-470	100 – 250	231	340	409	250 – 500	226-326
Cl mg/l	<300	9.8-10.6	40 – 120	13.8	20 – 40	9.4-10.5	10 – 20	11.7-13.3	10 – 20	7.1	12.1	16.7	10 – 40	7.7-9.2
NH_4 mgN/l	<0.4	0.08-0.1	< 0.4	0.12	< 0.08	0.1-0.2	< 0.4	0.04-0.06	< 0.4	0.02	0.07	0.11	< 0.4	0.06-0.08
NO_3 mgN/l	<0.46	0.89-1.0	< 0.46	1.161	0	0.1-0.18	< 0.35	1.31-2	< 0.35	0.37	2.28	6.16	< 0.46	0.620.75
t-P mgP/l	<0.1	0.049-0.11	< 0.040	0.14	< 0.015	0.052	< 0.040	0.065-0.14	< 0.040	0.029	0.127	0.193	< 0.10	0.020-0.098

Table 6.6 Ranges of variables in Dutch, German and Danish (almost) natural streams.

chemical variable	Netherlands (STORA 1989)	Netherlands (Verdonschot et al. 2002)	Germany	Denmark
pH	6.59-7.18		7.1-8.3	5.7-7.2
electric conductivity microS/cm	113-440		295-644	
chlorides mg Cl/l	9.0-43.5		24-68	
ammonia nitrogen mg $N(NH_4)$/l	0.05-0.26	0.03-0.3	0.06-0.45	0.00-0.03
nitrate nitrogen mg $N(NO_3)$/l	0.16-8.6	0.83-5.08	16-42	
ortho-phosphates mg PO_4/l	<0.01-0.06	0.006-0.12	0.06-0.21	0.002-0.006
phosphates mg PO_4/l	0.01-0.19	0.024-0.19	0.06-0.38	

All chloride concentrations were very low and fell within the given ranges. The values of R2 and R12 were even below the range (Table 6.5). For the large river R10 all concentrations were within the given ranges, except for the nitrate concentration which was about twice as high. The intermittent upper course, R9 did not fit well in the Nature Target Type concerning the chemical variables. pH, electric conductivity, nitrate and total phosphate concentrations were higher than the range given for the type. For the fast flowing upper courses the ranges were higher for pH and electric conductivity and the Polish system R12 fitted well within these ranges. The nutrient concentrations were all higher than the ranges given. This goes for the fast flowing small river R11 as well. In this type also the pH was higher than the given range. The slowly flowing streams (from small upper to lower courses) had a relatively high pH and electric conductivity. Chloride and ammonium concentrations were within the given ranges. Nitrate and phosphate concentrations exceeded the given ranges in most cases.

In a number of cases the nutrient ranges were not met. This goes mostly for nitrate and phosphate. Table 6.6 shows ranges for these variables in some other near natural streams. The Table illustrates that nitrate values were highly variable and could reach high concentrations. Phosphates were within the same range as in the Polish systems. The question is whether the ranges for the Nature Target Types are to low or that many of the Polish water bodies that still look natural are polluted by nutrients as well.

6.1.2.2 Oxbow lakes

Table 6.7 Ranges of chemical variables given for the Nature Target Types described for shallow oxbow lakes. Average, 10th percentile and 90th percentile of the Polish sampling sites belonging to the respective Nature Target Type are given.

chemical variables	shallow, isolated, <20 days/year inundated water bodies	O2, O3, O4, O5, O6, O7			shallow water bodies often inundated or with connection to the river	O1, O8, O9, O10		
		10th perc.	average	90th perc.		10th perc.	average	90th perc.
chlorides mg Cl/l	<300	4.0	7.8	12.6	<300	9.5	11.6	13.2
ammonia nitrogen mg N/l	<0.4N	0.10	0.14	0.23	<0.4N	0.04	0.09	0.15
nitrate nitrogen mg N/l	<0.35N	0.10	0.23	0.49	<0.46N	0.10	0.66	1.13
ortho-phosphates mg P/l	<0.03P	0.065	0.11	0.19	<0.07P	0.07	0.095	0.12
phosphates mg P/l	<0.04P	0.023	0.036	0.065	<0.1P	0.026	0.029	0.039

For oxbow lakes the Nature Target Types only describe nutrient contents and chloride concentrations (Table 6.7). The Polish oxbow lakes had very low chloride and ammonium concentrations, as was found in the other water types as well. The nitrate concentrations were within the given range for some of the oxbow lakes. The ortho-phosphate range was exceeded, but values of total phosphates were mostly within the given ranges. It is strange that the total phosphate concentration was often lower than the ortho-phosphate concentration. Probably this was due to the analysing method.

6.2 Comparability of macroinvertebrate data

Macroinvertebrate data collected in Poland were comparable with Dutch data collected with a standardised protocol. In the Polish data more individuals and taxa were collected except for springs, where the numbers of taxa and specimens were relatively low (Table 6.8). The matrix with taxa and samples was filled for 15-27 % with data. That is a high percentage compared to the Dutch data of EKOO and the stream typology. This means that the samples are less different and diverse than in the Dutch data. This was expected because the Dutch data include many more samples, including more varying water bodies. For qualitative data comparison and use for the description of reference conditions the Polish data are suitable, as long as the abundances are given proportionally, e.g. in percentages instead of absolute numbers.

Table 6.8 Structure of Polish data and Dutch data (EKOO and Stream typology).

data parameter	Polish water bodies				Dutch water bodies	
	streams and rivers	oxbow lakes	springs	lake	EKOO	stream typology
total number of samples	24	20	24	2	666	2243
total number of taxa	563	525	211	104	1289	1864
total number of individuals	122220	93441	24491	10379	763561	3696012
average number of taxa per sample	84	140	31	54	59	45
average number of individuals per sample	5093	4672	1020	5190	1146	1648
percentage matrix coverage	15%	27%	15%	52%	5%	2%

6.3 Comparing taxa lists

Less than 5% of all taxa (32 taxa) observed in the Polish data are not known from the Netherlands. This means most taxa occur in both countries. Appendix 15 shows the occurrence in Polish samples and Dutch data sets for each taxon. The taxa that are unknown from the Netherlands are listed in Table 6.9. These taxa belong to different taxonomic groups thus unfamiliarity for the Netherlands is probably not due to identification difficulties. Most of these species occur in low numbers and therefore probably have a minor role in the macroinvertebrate community. Only two species of Baetidae and *Cryptochironomus borysthenicus* occurred in higher numbers and might be important in the community. It would be useful to investigate which species has a similar role in the Dutch systems.

