Project no. **GOCE-CT-2003-505540**

Project acronym: **Euro-limpacs**

Project full name: **Integrated Project to evaluate the Impacts of Global Change on European Freshwater Ecosystems**

Instrument type: **Integrated Project**
Priority name: **Sustainable Development**

Deliverable No. 116
Overview paper on the macroinvertebrate database (WP7 task 4)

Due date of deliverable: **Month 19**
Actual submission date: **31/08/2005**

Start date of project: **1 February 2004** Duration: **5 Years**

Organisation name of lead contractor for this deliverable:
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UDE – Lorenz A.

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level (tick appropriate box)		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Introduction

Main aim of WP 7 task 4 is the development of an indicator database for European freshwater species. As a first step a database for macro-invertebrate indicators was established that will be extended to other freshwater organism groups throughout the duration of the project. The current version of the macro-invertebrate taxa and autecology database is presented on www.freshwaterecology.info. A first overview on the online database was given in Deliverable 31. The database is continuously updated, further developed and improved.

The present deliverable consists of a manuscript, entitled "The AQEM/STAR taxalist – a pan-European macro-invertebrate ecological database and taxa inventory" by Astrid Schmidt-Kloiber (BOKU), Wolfram Graf (BOKU), Armin Lorenz (UDE) and Otto Moog (BOKU). It summarises the work carried out to set up the database, the following development as well as the state of the art and future aims to be achieved within Euro-limpacs. The paper was submitted to an accepted by Hydrobiologia.

The AQEM/STAR taxalist – a pan-European macro-invertebrate ecological database and taxa inventory

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Keywords: aquatic macro-invertebrates, European taxa inventory, autecological database, ecological classifications, biological assessment systems

This paper has not been submitted elsewhere in identical or similar form, nor will it be during the first three months after its submission to *Hydrobiologia*.

Abstract

The European list of aquatic macro-invertebrate taxa, and its associated ecological database, originated within the context of the AQEM project and has been extended during the STAR project. The AQEM/STAR taxalist is a product of co-operation between applied freshwater ecologists and scientists from different zoological fields, applied partners and the administration. The basic idea is that a sound understanding of benthic invertebrate ecology is a prerequisite for the implementation of a biological approach to aquatic ecosystem management in Europe. The database has been generated under the management of BOKU (University of Natural Resources and Applied Life Sciences, Vienna) and UDE (University of Duisburg-Essen) and provides an important means of standardisation and unification of ecological classifications in Europe. This paper outlines the aims for setting up the AQEM/STAR macro-invertebrate taxalist and autecological database and provides a current summary of the numbers of aquatic orders, families, and species, and species occurrences in 14 European countries. The number of available and applicable assignments of taxa to each ecological parameter is summarised and examples are given for different parameters and taxonomic groups. Gaps in the autecological information are identified and discussed. Besides its ecological relevance, the operational character of this database is underlined by the fact that it provides the associated taxon codes for each of five different European assessment systems for nearly 10,000 European macro-invertebrate taxa.

1 Introduction

The temporal and spatial distributions of freshwater organisms are tightly connected to aspects of zoogeography plus their physiological and behavioural responses to varying levels of environmental factors. The most frequently studied key factors, such as water temperature, flow velocity, oxygen balance, food composition and the availability, and quality of habitat, are regarded as the main predictors of the community composition and distribution of benthic invertebrates. The comparatively good knowledge of their environmental needs, and of species' responses to various environmental factors, has led to these organisms being widely used as (bio)indicators in water management and in applied ecology (see Rosenberg & Resh, 1993; Davis & Simon, 1995).

Numerous commonly used biological assessment systems for rivers and streams across the USA and Europe are based on so-called “metrics” or – synonymously used - “measures” or “biological attributes”. Following Karr & Chu (1999) metrics are defined as “measurable parts or processes of a biological system empirically shown to change in value along a gradient of human influence”. The metrics of assessment systems use either, 1) taxonomic richness and composition (number of species/taxa, diversity indices, number of individuals, % Trichoptera, etc.), or 2) biological information on ecological functions or requirements (e.g. habits and species traits of the aquatic fauna, such as feeding types, stream zonation preferences, habitat preferences, tolerance/intolerance measures such as, e.g. saprobic indices, individual health and others; Statzner et al., 1994; Barbour et al., 1999; Karr & Chu, 1999; Hering et al., 2004). The first type of metric depends only on species/taxa lists, whereas the second needs a profound knowledge of species' ecological demands. In order to use this ecological knowledge in a comprehensible system of bio-indicators it needs to be “translated” into numerical values.

The requirements of the European Water Framework Directive (EC, 2000/60; WFD) for an integrated assessment methodology with which to evaluate the ecological status of water bodies is a big challenge for the applied limnological sciences. The “ecological status” of rivers, which is mainly based on their biotic components, is an important parameter for European water management. To assess the ecological status of a water body selected attributes of the biological indicators have to be considered, and compared to relevant target values under reference conditions. As a consequence, new assessment systems and evaluation techniques have had to be developed throughout Europe during the last few years. Among other approaches, the applicability of multi-metric techniques, i.e. combinations of several measures and indices addressing different stressors or different components of the biocoenosis, has been tested (Brabec et al., 2004; Buffagni et al., 2004; Lorenz et al., 2004; Ofenböck et al., 2004; Pinto et al., 2004; Sandin et al., 2004; Vlek et al., 2004). An important scientific input into this recently adopted approach has been the creation of taxa inventories with associated autecological databases.

Currently, the collections of data on European taxa used for this purpose are species/taxa checklists for single countries (e.g. Austria, Bavaria, Slovakia) or large-scale regions (e.g. Limnofauna Europaea, Illies, 1978). The most comprehensive inventory is the Fauna Europaea (Fauna Europaea Web Service, 2004), which was developed at the same time as the AQEM/STAR taxalist. It contains country-related occurrences of species from most freshwater groups at species level, checklists of species within genera and higher taxonomic units, plus comments on nomenclature and phylogenetics. Nevertheless, ecological data are not included because the Fauna Europaea is primarily focused on taxonomy and faunistics.

Compared to the compilation of national or international checklists (species inventories) the gathering of autecological information on macro-invertebrate species, and its transformation into numerical values, is a sophisticated, responsible and thus time consuming and costly task. Therefore only a few databases dealing with this kind of information have so far been established (Merrit & Cummins, 1984; Moog, 1995; 2002; Schmedtje & Colling, 1996; Usseglio-Polatera et al., 2000; Sporka, 2003).

Within the European Union the task of inter-calibration seeks to harmonise the results of the different national assessment systems throughout the European countries. The necessity of evaluating streams and water courses in a wider perspective than national guidelines leads to the need for a standardised pan-European macro-invertebrate species list and for widely harmonised autecological data as a basis for ecological quality assessment. This paper presents a new collection of European data that fulfils these criteria and will be accessible not only to the scientific public but also to stakeholders and national monitoring institutions in a public WWW service under www.freshwaterecology.info.