Table 6.9 Taxa observed in the Polish water bodies but not occurring in the Netherlands.

taxon name	no. of sites	mean abundance
Agabus subtilis	1	1
Agnetina elegantula	2	1
Anabolia furcata	9	5
Analycus armatus	1	1
Athripsodes bilineatus	1	3
Atractides acutirostris	1	5
Atractides pavesii	2	1
Baetis calcaratus	2	14
Caspiobdella fadejewi	1	1
Cercyon analis	3	4
Cryptochironomus borysthenicus	5	21

Ephemerella karelica	1	2
Hygrobates norvegicus	2	7
Labiobaetis tricolor	2	179
Larsia curticalcar	7	4
Lebertia exuta	2	1
Lebertia pilosa	1	2
Lebertia safvei	1	5
Lebertia shadini	1	3
Leuctra hippopus	1	4
Limnophyes prolongatus	2	1
Limnoxenus picipes	7	2
Mideopsis roztoczensis	4	6
Nais christinae	1	2
Paracladius alpicola	1	1
Parametriocnemus boreoalpinus	1	1
Parapoynx nivalis	4	5
Rheosmittia languida	1	8
Rheotanytarsus curtistylus	1	2
Sinurella ambulans	3	5
Tonnoiriella nigricauda	4	6

6.4 Assignment to Dutch WFD water types

The classification of the Polish water bodies is given in detail in Appendix 16, which includes environmental variables and the categories in which the water body belongs. The rivers were classified using the Dutch WFD typology (Table 6.10). Only two rivers could not be classified using the criteria given in Elbersen et al. (2003). These were two sites at the Pilica river, a very wide calcareous river. This combination of large width and a calcareous geology does not regularly occur in the Netherlands and was therefore not included in the decision tree. The WFD water type that was most similar to the river Pilica was WFD-R16: Fast flowing river on sand or gravel.

It appeared that only 8 (including WFD-R16) out of 18 river types were represented by the Polish river sites. River types that were not represented are: Temporary spring (WFD-R1), slowly flowing middle/lower course on sand (WFD-R5), slowly flowing river on sand/clay, freshwater tidal river on sand/clay (R8), slowly flowing upper, middle/lower course on peat (WFD-R11 and R12), fast flowing upper, middle/lower course on sand (WFD-R13 and R14), fast flowing river on calcareous soil (WFD-R15), and fast flowing middle/lower course on calcareous soil (WFD-R18).

The oxbow lakes studied were all classified as shallow, calcareous lakes (Table 6.11). Only one oxbow lake was classified as deep, calcareous lake. The temporary lake was classified as weakly buffered lake. In this lake alkalinity and calcium concentration were lower than in all other oxbow lakes.

Table 6.10 Assignment of Polish streams, rivers, and spring to the Dutch WFD typology.

site code	site name	WFD type code	WFD type name
R1	Jeżówka River	WFD-R10	Slowly flowing middle course on calcareous soil
R2	Czarna river	WFD-R6	Slowly flowing small river on sand/clay
R3	Stobnica stream	WFD-R4	Permanent, slowly flowing upper course on sand
R4	Gać River (swamp stream)	WFD-R10	Slowly flowing middle course on calcareous soil
R5	Gać River (near Spała)	WFD-R10	Slowly flowing middle course on calcareous soil
R6	Sulejów stream	WFD-R9	Slowly flowing upper course on calcareous soil
R7	Grabia river	WFD-R10	Slowly flowing middle course on calcareous soil
R8	Brodnia river	WFD-R10	Slowly flowing middle course on calcareous soil
R9	Rawka river temporary stream	WFD-R3	Temporary, slowly flowing upper course on sand
R10	Pilica river (Sulejów)	no type available (WFD-R16)	Fast flowing river on sand or gravel
R11	Pilica river (Maluszyn)	no type available (WFD-R16)	Fast flowing river on sand or gravel
R12	Forest stream (Gać)	WFD-R17	Fast flowing upper course on calcareous soil
S1	Dobieszków spring I	WFD-R2	Permanent spring
S2	Dobieszków spring outflow	WFD-R10	Slowly flowing middle course on calcareous soil
S3	Dobieszków spring II	WFD-R2	Permanent spring
S4	Imielnik spring	WFD-R2	Permanent spring
S5	Imielnik spring outflow	WFD-R9	Slowly flowing upper course on calcareous soil
S6	Janinów spring	WFD-R2	Permanent spring
S7	Janinów spring outflow	WFD-R2	Permanent spring
S8	Rochna spring	WFD-R2	Permanent spring
S9	Grotniki spring	WFD-R2	Permanent spring
S10	Grotniki spring's outflow	WFD-R9	Slowly flowing upper course on calcareous soil
S11	Acid spring (near Ldzań)	WFD-R2	Permanent spring
S12	Acid spring' s outflow (near Ldzań)	WFD-R4	Permanent slowly flowing upper course on sand

Table 6.11 Assignment of Polish lakes to the Dutch WFD typology..

site code	site name	WFD type code	WFD type name
L1	Lake near Paskrzyn	WFD-M12	Shallow, weakly buffered lake
O1	Rawka oxbow 1 (connection with river)	WFD-M22	Shallow, calcareous lake
O2	Rawka oxbow 2	WFD-M24	Deep, calcareous lake
O3	Rawka oxbow 3	WFD-M22	Shallow, calcareous lake
O4	Grabia oxbow I Zimne Wody	WFD-M22	Shallow, calcareous lake
O5	Grabia oxbow II	WFD-M22	Shallow, calcareous lake
O6	Grabia oxbow III (with culvert)	WFD-M22	Shallow, calcareous lake
O7	Pilica small oxbow	WFD-M22	Shallow, calcareous lake
O8	Pilica large oxbow site III	WFD-M22	Shallow, calcareous lake
O9	Pilica large oxbow site II	WFD-M22	Shallow, calcareous lake
O10	Pilica large oxbow site I	WFD-M22	Shallow, calcareous lake

6.5 Assignment to Dutch macroinvertebrate typologies

6.5.1 EKOO typology

Table 6.12 shows the assignment of the Polish macroinvertebrate samples to the Dutch EKOO typology. Most oxbow lakes were assigned to type P8: 'large channels and small, shallow lakes'. The ecological quality class of this type is 3, moderate. The oxbow lakes O1 (Rawka oxbow 1) and the spring sample of O2 (Rawka oxbow 2) were assigned to R4, organically polluted small to medium sized channels with bad ecological quality (class 1). The same result (R4) was observed for the three sites in the large oxbow in connection with the Pilica river, O8 t/m O10, although assignment to R9, regulated lower courses also occurred here. Assignment to R4 or R9 probably occurs when there is influence from the river, either by inundation with river water or by an open connection with the river itself. The lake was identified as type R2, wide peat channels or S9, saprobic stream ponds/temporary regulated upper courses with moderate and poor ecological quality, respectively. This can not be explained with the data. Probably, the temporary character of this lake causes the presence of drought tolerating species which also occur in temporary streams.