2 Methods

2.1 History of the AQEM/STAR macro-invertebrate taxalist

The AQEM/STAR macro-invertebrate taxalist is a “living document” that was first set up for the purposes of the EU funded AQEM project (AQEM consortium, 2002; www.aqem.de). The aim of this project was the development and testing of an integrated system for assessment of the ecological quality of streams and rivers throughout Europe using benthic macro-invertebrates (Hering et al., 2004). The eight project member countries (Austria, Czech Republic, Germany, Greece, Italy, The Netherlands, Portugal, Sweden) developed multi-metric assessment systems for different stream types, which can be applied via a computer program (ASTERICS, to be downloaded at www.aqem.de). Because the assessment systems require ecological knowledge of the taxa it was essential to collect information on both occurrence and distribution of taxa within the partner countries, and ecological information on these taxa, to create a consistent and reliable database. To achieve this goal the AQEM/STAR macro-invertebrate taxalist builds on the scientific expertise of many scientists, universities, organisations and societies.

The steps taken towards the development of the AQEM/STAR database were:

- Election of persons responsible for the national checklists: from each partner country at least one person was selected to be responsible for collecting the national records of the targeted invertebrate groups. The minimum requirement for the quality of the national checklist was that it provides sufficient information to start developing the assessment system with which to evaluate the ecological status of a water body. In those cases of incomplete faunistic knowledge the national checklists were integrated into the database as "working taxalists". For information on national experts please consult www.freshwaterecology.info.
- Founding of a board of experts for the individual taxonomic groups: acknowledged and approved experts contributed to the checking of these national taxa inventories (Table 1). Besides the input of their own knowledge the experts kept contact with other experts throughout Europe to collect data files on their parts of the targeted taxonomic groups and performed quality control with respect to species validity, species nomenclature and synonymy. Basically, the taxonomy follows present day international taxonomic standards and the experts consequently used comprehensive taxonomic sources.
- Compiling the database: the data were compiled into an MS Access database, using the proven structure of the Austrian software ECOPROF that has been developed for data storage and evaluation (Moog et al., 2001a; www.ecoprof.at).
- Compiling the autecological information: as a basic data source, existing ecological classifications were critically checked and adopted. They were (in order of prioritisation) the Fauna Aquatica Austriaca (Moog, 1995; 2002), the Bavarian List (Schmedtje & Colling, 1996) and other national lists (for example Verdonschot, 1990; Van den Hoek & Verdonschot, 1994) were used. When possible, selected species were assigned to experts and project partners for amendment of their designations.
- Coding the new autecological information: depending on the parameter, data were given a numerical code using either a 10 points or single category assignment system. (see chapter 2.3).

In the succeeding, EU funded, STAR project (www.eu-star.at) which aimed to standardise river classifications, the AQEM/STAR macro-invertebrate taxa and autecology database was extended with national checklists from Denmark, France, Great Britain, Latvia, Poland and Slovakia.

The main goal of the AQEM/STAR taxalist was, and still is, to provide a tool for the ecological assessment of water bodies. For this reason the list was designed as a "living document" that should be available to the scientific public at a comparatively early stage of its development. This means that the species inventories and/or the ecological rankings accorded them, are in different stages of completeness for most of the targeted countries and taxonomic groups. Consequently the AQEM/STAR taxa inventory does not necessarily represent the state of the art of a country's recorded species: these lists must be understood as an operational tool for running bio-monitoring projects under the auspices of the new Directive. Nevertheless, besides its operational character, the final product should represent a numerically transformed, state of the art database of European zoogeographic and ecological knowledge on benthic invertebrates.

Table 1: Taxonomic experts who have contributed to the synthesis of the AQEM/STAR taxalist.

2.2 Database structure

The database is set up in MS Access. It is a relational database consisting of three main modules:

- Taxonomic tables: holding species, subfamilies, families, higher taxonomic groups and current synonyms. All the systematic units are number-coded. Beside the ID_Aqem (number code) the species/taxa are also linked with the Austrian ID_Ecoprof, an eight letter shortcode, the German DV-number, the British Furse code, the Dutch TCM code and the Czech Perla code.
- National checklist tables: containing the occurrence of species in different countries.
- Ecological information tables: holding the ecological attributes, as numerical classification values, of different taxonomic levels (species, genus, subfamily, family).

A mySQL database with a PHP-interface for presenting the data on the web is currently under construction (www.freshwaterecology.info).

2.3 Systems for assigning the ecological information

Since most of the scientific information on the environmental needs of the biota is recorded in narrative form, two different methods were used to transform the ecological knowledge into numerical values that can be processed for ecological quality assessment.

Ten point system

The ecological designations of the taxa used in the database are based on the known, or estimated, average distributions, occurrences or behaviours of the organisms within the environmental gradient under consideration. The 10 point system goes back to Zelinka & Marvan (1961) who introduced the saprobic valences approach into the calculation of a Saprobic Index. This author used 10 points as a substitute for 100% occurrence of each taxon. Up to 10 points were allocated to the saprobic state of a water body according to the tolerance of a species for each of the five saprobic quality classes (xeno-, oligo-, beta-meso-, alpha-meso-, and polysaprobic water quality). This 10 point system was extended by Moog (1995) to other ecological classifications, such as stream zonation preferences and feeding types. If, for example, 70% of a species' records were observed in spring brooks and 30% in the upper trout region, 7 out of 10 points will be allocated to spring brook preference (hypocrenal rivers) and 3 points to upper trout region reference to describe the expected occurrence of this species within the longitudinal zonation of a stream. The parameters for which the 10 point ranking system is used in the AQEM/STAR database are summarised in table 2.

Single category assignment system

The single category assignment system is used if a taxon can be allocated to only one ecological parameter, criterion or zone. If a criterion applies to the species, “1” is assigned, if not “0” is used. The parameters for which the single category assignment system is used are summarised in table 2.

Ecological parameters without indicated assignment system in the column “Syst.” in table 2 represent different kind of indices. For details see the according references.

Table 2: Ecological parameters integrated into the current AQEM/STAR database including lowest taxonomic level of assignment (Level), assignment system (Syst.; 10p: 10 point system, sc: single category assignment system, -: different kind of indices), number of categories (Cat.), number of classified taxa (No. taxa) and references.

2.4 Categories for assigning the ecological information

Different numbers of categories are used for the designation of ecological information (table 2). The six main parameters, their categories, and their definitions are presented in tables 3 to 8.

Table 3: Saprobic classes and definitions of the amount of decomposable, organic material at a recording site, according to Moog (1995).

Table 4: Feeding types of invertebrates and their definitions according to Moog (1995).

Table 5: Stream zonation preferences of invertebrates and their definitions according to Moog (1995).

Table 6: Current preferences of invertebrates and their definitions according to Schmedtje & Colling (1996).

Table 7: Habitat/substrate preferences of invertebrates and their definitions according to Schmedtje & Colling (1996).

Table 8: Locomotion types among invertebrates and definitions according to Schmedtje & Colling (1996).

3 Results

3.1 Number of families, genera and species/taxa recorded

The AQEM/STAR taxa database currently (status 01/04/05) holds a total of 6971 European benthic invertebrate species, categorised into 1317 genera, 279 families and 28 higher taxonomic groups (mostly orders). Including working taxa like species-groups the list contains 9612 taxa. Table 9 shows the occurrence of species among the higher taxonomic units and countries. The taxa inventories (number of families, genera and species) per country are presented in figure 1.

Table 9: Numbers of aquatic invertebrate species among the different higher taxonomic groups and countries according to national checklists or "working lists" (marked by a asterisk); EU: all AQEM/STAR countries, LV: Latvia, SE: Sweden, DK: Denmark, FR: France, GB: Great Britain, NL: The Netherlands, PL: Poland, AT: Austria, CZ: Czech Republic, DE: Germany, SK: Slovakia, GR: Greece, IT: Italy, PT: Portugal.

The numbers of species indicated in table 9 need not reflect the current state of the zoogeographic art since the conceptual design of the AQEM/STAR list focuses on its operative character and the use of its ecological classifications in assessment systems. Nevertheless, table 9 and figure 1 clearly indicate that several taxonomic groups have been well investigated in most parts of Europe: for example for Coleoptera, Heteroptera, Odonata or Trichoptera the AQEM/STAR taxalist does seem to cover the current state of the art of a countries' species spectrum. With respect to other groups there are clear gaps concerning the number of recorded species in individual countries, particularly in Southern Europe. For example, Bivalvia are poorly documented for Portugal so they were only considered at higher taxonomic levels and are therefore not included in table 9. But there are also "neglected" taxonomic groups in well investigated, Central European countries. These include species-rich taxonomic units such as Hydrachnidia, that are poorly documented in most European countries, but also groups such as aquatic Lepidoptera, Porifera or Polychaeta with a naturally low diversity. Basically, small numbers of species in table 9 may indicate both missing data and/or deficient knowledge of species distribution (for example Crustacea, Diptera or Oligochaeta in Southern European countries).

Figure 1: Numbers of families (left third of the circles), genera (right third of the circle) and species (lower third of the circles) of aquatic invertebrates within the different AQEM/STAR partner countries.

3.2 Autecological information

The autecological information compiled into the AQEM/STAR taxa database serves as an essential resource for assessment systems. Currently 26 ecological parameters and indices, with varying numbers of classified taxa, are integrated into the database. The available autecological information is summarised in table 2.

The six most commonly investigated ecological parameters included in the database are oxygen demand (saprobic indices), stream zonation, current and substrate preferences, as well as feeding and locomotion types. Table 10 shows the number and percentage of designated species and taxa respectively for which these parameters are available.

Table 10: Numbers and percentages of ecologically classified taxa/species of aquatic invertebrates for the six main ecological parameters in the AQEM/STAR database.

With respect to the ranking of functional feeding guilds 28.4% (i.e. 1980 species) of a total of 6971 species in the database are classified, followed by 26.3% (1833 species) designations for the stream zonation preferences, 21.1% (1569 species) for saprobic values, 17.5% (1217 species) for current preferences, 16.4% (1146 species) for substrate preferences and 10.3% (720 species) for locomotion types. This means – regarding those six main parameters - that numerically transformed autecological information is available for only 10 to 28% of all species and 10 to 30% of all taxa in the database. These values may vary considerably among the different countries and taxonomic groups. Compared to the averages of other countries, the proportion of ranked taxa is generally highest for the Austrian and German taxa inventories, reaching e.g. about 73 % of Austrian taxa designated by feeding type (Lorenz & Schmidt-Kloiber, 2005).

The species of the orders Ephemeroptera, Plecoptera, Trichoptera and Coleoptera which have been classified indicate a relatively good state of knowledge of the ecological requirements of these groups. Mayflies show 55% feeding type designations and 50% stream zonation preferences. Most stoneflies are assigned saprobic values (40%) and, again, feeding types (38%). Thirty eight percent of the caddisflies are also classified according to feeding type and stream zonation preferences. For beetles, about 30% have been assigned for these two parameters (table 11). The lowest percentages of classified species are stonefly substrate preferences (9%) and locomotion types (3%) as well as Coleoptera locomotion types (4%). In general, more ecological knowledge can be transformed into numerical classifications for Ephemeroptera and Trichoptera than for the other two taxonomic groups considered here.

Table 11: Numbers and percentages of ecologically classified aquatic species within the orders Ephemeroptera, Plecoptera, Trichoptera and Coleoptera, for the six main ecological parameters in the AQEM/STAR database.

4 Discussion

4.1 Taxa richness of families, genera and species in different countries

Table 9 and figure 1 give the numbers of families, genera and species recorded in 14 European countries: Latvia, Sweden, Denmark, France, Great Britain, The Netherlands, Poland, Austria, Czech Republic, Germany, Slovakia, Greece, Italy and Portugal. The results of the AQEM/STAR records have not as yet been compared with the Fauna Europaea list (www.faunaeur.org), because both projects ran simultaneously. Because the focus of the AQEM/STAR consortium was concentrated on completing the ecological information for the database, the species inventories may differ from those of the taxonomically and faunistically oriented Fauna Europaea. Table 9 gives clear evidence of existing gaps in the AQEM/STAR database. In general, "low" numbers of species in the table may be caused by:

- The checklist submitted by a countries' responsible person does not reflect faunistic or taxonomic knowledge of this country ("working list").
- There is not enough information about the occurrence of species in the country; the biodiversity of aquatic invertebrates is poorly known.
- The biodiversity is generally low due to climatic factors and/or zoogeographical reasons.

The number of species recorded per country ranges from 632 (Portugal) to 4136 (Germany), (table 9). Although this broad span seems, remarkably, to be caused by nationally different states of the taxonomic art, this variation cannot be explained only by the effects of taxonomic resolution. Basically, there is a tendency for the species richness of a country to be positively correlated to its area (figure 2) which confirms the fundamental ecological principle of the species-area-relationship. However, this general observation is masked by two other factors that affect a countries' biotic inventory. Firstly, the number of species accumulates as the topographic heterogeneity of a country increases. In Austria, for example, a total of 2738 species are recorded although the area of this country covers only 84.000 km², but it includes portions of six out of 27 European ecoregions according to annex 11 of the WFD (Illies, 1978) and also has a wide altitudinal range. Secondly, species richness decreases from South to North, which may be explained by the history of glaciation (Rosenzweig, 1995). This postulate is confirmed by the comparatively small number of 1937 species recorded for Sweden (450.000 km²). This fact may not be clearly apparent from table 9, because most of the Southern European taxalists are "working lists" and do not reflect the complete species richness in these countries (see below).