The ecological quality of the EKOO types to which the samples were assigned is not indicating reference conditions for the Polish sites. However, this can be caused by the fact that oxbow lakes are very poorly represented in the EKOO typology and therefore the sites are assigned to other water types which are most similar. Because oxbow lakes are often eutrophic, similar types in the typology are connected to a low quality.

That the Polish samples do not fit in the assigned types very well is illustrated by Appendix 17, in which the values of the combined index are in general very high, which indicates a low similarity between the sample and the type. Also the numbers of weird species are high, thus there are many species in the samples that do not occur in the types the samples were assigned to.

Table 6.12 Assignment of the Polish samples to the EKOO typology (eqc = ecological quality class).

sample code	EKOO type	EKOO name	eqc
L1me00	R2	wide peat channels	3
L1no99	S9	saprobic stream ponds/temporary regulated upper courses	2
O1jl00	R4	organically polluted small to medium sized channels	1
O1se99	R4	organically polluted small to medium sized channels	1
O2jl00	R4	organically polluted small to medium sized channels	1
O2se99	P8	large channels and small, shallow lakes	3
O3jl00	P8	large channels and small, shallow lakes	3
O3se99	P8	large channels and small, shallow lakes	3
O4jn00	P8	large channels and small, shallow lakes	3
O4ok99	P8	large channels and small, shallow lakes	3
O5jn00	P8	large channels and small, shallow lakes	3
O5ok99	P8	large channels and small, shallow lakes	3
O6jn00	P8	large channels and small, shallow lakes	3
O6se99	P8	large channels and small, shallow lakes	3
O7jn00	P8	large channels and small, shallow lakes	3
O7ok99	P8	large channels and small, shallow lakes	3
O8jn00	R4	organically polluted small to medium sized channels	1
O8ok99	R9	regulated lower courses	2-3
O9jn00	R4	organically polluted small to medium sized channels	1
O9ok99	R4	organically polluted small to medium sized channels	1
O10jn00	R4	organically polluted small to medium sized channels	1
O10ok99	R9	regulated lower courses	2-3

6.5.2 Stream typology

The stream and river samples were assigned to the Dutch macroinvertebrate stream typology. Table 6.13 shows that most samples of streams and rivers were assigned to type 3a: ‘fast flowing, semi-natural upper-middle courses of streams’, having a moderate to good ecological quality. Samples of R3, R6 and R9 were assigned to type 7: ‘temporary, nearly natural small upper courses’, with moderate to good ecological quality as well. Samples of R10 and R11 were mainly assigned to type 19, including ‘semi-natural lower courses’. The autumn samples of R4 and R5 were assigned to type 10, indicating pollution. This might be due to the high amount of fine organic material, silt, leaves and detritus in autumn, which causes the presence of taxa indicating organic pollution as well. This can not be the reason for assignment to type 10 of the summer sample of R11, the large river Pilica. There might be real pollution in this river. The occurrence of pollution only in spring could be related to the discharge. This should be further investigated.

Table 6.13 Assignment of the Polish stream and river samples to the Dutch stream typology, including the ecological quality class (eqc) belonging to the stream typology types .

sample	stream type code	stream type name	eqc
R1me99	3a	fast flowing, semi natural upper-middle courses	3-4
R1no98	3a	fast flowing, semi natural upper-middle courses	3-4
R2me99	3a	fast flowing, semi natural upper-middle courses	3-4
R2no98	3a	fast flowing, semi natural upper-middle courses	3-4
R3ap99	7	temporary nearly natural small upper courses	3-4
R3ok98	3a	fast flowing, semi natural upper-middle courses	3-4
R4jn99	3a	fast flowing, semi natural upper-middle courses	3-4
R4no98	10	polluted, slowly flowing upper-middle courses	2
R5jn99	3a	fast flowing, semi natural upper-middle courses	3-4
R5no98	10	polluted, slowly flowing upper-middle courses	2
R6ap99	7	temporary nearly natural small upper courses	3-4
R6ok98	7	temporary nearly natural small upper courses	3-4
R7jn99	3a	fast flowing, semi natural upper-middle courses	3-4
R7ok98	3a	fast flowing, semi natural upper-middle courses	3-4
R8me99	3a	fast flowing, semi natural upper-middle courses	3-4
R8ok98	3a	fast flowing, semi natural upper-middle courses	3-4
R9ap99	7	temporary nearly natural small upper courses	3-4
R9ok98	7	temporary nearly natural small upper courses	3-4
R10au99	19	semi-natural lower courses	3
R10jn00	19	semi-natural lower courses	3
R11jn00	10	polluted, slowly flowing upper-middle courses	2
R11se99	19	semi-natural lower courses	3
R12me0	24c	(fast) flowing almost natural small upper courses	3-4
R12no99	24c	(fast) flowing almost natural small upper courses	3-4

The samples of the springs were mainly assigned to the Dutch types 21 and 24c, almost natural small upper courses (Table 6.14). The small difference between these two types is the current velocity. The ecological quality of these types is mainly good. The spring samples of S11 and S12 (the acid spring and it's outflow) were assigned to type 10, indicating organic pollution. The acid conditions are special and therefore, the samples might be species poor or become similar to sites that are organically polluted containing the same tolerant taxa. The autumn samples of both S11 and S12 were assigned as type 7, indicating that these water bodies are temporary. However, in the Netherlands temporary waters are often acid as well and therefore this site could be assigned to this type. There was no dry period recorded for this site.

Table 6.14 Assignment of the Polish spring samples to the Dutch stream typology, including the ecological quality class (eqc) belonging to the stream typology types.

sample code	stream type code	stream type name	eqc
S1me99	21	fast flowing almost natural small upper courses	4
S1no98	21	fast flowing almost natural small upper courses	4
S2me99	24c	(fast) flowing almost natural small upper courses	3-4
S2no98	24c	(fast) flowing almost natural small upper courses	3-4
S3me99	21	fast flowing almost natural small upper courses	4
S3no98	24c	(fast) flowing almost natural small upper courses	3-4
S4me99	24c	(fast) flowing almost natural small upper courses	3-4
S4no98	21	fast flowing almost natural small upper courses	4
S5me99	24c	(fast) flowing almost natural small upper courses	3-4
S5no98	24c	(fast) flowing almost natural small upper courses	3-4
S6me99	24c	(fast) flowing almost natural small upper courses	3-4
S6no98	24c	(fast) flowing almost natural small upper courses	3-4

S7me99	21	fast flowing almost natural small upper courses	4
S7no98	24c	(fast) flowing almost natural small upper courses	3-4
S8jn99	24c	(fast) flowing almost natural small upper courses	3-4
S8no98	24c	(fast) flowing almost natural small upper courses	3-4
S9me99	21	fast flowing almost natural small upper courses	4
S9no98	21	fast flowing almost natural small upper courses	4
S10me99	21	fast flowing almost natural small upper courses	4
S10no98	24b	(fast) flowing natural (small) upper courses	4
S11me00	10	polluted, slowly flowing upper-middle courses	2
S11no99	7	temporary nearly natural small upper courses	3-4
S12me00	10	polluted, slowly flowing upper-middle courses	2
S12no99	7	temporary nearly natural small upper courses	3-4

Appendix 18 shows that the values for the combined index are lowest for the spring samples, indicating that these samples are more similar to the assigned spring types than the stream samples and oxbow samples. Also, the numbers of weird species are lowest for spring samples. Remarkable is that the incompleteness is highest for the spring samples. This means that a number of species that occur in the spring types do not occur in the Polish spring samples.