Some of the national lists were primarily compiled for the development and use of new assessment systems containing the most frequently occurring taxa, regardless of whether or not these taxa reflect the complete national species inventory. These lists are still under construction and will have to be refined in future. For example, the Greek taxalist within the AQEM/STAR database included 152 species of Trichoptera. Recent studies provide evidence that this number is far too low and Malicky (in prep.) expects there to be more than 300 species. Another question is, how to put this updated knowledge into use since most Southern European species have so far only been described as adult stages. The juvenile instars are still unknown and thus not available for routine monitoring and assessment. Gaps of that kind reflect the limits of the current state of nationally used assessment approaches. To overcome this lack of knowledge more emphasis needs to be given to larval taxonomic studies so that, by this means, "working taxalists" can be upgraded to national checklists. The Fauna Europaea may be a valuable tool in combination with intensified research in these fields. As species ranges are in the process of expansion as well as regression we regard the AQEM/STAR database as a "living document" that should stimulate national experts to check their results and contribute to the knowledge of local fauna.

Figure 2: The relationship of numbers of species of aquatic invertebrates identified in individual AQEM/STAR partner countries to their areas.

4.2 Examples of sound metrics and identifying gaps within the ecological assignments

As a consequence of severe epidemics (e.g. cholera) in the 19th century, assessments of river quality historically focussed solely on impacts due to organic pollution. Yet, after the water quality of most European rivers has been restored, there is clear evidence that habitat impairment – mainly due to flood protection and hydropower generation – is a primary cause of degraded aquatic landscapes. Muhar et al. (2000) concluded that only 6% of the Austrian rivers with a catchment area >500 km² are of pristine character. Thus river restoration has evolved to include a crucial element of water management, and habitat quality has become an essential component of biological surveys. Therefore, in some countries special attention was given to the development of metrics that show the relationship between habitat quality and biological conditions (Feld, 2004; Moog et al., this issue). Nevertheless, we still see a gap between the need to improve the scientific quality of ecological surveys and the actual degree of attention that is given to biological sciences. Although the scientific literature in general is growing intensively the ecological potential of particular species across varying environmental factors is comparatively poorly known. On the one hand the current study of natural science has changed its focus towards other fields (e.g. genetics, biotechnology). On the other hand it is hardly possible to measure the complexity of species' responses in the field, especially considering the complex spatial and temporal distributions of all relevant factors. It has therefore become common practice to use surrogate parameters in ecological assessment, or to focus environmental evaluations on only a few, well studied and easily observable factors and measures, in order to transfer existing knowledge into applied practice most efficiently. Among these factors are the six most intensively investigated ecological attributes of aquatic species included in the database: oxygen requirements, stream zonation patterns, current and substrate preferences, as well as feeding and locomotion types. For these parameters our ability to classify species ranges from 10 to 28% of species. The situation is not even that good for other ecological parameters. The question whether the ecological designation of species can be extended to genus or even higher taxonomic levels is a controversially discussed topic (summarised for example in Schmidt-Kloiber & Nijboer, 2004).

This approach is, nevertheless, common practice, in order to increase the number of ecological assignments for the assessment system. Also, within the AQEM/STAR taxa database, higher taxonomic units are classified ecologically, but only if the underlying references allow (e.g. if all species of a genus are classified identically then the genus gets the same designation). In this way the number of species classified by feeding type increases from 1980 to 2924 (28.4 to 30.4%) or from 720 to 1006 for locomotion types. Similar rises, but not that high, are true for all the other main parameters (table 10).

The current activities in progress for the implementation of the WFD emphasise the general necessity of having ecological classifications available. During the AQEM project, for a total of 28 stream-types, multi-metric indices were developed for assessing different types of human impact. More than half (15) of these indices use a kind of saprobic assignment as the metric, about half (13) apply the feeding behaviour, 10 use stream zonation preferences, 5 use current and substrate preferences (AQEM consortium, 2002). Generally, the analyses of functional feeding types are the most investigated ecological measures. Practical knowledge concerning trophic-relationships, food chains, food quotient, and essential nutrients is widely available. There are not only a lot of individual publications, but also several substantial catalogues available, that are based on anatomical structures and behaviours concerned with food acquisition (Merritt & Cummins, 1984; Moog, 1995; 2002; Schmedtje & Colling, 1996). Discussing the distribution of functional feeding guilds within an assemblage permits a relatively dynamic view of the nutrient status of a particular river site. Changes in the composition of the feeding guild structure of a site, compared to the reference condition, may indicate a disturbance. Clear trends between the composition of feeding types in the community and an investigated stressor are graphed in figure 3; the left corner of the figure indicates the best ecological conditions (reference); the ecological quality of the river sites under investigation decreases to the right ending with bad sites. The classification of these sites follows the application of a multi-metric procedure as described in Moog et. al (this issue), the calculation of the "% gatherer/collector" value follows the AQEM manual (AQEM consortium, 2002). Statistical analyses regarding the discrimination efficiency between the individual ecological quality classes are to be found in Ofenböck et al. (2004). The increase of the feeding type "gatherer/collector" is proportional to a decrease in river quality. Examples are given from the Austrian stream type "Mid-sized streams in the Bohemian Massif, ecoregion Central Highlands" (coded as A04) during investigations of river impoundment, due to hydropower generation, as a stressor. Values decrease from about 70% "gatherers/collectors" in bad ecological classes to 20% in reference sites. In the same way, sound responses to environmental exposure can be shown for the feeding type "grazer/scraper" in figure 3. The proportion of this functional guild increases with decrease of the stressor from about 5% in rivers with bad status to 45% in reference sites.

Figure 3: Different feeding types (% individuals) of aquatic invertebrates and their responses to environmental stress expressed in ecological quality classes; a: feeding type "gatherer/collector", b: feeding type "grazer/scraper".

Analogous relationships exist between environmental stress and other parameters that describe ecological features or the needs of organisms, such as locomotion types, current or stream zonation preferences, and the predicted responses of the benthic assemblages are well known (Barbour et al., 1999). To illustrate the ability of functional measures to indicate the relationships between different morphological stressors and the benthic conditions, examples are given in figure 4. Figure 4a shows the use of a selected locomotion type for visualising the effects of damming rivers (impoundment to facilitate hydropower generation) in the Austrian stream type A05 "Small-sized streams in the Bohemian Massif". Compared to reference conditions the proportion of the swimmer/skaters decreases with increasing degree of impairment (stress). The stressor classes have been defined according to conditions of changed current flow and composition of bed sediments, as described by Moog & Stubauer (2003). Other decreasing metrics - relating to river morphology degradation as a stressor in the Austrian stream type A06 "Small-sized crystalline streams of the ridges of the Central Alps" - are stream zonation (preference for epirhithral zones; figure 4c) and substrate preferences (share of lithal preferences; figure 4d). With respect to current preferences, taxa designated as "indifferent" increase with increasing stress (figure 4b).

Figure 4: Different types of ecology-based metrics (% individuals) and their response to environmental stress expressed in ecological quality classes; a: locomotion type "swimmer/skater", b: current preference "indifferent", c: stream zonation preference "epirhithral", d: substrate preference "lithal".

These responses of the metrics to different kinds of stressors have generally been well investigated and documented, which makes them an indispensable part of assessment systems (Barbour et al., 1999, AQEM consortium, 2002). Basically, the power of a (multi-metric) assessment methodology to detect environmental influences increases the more ecologically classified species/taxa are included. Therefore it is seen as an important future task to extend the current knowledge of more ecological parameters. Gaps within the specification of species' ecological requirements are most often due to:

- existing but unavailable information (grey literature)
- lack of adequate biological/ecological studies
- missing translations of complex ecological responses into abstract scores which can be used for assessment systems
- deficient information due to taxonomic problems

These gaps could be filled, and the ecological information enlarged, through analysis of large, existing datasets such as the AQEM/STAR dataset. Verdonschot (in print) for instance, showed that for Oligochaeta it is possible to extend the knowledge of many ecological parameters within the autecological database by performing statistical analysis of the AQEM/STAR dataset. Another example was demonstrated by Moog & Schmidt-Kloiber (1999) with a statistical analysis of observed saprobic preferences, followed by a refinement of saprobic indices for selected groups of the Austrian stream fauna.

5 Conclusion and outlook

The composition of a stream community is the result of interaction between environmental and biological factors. The routine use of benthic invertebrates as sentinel organisms to monitor ongoing environmental impairment requires considerable understanding of the factors involved (Johnson et al., 1993). The presence of a taxon indicates that the habitat is suitable for that taxon and, because some of their environmental requirements are known for many species, their presence indicates something about the nature of the environment in which they are found. The community's response to the combined effects of single factors can be approximated in the form of biological measures (e.g. indices) that evaluate specific features such as, for example, pollution (saprobic) conditions and ecosystem functions such as e.g. the longitudinal distribution patterns of species and functional-feeding guilds. The saprobic indices indicate the reaction of the biota to the oxygen conditions in the system (Sladecek, 1973). The functional-feeding-guild classification allows assessment of the nutrient availability and the dominant bio-processing functions of the community (Cummins & Klug, 1979; Schweder, 1992). An analysis of the longitudinal zonation patterns of a community, based on the concept of uni-directional spatial succession within river systems, provides the opportunity to discuss the effect of serial discontinuities (Ward & Stanford, 1995) such as altered thermal conditions (temperature regimes) and current velocity (Moog, 1995). Thus, some of the key factors are adequately covered within the AQEM/STAR database. Other evaluation approaches based on e.g. habitat/substrate or current preferences (Schmedtje, 1995) provided promising results but still need to be developed, because only a few species can be ranked according to their preferences (17% and 16% for current and substrate preferences respectively). As one of the purposes of the WFD is to establish a framework for the protection of terrestrial ecosystems depending directly on aquatic ecosystems, the multidimensional functionality of aquatic ecosystems, which is determined in an essential way by surrounding wetlands, aquifers and connections to groundwater aspects of lateral and vertical connectivity, needs to be included in future bio-monitoring tasks (Jungwirth et al., 2002; 2003; Ward, 1989; Ward et al., 1998).

The AQEM/STAR database is a product of applied freshwater ecology in co-operation with scientists from different zoological fields, applied partners and the administration. The basic idea is that a sound understanding of benthic invertebrate ecology is a prerequisite for the implementation of a biological approach to European aquatic ecosystem management. Even though there are still gaps within the AQEM/STAR database, it is the first comprehensive taxalist integrating taxonomic knowledge and species distribution ranges with autecological information. It is a first big step towards improvement of the usability of macro-invertebrates in freshwater assessment on a pan-European scale.

The integrated national checklists (even if some of them are still "working lists") may serve as a first base on the way to realising an update of Illies (1978) widely available Limnofauna Europapaea. In addition to listing the geographic distribution of 14,457 European aquatic species Illies outlined some ecological information on these taxa, such as their preference for types of water bodies. The current need for an up-dating of the Limnofauna Europapaea is clearly reflected in the fact that these 27 zoogeographic regions were adopted as "European ecoregions" by the European Water Framework Directive (Annex 11) in the year 2000. Originating from the US nearly 20 years ago (Omernik, 1987; Hughes & Larsen, 1988), ecoregions are used as a spatial framework for environmental resource management on a worldwide scale. The main reasons for the use of ecoregions are because they 1) provide an ecological framework for organising environmental data, 2) are independent of political boundaries, and 3) provide a logical approach to monitoring and assessment. Ecoregions exhibit similar features and environmental characteristics such as e.g. geology, climate, topography, soil, and vegetation. The big advantage of using ecoregions as a geographical/typological framework for assessment models can be explained by the fact that within ecoregions the environmental conditions and the biota are relatively homogenous. Ecoregions have a high internal similarity of abiotic and biotic components compared to the conditions in adjacent ecoregions (Hawkins & Norris, 2000; Moog et al., 2001b). This relative homogeneity reduces the natural variation and makes it easier to distinguish between signal and noise when developing ecological assessment systems. Besides their scientific advantages, the use of ecoregions provides the opportunity for states or agencies to share resources. For this reason the inclusion of ecoregional aspects (integration of ecoregions and where necessary sub-units) will be a future focus of the AQEM/STAR database.

Concluding, from the analysis of gaps in the system the following future aims of the database development are defined as:

- Completion of national benthic invertebrate taxa inventories (checklists) for all European countries and adjustment with the findings of the Fauna Europapaea group. Checklists from other European countries will be included (e.g. Norway, Finland, Spain).
- Amendment of the checklists on a zoogeographic scale according to Illies' ecoregions (1978).
- Filling the gaps in our knowledge of the ecological parameters treated so far.
- Inclusion of more ecological parameters such as temperature preference, resistance to droughts, hydrological preference, reproductive cycles and life cycle duration, altitude preference, and others. The focus will be on wetland-groundwater-interactions with the river corridor as an entity of aquatic systems in the sense of lateral and vertical connectivity.

Major steps towards the realisation of these aims will be achieved within the scope of another EU funded project, Euro-limpacs (www.eurolimpacs.ucl.ac.uk, Contract No: GOCE-CT-2003-505540). During the five-year project 37 European partner institutions will investigate and evaluate the impacts of climate change on European freshwater ecosystems. The Euro-limpacs consortium has agreed to adopt the AQEM/STAR database as a basic data source that will be extended to include ecological parameters which are assumed to be sensitive to direct or indirect impacts of climate change. As a final outcome of this project all parameters will be made available to the scientific public for multiple uses, e.g. the development of future assessment systems.

Within recent years the design of systems for the assessment of the ecological status of freshwater ecosystems has enormously increased to meet the requirements of the WFD. From traditional saprobic water quality monitoring, to the evaluation of various stressors and their integrated impact on benthic invertebrate assemblages, these assessment methodologies have become more and more complex and sophisticated. On the other hand, the performance of autecological studies seems to be decreasing due to the fashion for "up-to-date" sciences as mentioned above. The gap between our basic knowledge of indicators and the number of different so-called indicator-based assessment systems is, in fact, becoming greater, which seems to be contradictory. Fundamental and applied sciences need to develop synchronously. It is important to fill as many as possible of the taxonomic and autecological gaps identified in this paper. The more ecologically classified species are included in an assessment methodology, the more likely the model will become both quantitatively powerful and increasingly sensitive to the full range of possible environmental influences. Effective assessment programmes to evaluate the ecological status of freshwater systems can contribute to the overall health of the aquatic environment.