6.6 Assessment of the AQEM ecological quality class

The ecological quality classes were determined using the AQEM assessment system. The results are shown in Table 6.15. In general, the scores of the German system were higher than those of the Dutch system (0.8 for streams and rivers and 0.6 for springs). In some cases the deviation between scores was two classes. The German system seemed to be more stable. The Dutch system gave different results between seasons at one site in more cases. That seasonal differences can give contradictory results appeared from R6, which scores class 3 in spring with both systems but 4 in autumn with the German system and 2 in autumn with the Dutch system.

The springs had a higher ecological quality than the streams and rivers. This was the case for both, the German and the Dutch method. The springs scored on average 1 class higher than the streams and rivers. Most of the springs got class 5, reference conditions. The mean score for all springs is 4.5. From this analysis can be concluded that the Polish springs are natural and can be used as reference conditions. There are two exceptions, S5 scored class 2 with the Dutch system in autumn, although both methods resulted in class 5 in springtime. S11 and S12 gave lower scores overall, with both systems. This might be due to the acidity at this site, which is the reason why many species that normally occur in springs are lacking. Determining an ecological quality class with a system based on pH-neutral springs is not suited for these sites.

The rivers had a lower ecological quality. The German system resulted in an average score of 3.9. The Dutch system resulted in an average score of 3.1 and gave different scores between seasons for a number of sites. In general, the streams and rivers are further from reference conditions than the springs. This might be due to the fact that the smaller waters (the S types) are more often situated in natural area and the larger streams and rivers flow in most cases also trough agricultural areas. Moreover, the larger streams and rivers are more influenced by discharges from villages because they have already travelled over a great distance. That the streams and rivers were not assessed as reference conditions might also be an artefact of the assessment system, which is based on German and Dutch data, in which the larger systems are often more disturbed than the smaller ones. Still class 4 is higher than most Dutch streams and rivers get using the system and therefore the description of the conditions in these waters is useful.

R5, R6 and R9 get low scores with both systems. Probably these streams do not fit in the assessment system. R5 and R6 are both streams in the Gać catchment situated in swamp forests. In these streams there is much organic material, which might lead to high saprobic values. In the assessment system this results in lower scores, although it is a natural phenomenon in these streams. R9 is a temporary stream, which is often species poor. Temporary streams are not included in the assessment system and therefore the resulting ecological quality class is underestimated.

Table 6.15 Ecological quality classes for streams, rivers and springs resulting from the AQEM assessment system.

stream/river sample	German method	Dutch method	mean score	spring sample	German method	Dutch method	mean score
R1me99	4	4	4	S1me99	5	5	5
R1no98	4	4	4	S1no98	5	5	5
R2me99	4	3	3.5	S2me99	5	5	5
R2no98	4	3	3.5	S2no98	5	4	4.5
R3ap99	4	2	3	S3me99	5	5	5
R3ok98	5	5	5	S3no98	5	5	5
R4jn99	4	3	3.5	S4me99	5	5	5
R4no98	4	3	3.5	S4no98	5	5	5
R5jn99	3	2	2.5	S5me99	5	5	5
R5no98	3	2	2.5	S5no98	5	2	3.5
R6ap99	3	3	3	S6me99	5	4	4.5
R6ok98	4	2	3	S6no98	5	4	4.5
R7jn99	4	5	4.5	S7me99	5	5	5
R7ok98	4	4	4	S7no98	5	4	4.5
R8me99	4	2	3	S8jn99	5	4	4.5
R8ok98	4	4	4	S8no98	5	5	5
R9ap99	3	2	2.5	S9me99	5	5	5
R9ok98	4	3	3.5	S9no98	5	5	5
R10au99	4	4	4	S10me99	5	5	5
R10jn00	4	3	3.5	S10no98	5	5	5
R11jn00	4	4	4	S11me00	3	1	2
R11se99	4	4	4	S11no99	4	2	3
R12me00	4	2	3	S12me00	4	3	3.5
R12no99	4	2	3	S12no99	4	3	3.5
mean score	3.9	3.1	3.5	mean score	4.8	4.2	4.5

6.7 Similarity to Dutch Nature Target Types

6.7.1 Target species

The number of target species from each Nature Target Type found in the Polish samples is given in Appendix 18 for springs, streams and rivers. In most spring samples one or two target species were found, especially target species from spring types, as was expected. Target species described in spring target types were hardly found in streams. The other way around were target species described for stream types found in springs as well. In general, in streams and rivers the number of target species described for the types and found in the samples was larger than in springs.

Of the large river types few target species were found. Even in R10, the only sample assigned to the large river types the number was low, only 1 or 2 % of the available target species in the type were found in the samples. On the other hand, R10 has many target species of slowly flowing small rivers, lower courses and middle courses. Probably the macroinvertebrate community fits better to the community described for small rivers than for large rivers. This might be due to the fact that the descriptions of the large river type were made for the large rivers Rhine and Meuse, which are inhabited by a specific community.

For the other streams the results were similar. None of the streams has the highest number of target species for the type it was assigned to, although deviations were small (for example a larger or smaller stream type). Not all Nature Target Types have similar numbers of target species and target species overlap between types, because they can occur in more than one type. However, there are target species that are specific, e.g. in the intermittent small upper courses and upper courses, 5 and 4 target species were described, respectively. One of these species was only found in R9, the intermittent stream.

Overall, of each river type 12 % of the target species was found, of each spring type 27% and of each stream type 37 % (Table 6.16).

No target species of the oxbow lake types were found in the Polish oxbow lake samples (Appendix 19). To compare the oxbow lakes with other standing waters, some similar types (water types on peaty soil and channel types) were added. From these types target species were found, up to 60 % of the target species for eutrophic lakes. Target species were mainly found in O2, O3, the two Rawka oxbow lakes without connection to the river and O6 (Grabia oxbow lake) and O7 (Pilica isolated oxbow lake).