6 Acknowledgements

We greatly appreciate the work of all the taxonomic experts who volunteered for the taxonomic validity checking. We also want to thank Robert Vogl for computer technical support and realisation, as well as Thomas Ofenböck for providing some graphs and analysis. Thanks to Daniel Hering and Mike Furse for the co-ordination of the EU funded AQEM (Contract No. EVK1-CT-1999-00027) and STAR (Contract No: EVK1-CT 2001-00089) projects as well as to all partners in these projects for their contribution to the database. This paper represents a deliverable of WP7 within the EU funded Euro-limpacs project (Contract No: GOCE-CT-2003-505540). Thanks to Martin Kernan for co-ordinating this project. We want to express our gratitude to Mary Burgis for linguistic assistance.

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Table 1: Taxonomic experts who have contributed to the synthesis of the AQEM/STAR taxalist.

Taxonomic group	Expert	Organisation
Turbellaria	Piet Verdonschot	Alterra Green World Research, Wageningen
Mollusca	Michal Horsak, Lubos Beran	Masaryk University, Brno
Oligochaeta	Piet Verdonschot	Alterra Green World Research, Wageningen
Polychaeta	Piet Verdonschot	Alterra Green World Research, Wageningen
Hirudinea, Branchiobdellida	Hasko Nesemann	BOKU Vienna
Hydrachnidia	Tj.H. van den Hoek	Alterra Green World Research, Wageningen
Crustacea	Tj.H. van den Hoek	Alterra Green World Reserach, Wageningen
Ephemeroptera	Tomas Soldan	Entomological Institute, AS, Ceske Budejovice
Odonata	Jiri Zeleny	Entomological Institute, AS, Ceske Budejovice
Plecoptera	Wolfram Graf	BOKU Vienna
Heteroptera	Tj.H. van den Hoek	Alterra Green World Research, Wageningen
Megaloptera	Tomas Soldan	Entomological Institute, AS, Ceske Budejovice
Planipennia	Jiri Zeleny	Entomological Institute, AS, Ceske Budejovice
Coleoptera	Wolfram Sondermann	private consultant
Trichoptera	Wolfram Graf	BOKU Vienna
Chironomidae	Karel Brabec	Masaryk University, Brno
Ceratopogonidae	Jan Knoz	Masaryk University, Brno
Simuliidae	Gunther Seitz, Ellen Kiel	Regierung Niederbayern, Landshut Hochschule Vechta
Pediciidae	Herbert Reusch	private consultant
Limoniidae	Herbert Reusch	private consultant
Tipulidae	Herbert Reusch	private consultant
Brachycera	Rudolf Rozkosny	Masaryk University, Brno

Table 2: Ecological parameters integrated into the current AQEM/STAR database including lowest taxonomic level of assignment (Level), assignment system (Syst.; 10p: 10 points system, sc: single category assignment system, -: different kind of indices), number of categories (Cat.), number of classified taxa (No. taxa) and references.

Ecological Parameter & Indices	Level	Syst.	Cat.	No. taxa	References
Austrian saprobic valences, index & indicator weight	species	10p	5	1244	Moog, 1995; 2002
Czech saprobic valences, index & indicator weight	species	10p	5	923	CSN 75 7716, 1998
Dutch saprobic valences	species	10p	5	1329	Verdonschot, 1990 Van der Hoek & Verdonschot, 1994
German saprobic index & indicator weight (1992 & 2003)	species	-	-	146, 619	DEV, 1992; 2003 Rolauffs et al., 2003
Slovak saprobic valences, index & indicator weight	species	10p	5	982	Sporka, 2003
feeding types	species	10p	10	2924	Moog, 1995; 2002 Schmedtje & Colling, 1996 AQEM consortium, 2002 Wolf, 2004
stream zonation preferences	species	10p	10	1955	Moog, 1995; 2002 Schmedtje & Colling, 1996 AQEM consortium, 2002 Wolf, 2004
current preferences	species	s.c.	7	1540	Schmedtje & Colling, 1996 AQEM consortium, 2002 Wolf, 2004
substrate preferences	species	10p	8	1452	Schmedtje & Colling, 1996 AQEM consortium, 2002 Wolf, 2004 Bochert, 2003
locomotion types	species	10p	6	1006	Schmedtje & Colling, 1996 AQEM consortium, 2002 Wolf, 2004
German PTI (Potamon Typie Index)	species	s.c.	5	342	Schöll et al., in print
German RTI (Rhithron Typie Index)	species	s.c.	6	882	Biss et al., 2002
Rheoindex	species	s.c.	3	350	Banning, 1998
r/k-strategy	species	s.c.	2	87	Schöll et al., in print
Acid Index Braukmann (2000 & 2003)	species	s.c.	4, 5	89, 264	Braukmann, 2000 Braukmann & Biss, 2004
Swedish Acid Index	species	s.c.	3	56	Henrikson & Medin, 1986
MAS (Mayfly Average Score) small & large streams	species/ genus	-	-	299	Buffagni, 1997 Buffagni, 1999
German Fauna Index stream type D01, D02, D03, D04, D05	species	s.c.	5	335	Lorenz et al., 2004
"Sensitive taxa" of Austrian rivers & streams	species	s.c.	2	393	Moog et al., 2003
DSFI (Danish Stream Fauna Index)	genus/ family	-	-	630	Skriver et al., 2001
IBE (Indice Biotico Esteso)	genus/ family	-	-	1124	Ghetti, 1997
BBI (Belgian Biotic Index)	genus/ family	-	-	1415	De Pauw & Vanhooren, 1983 De Pauw et al., 1992

Portuguese Index	subfamily	-	-	110	Pinto et al., 2004
BMWP (Biological Monitoring Working Party)	family	-	-	277	Armitage et al., 1983
BMWP - Spanish Version	family	-	-	299	Alba-Tercedor & Sanchez-Ortega, 1988
LIFE	family	s.c.	6	337	Extence et al., 1999

Table 3: Saprobic classes and definitions of the amount of decomposable, organic material at a recording site, according to Moog (1995).

Saprobic Preference	Explanation
xenosaprobic zone	clean water (no organic pollution)
oligosaprobic zone	little organic pollution
beta-mesosaprobic zone	moderately polluted
alpha-mesosaprobic zone	heavily polluted
polysaprobic zone	extremely polluted

Table 4: Feeding types of invertebrates and their definitions according to Moog (1995).

Feeding type	Sources of food
grazer and scrapers	endo & epilithic algal tissues, biofilm, partially POM, partially tissues of living plants
miners	leaves of aquatic plants, algae & cells of aquatic plants
xylophagous taxa	woody debris
shredders	fallen leaves, plant tissue, CPOM
gatherers/collectors	sedimented FPOM
active filter feeders	food in water current is actively filtered: suspended FPOM, CPOM, micro prey is whirled
passive filter feeders	food brought by flowing water current: suspended FPOM, CPOM, prey
predators	Prey
parasites	Host
other feeding types	cannot be classified into this scheme or omnivorous

Table 5: Stream zonation preferences of invertebrates and their definitions according to Moog (1995).

Stream Zonation	**Region**
eucrenal	spring region
hypocrenal	spring-brook
epirhithral	upper-trout region
metarhithral	lower-trout region
hyporhithral	grayling region
epipotamal	barbel region
metapotamal	bream region
hypopotamal	brackish water region
littoral	lake and stream shorelines, ponds, etc.
profundal	bottom of stratified lakes

Table 6: Current preferences of invertebrates and their definitions according to Schmedtje & Colling (1996).

Current Preference	**Explanation**
limnobiont	occurring only in standing waters
limnophil	preferably occurring in standing waters; avoids current; rarely found in slowly flowing streams
limno- to rheophil	preferably occurring in standing waters but regularly occurring in slowly flowing streams
rheo- to limnophil	usually found in streams; prefers slowly flowing streams and lentic zones; also found in standing waters
rheophil	occurring in streams; prefers zones with moderate to high current
rheobiont	occurring in streams; bound to zones with high current
indifferent	no preference for a certain current velocity

Table 7: Habitat/substrate preferences of invertebrates and their definitions according to Schmedtje & Colling (1996).

Microhabitat Preference	Explanation
pelal	mud; grain size < 0.063 mm
argyllal	silt, loam, clay; grain size < 0.063 mm
psammal	sand; grain size 0.063-2 mm
akal	fine to medium-sized gravel; grain size 0.2-2 cm
lithal	coarse gravel, stones, boulders; grain size > 2 cm
phytal	algae, mosses and macrophytes including living parts of terrestrial plants
particulate organic matter	woody debris, CPOM, FPOM
other habitats	other habitats (e.g. host of a parasite)

Table 8: Locomotion types among invertebrates and definitions according to Schmedtje & Colling (1996).

Locomotion Type	**Explanation**
swimming/skating	species, which float in lakes or drift in rivers passively
swimming/diving	species, which swim or dive actively
burrowing/boring	species, which burrow in soft substrates or bore in hard substrates
sprawling/walking	species, which sprawl or walk actively with legs, pseudopods or on a mucus
(semi)sessil	species, which are tightened to hard substrates, plants or other animals
other locomotion type	other locomotion type like flying or jumping (mainly outside the water)

Table 9: Numbers of aquatic invertebrate species among the different higher taxonomic groups and countries according to national checklists or "working lists" (marked by a asterisk); EU: all AQEM/STAR countries, LV: Latvia, SE: Sweden, DK: Denmark, FR: France, GB: Great Britain, NL: The Netherlands, PL: Poland, AT: Austria, CZ: Czech Republic, DE: Germany, SK: Slovakia, GR: Greece, IT: Italy, PT: Portugal.

	EU	**LV**	**SE**	**DK**	**FR**	**GB**	**NL***	**PL**	**AT**	**CZ**	**DE**	**SK**	**GR***	**IT***	**PT***
area (in 1000 m^2)	10500	65	450	43	550	243	42	313	84	79	357	49	132	301	92
Araneae	1	1	1	1	1	1	1	1	1	1	1			1	
Bivalvia	58	29	31	22	32	29	24	32	36	31	47	28	15	18	
Branchiobdellida	7	2	1	2		1		4	6	1	4	1		4	
Bryozoa	14	6		7	11	11		11	10	10	13	9		9	
Cestoda	1				1			1					1		
Coelenterata	13	4		6	8	8	1	9	1	6	11				
Coleoptera	1112	202	354	294	578	410	201	420	358	287	480	349	269	342	225
Crustacea	125	15	23	18	51	39	18	55	44	11	108	25	9	6	3
Diptera	3236	194	857	1091	1511	1406	274	1571	1270	1365	2233	568	103	151	37
Ephemeroptera	241	49	60	43	147	51	35	114	116	97	141	123	58	113	42
Gastropoda	174	47	48	38	53	59	47	63	98	51	97	52	51	46	14
Heteroptera	123	23	64	60	79	56	65	66	61	62	73	37	60	89	52
Hirudinea	63	15	15	17	16	16	25	42	34	19	45	22	14	19	10
Hydrachnidia	253	116		159	202	175	252	205	35		163				
Hymenoptera	39	1				39			1		2				
Kamptozoa	1								1		1	1			
Lepidoptera	11	4		5	6	6	5	11	7	4	7				
Megaloptera	6	5	5	3	3	3	2	3	3	3	5	4	1		2
Nematomorpha	1	1		1	1			1	1	1	1			1	
Nemertini	1				1						1				
Odonata	125	54	59	52	97	52	53	73	77	69	84	71	84	87	54
Oligochaeta	232	71	144	98	111	102	56	158	111	127	126	102	17	15	18
Planipennia	6	1	5	5	5	3	1	4	4	4	5	1	1	2	
Plecoptera	313	10	37	25	143	34	10	113	123	101	126	101	92	144	36
Polychaeta	12	1		1	2	1		1	3	2	11	2			
Porifera	9	5		5	5	5		6	2	6	8	5	2		
Trichoptera	734	191	221	168	479	196	112	264	308	252	321	176	152	391	138
Turbellaria	60	7	12	11	32	34	11	14	27	36	22	13	15	3	1
sum	6971	1054	1937	2132	3575	2737	1193	3242	2738	2546	4136	1690	944	1441	632

Table 10: Numbers and percentages of ecologically classified taxa/species of aquatic invertebrates for the six main ecological parameters in the AQEM/STAR database.

	species (6971)		**taxa (9612)**	
	no.	**%**	**no.**	**%**
saprobic classifications	1569	21.1	1855	19.3
feeding types	1980	28.4	2924	30.4
stream zonation preferences	1833	26.3	1955	20.3
current preferences	1217	17.5	1540	16.0
substrate preferences	1146	16.4	1452	15.1
locomotion types	720	10.3	1006	10.5

Table 11: Numbers and percentages of ecologically classified aquatic species within the orders Ephemeroptera, Plecoptera, Trichoptera and Coleoptera, for the six main ecological parameters in the AQEM/STAR database.

	Ephemeroptera (241)		**Plecoptera (313)**		**Trichoptera (734)**		**Coleoptera (1112)**	
	no.	**%**	**no.**	**%**	**no.**	**%**	**no.**	**%**
saprobic classifications	121	50.2	124	39.6	242	33.0	190	17.1
feeding types	133	55.2	118	37.7	282	38.4	331	29.8
stream zonation preferences	119	49.4	111	35.5	277	37.7	332	30.0
current preferences	78	32.4	50	16.0	224	30.5	280	25.2
substrate preferences	66	27.4	28	9.0	195	26.6	215	19.3
locomotion types	57	23.7	9	2.9	88	12.0	47	4.2

Figure 1: Numbers of families (left third of the circles), genera (right third of the circles) and species (lower third of the circles) of aquatic invertebrates within the different AQEM/STAR partner countries.