Table 6.16 Percentage of target and indicator species described in the Nature Target Types that was found in the Polish water bodies (in brackets the number of water types is given for the main types).

water type	% of species	
	target	indicator
rivers (3)	12	38
springs (4)	37	44
streams (12)	27	42
oxbows (5)	0	39

6.7.2 Indicator species

There were more indicator species found than target species. The percentages are about 40 % for all main water types (Table 6.16). Appendix 20 shows that R10, the only large river, again has more indicator species of the stream types than of the river types. Remarkable is the relatively high number (18) of indicator species of the habitat gravel and stones in fast flowing water, because this substrate was not recorded. Possibly it was still present or indicator species given for gravel and other hard substrates are not that specific.

The springs again show the highest numbers of indicators described for the spring types, although indicator species from springs occurred as well. Indicator species from river types were scarce in the springs. Note that the springs outflows, which are slowly flowing (small) upper courses contained more indicator species from the spring types than from these small upper course types. Probably samples were taken close to the spring, where the macroinvertebrate species composition looks more like the spring composition than the stream composition. In all springs similar number of indicator species from springs with moderate mineral content and mineral poor springs were found. Probably the differences between these types are small and indicator species overlap. This was also shown by S11; the only mineral poor spring that has more indicators of springs with moderate mineral content.

In the streams most indicator species were found, most of them described for stream types but also indicator species from river and spring types often occurred. The same results as for target species was found: the streams and rivers contained many indicator species of many different stream types. The relation between the samples and the stream types they belong to can not be seen in the results. For example, the fast flowing streams R11 and R12 had higher numbers of indicator species of the slowly flowing stream types.

It can be concluded that overall about 40 % of the indicator species were found in the Polish data, which is a high percentage. However, the overlap between types is large and the indicators seem not to be type specific.

Of the Nature Target oxbow lake types the type ‘shallow, isolated hardly inundated water bodies’ the highest percentage (74%) of indicator species was found in the Polish oxbow lakes (Appendix 21). The number of indicator species of this type was lower for the open Pilica oxbow (O8, O9 and O10), which was expected. However, for O1, the other oxbow lake with an open connection with the river, this was not the case. Other high percentages were found for different other standing water types: clay channels (82 %), eutrophic peat channels (65 %), and meso-eutrophic small channels (69 %). These percentages are high which suggests a high similarity with these types. Probably there is a high overlap between indicator species in standing water types.

6.8 Dutch distribution classes

For each taxon the Dutch distribution class was added to see how many and which taxa that are rare in the Netherlands occur in the sampled Polish water bodies. Distribution classes could not be assigned to all taxa, because they were at family, genus or variety level, because the distribution class of a species is unknown, or because the taxon does not occur in the Netherlands.

It appeared that oxbow lakes and stream and rivers almost show the general pattern: from many abundant to few very rare species (Figure 6.1). Only the number of very rare species is very high in streams (59). In springs, the pattern is completely different, of each distribution class a similar number of taxa is present and the number of abundant taxa is low. Probably the springs have a special environment to which very common and abundant species have not adapted.

Five species which are extinct in the Netherlands occurred in the Polish streams and oxbow lakes (Figure 6.1, Appendices 23 and 24): *Albia stationis* (streams), *Brachypoda modesta* (streams), *Ecdyonurus affinis* (streams and oxbow lakes), *Isonychia ignota* (streams) and *Siphlonurus aestivalis* (streams and oxbow lakes).

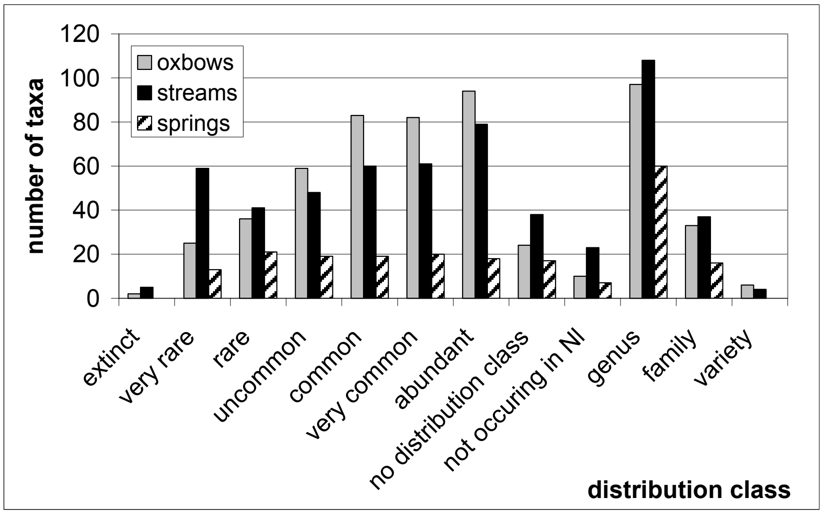

Figure 6.1 Total number of taxa in each distribution class for oxbow lakes, springs & streams/rivers.

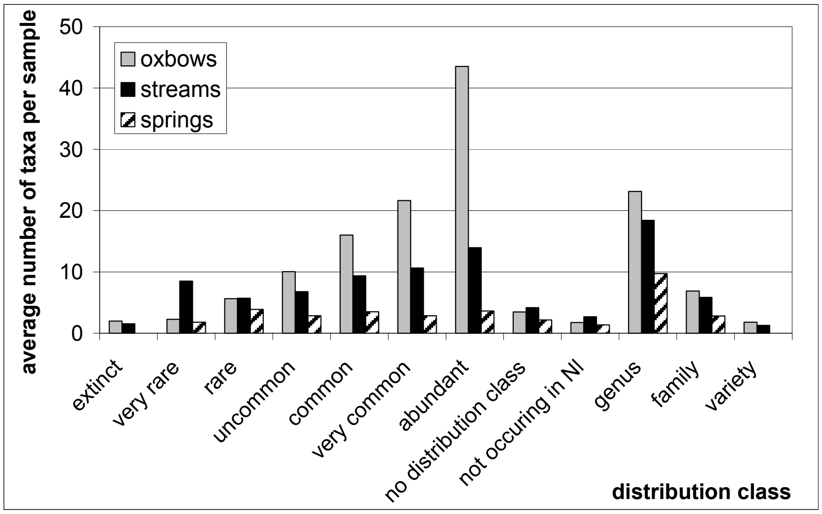

Figure 6.2 Average number of taxa per sample in each distribution class for oxbow lakes, springs, streams and rivers.

Figure 6.2 shows the average number of rare taxa in the samples. The numbers of rare species in samples of the Polish streams and rivers and oxbow lakes were much higher than in Dutch data of the stream typology and channel typology. In the Dutch stream typology the average number of rare taxa (very rare, rare and uncommon taxa added) is 2.2. Only 15 % of the samples has more than 4 rare species. The stream types with the highest quality have 3-4 rare taxa per sample. In the Polish data the number of rare taxa in streams was about 20. In the springs the numbers were lower but still about 10.

The oxbow lakes had high numbers of rare species as well (about 20 very rare, rare and uncommon species per sample). There are no Dutch oxbow lake data to compare these numbers with. The only standing water data base is the channel database. In the Dutch channels the number of rare species is low, an average of 0.8 rare taxa per sample. This is due to the quality of the channels which often are situated in heavily fertilised agricultural areas. Channels especially chosen and sampled to describe reference conditions (the 10 best channels of the Netherlands) showed an average number of 9 rare species per sample. Probably the quality of the oxbow lakes is even better. The number of rare species is often related to naturalness (Nijboer 2006). This means that the Polish waters would have a good quality and that they can serve as reference conditions for Dutch water bodies. On the other hand, oxbow lakes might always have more rare species because they sometimes contain standing water species and running water species.

The numbers of rare species per sample were relatively low in the springs compared to the two other water types (Figure 6.2), but this is due to the overall low species richness in the spring samples. The highest numbers were found in S8 (Rochna spring), S11 (only in the spring season) and S12 (acid spring and its outflow) (Figure 6.3). The high numbers in S11 and S12 were expected because this is a very special habitat in which only species that have adapted to acid conditions can survive. These species are rare because they can not compete in other habitats. The lowest numbers were observed in S4 (Imielnik spring), S7 (Janinów spring outflow), S9 and S10 (Grotniki spring and its outflow). The other springs had intermediate values. In some cases the spring itself had the highest number of rare species, in other cases the spring outflow had the highest number. In some springs the differences between the two seasons were large, for example in S11 (Figure 6.3).

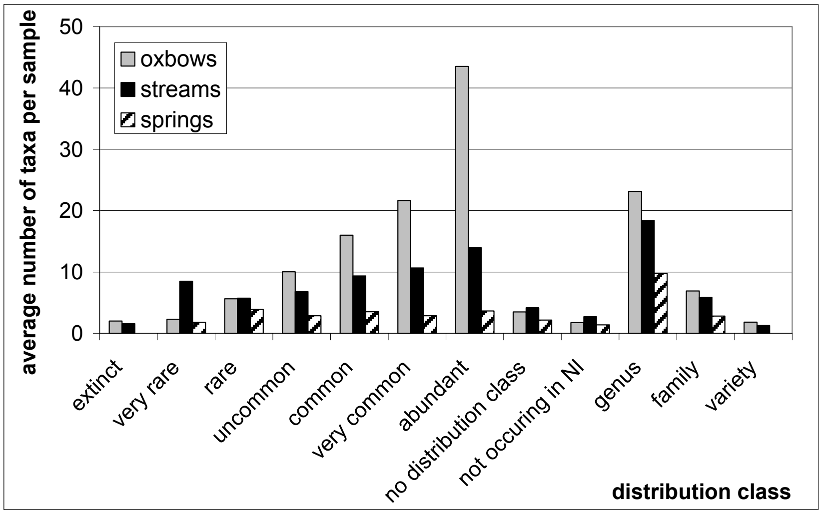

Figure 6.3 The number of rare species (extinct, very rare, rare and uncommon) in spring samples.

In streams and rivers the highest numbers of rare species were found. R11 contained 53 rare species in June (Figure 6.4). Together with R10 this site had over 40 rare species in each season. R10 and R11 are both sites in the Pilica river. Also the Grabia river (R7) had high numbers of rare species in both seasons. Lowest numbers were found in R5 (Gać river near Spała), R6 (Sulejów stream), R8 (Brodnia river) and R9 (Rawka, temporary stream). These sites had 12 or less rare species in each season.

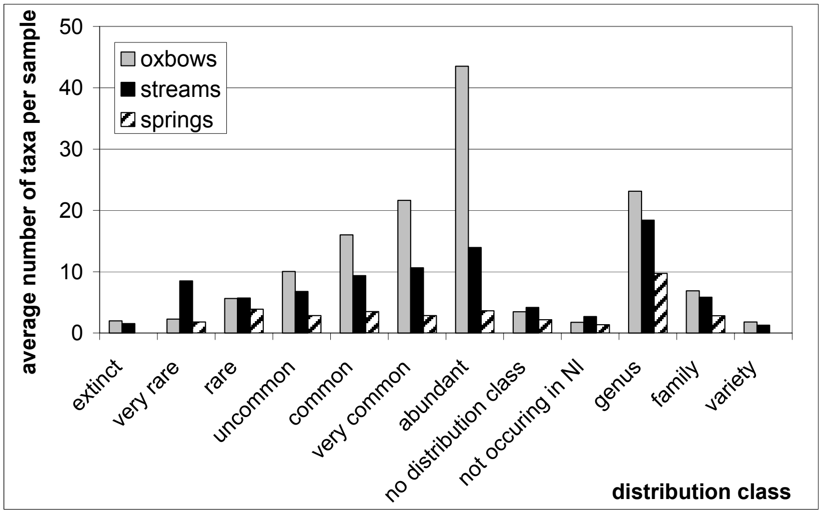

Figure 6.4 The number of rare species (extinct, very rare, rare and uncommon) in stream and river samples.

In the oxbow lakes the highest number (31) of rare species (extinct, very rare, rare and uncommon species) was found in O9, the middle site in the large Pilica oxbow (Figure 6.5). At the other sites in this oxbow (O8 and O10) the numbers were much lower). O9 even had 2 species that are extinct from the Netherlands. O5, O6 and O10 had the lowest numbers of rare species. O10 is the site in the large oxbow near the connection with the Pilica river. O5 and O6 are both Grabia oxbow lakes. O4, also a Grabia oxbow lake had a higher number of rare species. The oxbows in the Rawka catchment contained more rare species than the ones in the Grabia catchment.

There were differences in the numbers of rare species between seasons (e.g. for O7), but the season in which numbers were highest is not the same at all sites.

In the lake the number of rare species was high in spring (24) but very low in autumn (3), probably because the lake had fallen dry.

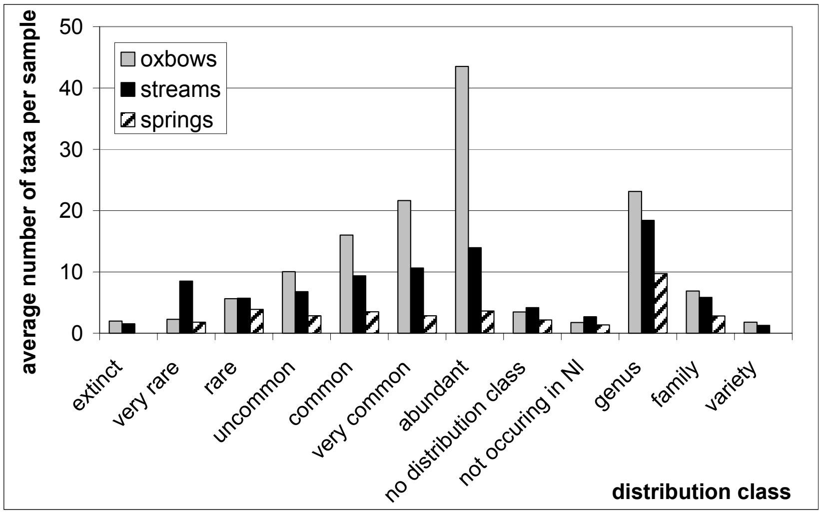

Figure 6.5 The number of rare species (extinct, very rare, rare and uncommon) in lake and oxbow lake samples.

The numbers of species in each distribution class are given for each sample in Appendix 22. Abundances of rare (extinct, very rare, rare and uncommon) are given in Appendix 23 and 24 for springs/streams/rivers and oxbow lakes, respectively.

7 Conclusions

7.1 Are the Polish water bodies suitable as reference conditions?

The selected Polish water bodies are still pristine. Of each main type (springs, streams and rivers, and oxbow lakes) waters in grassland and waters in the forest were selected. Thus the major land-use types were included. Water bodies near a village or industrial area were not selected because the chance of pollution in these waters was high. The grasslands were not heavily fertilised, so the water quality was good. Saproby was low, oligo- to β-meso-saprobic, which is indicative for pristine river systems.

Many alterations that took place in other European countries did not take place in Poland (yet?). One of the streams (R1) was probably straightened and had bank consolidation. However, this stream had a good ecological quality, based on the AQEM assessment system.

The chemical variables showed that in relation to the Netherlands chloride and potassium concentrations are low. The nutrient levels vary. The ammonium level was in many cases within the range given for the Nature Target Types, but the nitrate and phosphate levels often exceeded these ranges. Compared to other near natural streams the Polish streams seem to have a good chemical quality. Many of the streams are in the forest and contain much organic material, which can be a source of phosphorus and nitrate.

Most of the samples of springs, streams and rivers were assigned to the best stream types in the stream typology (classes 3-4 and 4). Only two springs samples were assigned to a type indicating class 2, but this is probably due to a huge amount of organic material in autumn (in springtime the same sites was assigned to a type with class 3-4). Samples of S11 and S12 were assigned to a temporary spring type in autumn. In springtime these samples were assigned to a type indicating quality class 2. Probably this type does not fit in the typology.

With the AQEM assessment system almost all of the springs scored high ecological quality (reference conditions). For streams the results were a little worse, although with the German method in most cases class 4 was assigned. The Dutch method was less stable, because it gave different values between seasons.

The oxbow lakes mostly got class 3 by assigning them to the EKOO typology, however, the samples did not fit well to this typology, which includes samples of many different water types and only few oxbow lakes.

In general, the samples all contained high numbers of rare taxa. There are thus many taxa that are rare in the Netherlands, present in these water bodies. Nijboer (2006) has stated that the number of rare species is related to a high ecological quality and naturalness of a water body. Because natural waters are scarce in the Netherlands their species are rare as well. The high numbers of rare species in the Polish water bodies makes them valuable for describing references, in which the more natural state of water types is given. Rare species are important in these lists.

In the Nature Target Types reference conditions were described for a number of water types. Therefore, literature was used to makes lists with indicator species (specific for a type) and target species (species that are rare, declining and of international importance). From this study resulted that many of the indicator species were found in the Polish data (about 40 %). However, it concerned the whole Polish database and in a separate sample about 20 % of the indicator species was found for the most similar or a few types. It appeared that the samples did not have the highest numbers of indicators of the types they were assigned to using the environmental criteria. Often they contained indicator species from a number of types assuming that there is overlap between types in the indicator species lists. This can also be due to the high habitat diversity in the Polish river systems, including slowly and fast flowing parts and sometimes small springs in the stream banks. The same goes for the target species. They are even less type specific. Fewer target species than indicator species were found, which is expected because of their rarity. It ranges from 0 target species in the oxbow lakes to 37 % of the target species described for spring types. Except for the oxbow lakes the results are good, in the Netherlands target species are extremely rare and hardly observed. Again, this confirms that the Polish water bodies are suited as reference systems. The fact that no target species of oxbow lake types were found at the Polish sites suggests that the target species described do not occur in these types or that they are rare in Poland as well.

For short, the Polish systems can be used as reference conditions, they are natural and have a good chemical and ecological quality.

7.2 Are the data comparable?

The Polish data are comparable with the Dutch data. The number of taxa per sample is higher in Poland, except for springs. Mean numbers of individuals differ and therefore it is recommended to use percentages of species abundances instead of absolute abundances. This compensates for small differences in sampling and sorting methods.

Only 32 taxa found in the data can not occur in the Netherlands because this country is outside their biogeographical region. Most of these taxa have only low abundances and are not relevant to the community. For the three taxa with higher abundances it is recommended to study their role in the ecosystem and to investigate which species have the same role in the Netherlands.

7.3 Natural variation

From the analyses in part one of this report it appeared that there are major seasonal differences, especially in the waters that are situated in the forest. Therefore, it is necessary to sample in at least two seasons as was done for this study. To describe reference conditions, samples from two seasons should be used, to cover the natural variation over the year. In some cases the differences between seasons were larger than the differences between sampling sites.

Reference descriptions are often made for a water type and included the variation that occurs within the type. How more detailed a water type, the fewer sites belong to it and the less the variation will be. If types are defined at a larger scale, they include more different sites and therefore variation is higher. The higher the variation, the more samples are needed to make an accurate description of the macroinvertebrate community. In this study the Polish sites were assigned to different typologies: EKOO typology, stream typology, WFD typology and Nature Target Types. It appeared that there were types, which included only one sampling site, but also types which were represented by 6 sampling sites (= 12 samples).

To cover variation within a type, samples representing the whole range should be included. In future more sites of the lacking types (only 8 out of 18 WFD running water types were represented) and of types which were only represented by one or two sites should be sampled.

To fulfil the WFD criteria not only macroinvertebrates and macrophytes but also algae and fishes should be sampled as well. This should be done additionally at the same sites and for newly selected sites.

7.4 How to develop/improve descriptions of reference conditions?

To develop descriptions for reference conditions the following steps should be taken:

- Determine the reference target type;
- Select sites using environmental variables, sample or collect biological data, analyse the species composition;
- Determine ecological quality with the WFD assessment system as soon as it is finished;
- Compare the species found with the species described theoretically for this type;
- Compare the species found with species lists of best available sites in the Netherlands (to get more insight in species composition and which species are lacking or rare in the Netherlands);
- Add characteristic species (see characterisation in part one of this report) and rare species;
- Add ratio's of abundances for species;

Literature

Bal, D., H.M. Beije, M. Fellinger, R. Haveman, A.J.F.M. van Opstal en F.J. van Zadelhoff, 2001. Handboek natuurdoeltypen; tweede, geheel herziene editie. Expertisecentrum LNV. Ministerie van Landbouw, Natuurbeheer en Visserij. Wageningen.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. Research report of the Office of Research and Development, US Environmental Protection Agency.

Elbersen, J.W.H., Verdonschot, P.F.M., Roels, B. & Hartholt, J.G. 2003. Definitiestudie Kaderrichtlijn Water (KRW); I. typologie Nederlandse Oppervlaktewateren. Wageningen, Alterra, Research Instituut voor de Groene Ruimte. Alterra-rapport 669. 70 pp.

European Commission 2000. Directive 2000/60/EC of the European Parliament and of the Council. Establishing a framework for Community action in the field of water policy. Brussels, Belgium, 23 October 2000.

Hering, D., Buffagni, A., Moog, O., Sandin, L., Sommerhäuser, M., Stubauer, I., Feld, C., Johnson, R., Pinto, P., Skoulikidis, N., Verdonschot, P. & Zahrádková̀, S. 2003. The development of a system to assess the ecological quality of streams based on macroinvertebrates – design of the sampling programme within the AQEM project. Internat. Rev. Hydrobiol. 88: 345-361.

Hering, D., Moog, O., Sandin, L. & Verdonschot, P.F.M. 2004. Overview and application of the AQEM assessment system. Hydrobiologia 516: 1-20.

Nijboer, R.C. 2006. The myth of communities. Detemining ecological quality of surface waters using macroinvertebrate community patterns. Thesis. Alterra Scientific Contributions 17, Alterra, Wageningen. 188 pp.

Nijboer, R.C., Jaarsma, N., Verdonschot, P.F.M., Van der Molen, D., Geilen, N. & Backx, J., 2000. Natuurlijke levensgemeenschappen van de Nederlandse binnenwateren deel 3 wateren in het rivierengebied. Rapport AS-03, EC-LNV, Wageningen, 156 pp.

Nijboer, R.C. & Van den Hoorn, M.W. 2003. Verkenning van de waarde van historische gegevens voor het invullen van biologische referentietoestanden voor beken en sloten. Alterra-rapport 755, Alterra, Wageningen, 112 pp.

Nijboer, R.C., Verdonschot, P.F.M. & Van den Hoorn, M.W. 2003. Macrofauna en vegetatie van de Nederlandse sloten. Een aanzet tot ecologische beoordeling. Alterra-rapport 688, Alterra, Wageningen, 256 pp.

Nijboer, R.C., Johnson, R.K., Verdonschot, P.F.M., Sommerhäuser, M. & Buffagni, A. 2004. Establishing reference conditions for European streams. Hydrobiologia 516: 91-105.

Nijboer, R.C. & Verdonschot, P.F.M. 2004. Rare and common macroinvertebrates; definition of distribution classes and their boundaries. Archiv für Hydrobiologie, 161: 45-64.

Reynoldson, T.B., Norris, R.H., Resh, V.H., Day, K.E.& Rosenberg, D.M. 1997. The reference condition: a comparison of multimetric and multivariate approaches to assess water-quality impairment using benthic macroinvertebrates. Journal of North American Benthological Society 16: 833–852.

STORA 1989. Kenmerken van niet rechtstreeks door afvalwater beïnvloed binnenwater. (interimverslag). STORA, Rijswijk. 105pp.

Ter Braak, C.J.F. & Šmilauer, P. 2002, CANOCO Reference manual and CanoDraw for Windows user's guide: Software for Canonical Community Ordination (version 4.5), Microcomputer Power, Ithaca, NY, USA.

Tolkamp, H.H. 1980. Organism-substrate relationships in lowland streams. Thesis, Landbouwuniversiteit, Wageningen. 211pp.

Van Tongeren, O. 1986. Flexclus, an interactive flexible cluster program, Acta Botanica Neerlandica, 35: 137-142.

Van Tongeren, O. 2000. Programma ASSOCIA. Gebruikershandleiding en voorwaarden. Buro Data-Analyse Ecologie. 27 pp.

Verdonschot, P.F.M. 1984. The distribution of aquatic oligochaetes in the fenland area of N.W. Overijssel (The Netherlands). Hydrobiologia, 115, 215-222.

Verdonschot, P.F.M. 1990. Ecological characterization of surface waters in the province of Overijssel (The Netherlands), Province of Overijssel, PhD thesis, Alterra, Wageningen, The Netherlands.

Verdonschot, P.F.M. 2000a. Natuurlijke levensgemeenschappen van de Nederlandse binnenwateren. Deel 1, Bronnen. Achtergronddocument bij het 'Handboek Natuurdoeltypen in Nederland". Rapport AS-01, EC-LNV. Alterra, Wageningen. 88 pp.

Verdonschot, P.F.M. 2000b. Natuurlijke levensgemeenschappen van de Nederlandse binnenwateren. Deel 2, Beken. Achtergronddocument bij het 'Handboek Natuurdoeltypen in Nederland". Rapport AS-02, EC-LNV. Alterra, Wageningen. 128 pp.

Verdonschot, P.F.M., Nijboer, R.C. & Higler, L.W.G., 2002. Nutriënten in stromende wateren. Overzicht van normen. Alterra-rapport 516b, Alterra, Wageningen, 60 pp.

Verdonschot, P.F.M., Elbersen, J.W.H. & Van den Hoorn, M.W. 2003. Voorspelling van effecten van ingrepen in het waterbeheer op aquatische gemeenschappen. Validatie van de cenotypenvoorspellingsmodellen voor regionale watertypen (Overijssel) en voor beken en sloten in Nederland. Alterra-rapport 737, ISSN 1566-7197. 80pp.

Verdonschot, P.F.M. & Nijboer, R.C. 2004. Macrofauna en vegetatie van de Nederlandse beken. Een aanzet tot beoordeling van de ecologische toestand. Alterra-rapport 756, Alterra, Wageningen, 326 p.

Vlek, H.E., Verdonschot, P.F.M. & Nijboer, R.C. 2004. Towards a multimetric index for the assessment of Dutch streams using benthic macroinvertebrates. Hydrobiologia 516: 173-189.

Appendices

The appendices are available by sending an e-mail to P.F.M. Verdonschot (piet.verdonschot@wur.nl).