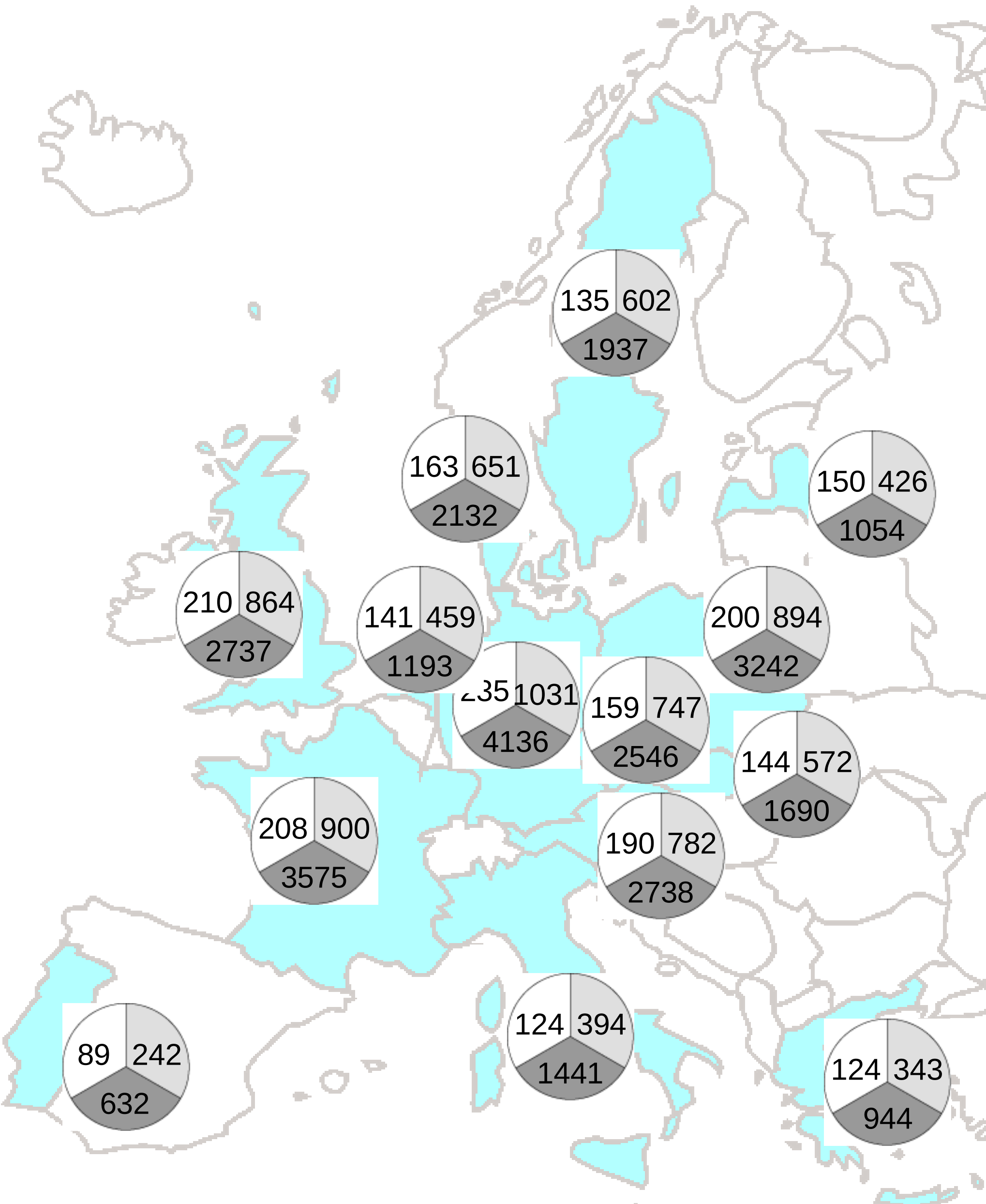


Figure 2: The relationship of numbers of species of aquatic invertebrates identified in individual AQEM/STAR partner countries to their areas.

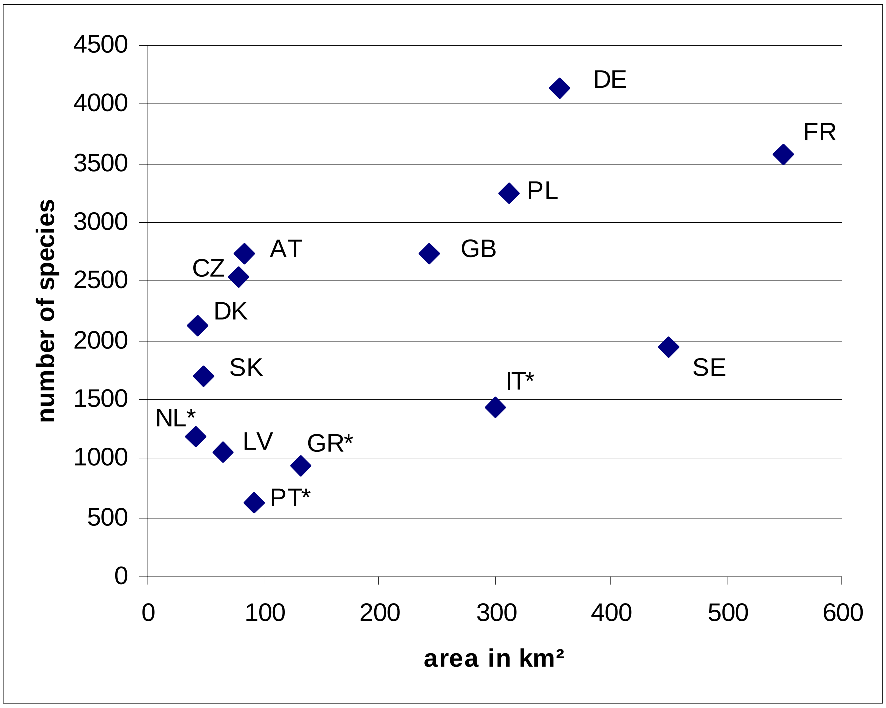
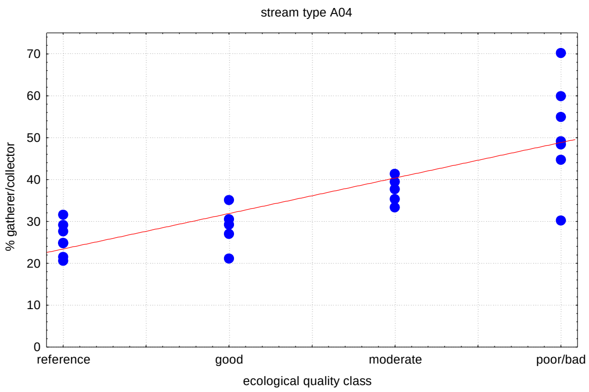


Figure 3: Different feeding types (% individuals) of aquatic invertebrates and their responses to environmental stress expressed in ecological quality classes; a: feeding type "gatherer/collector", b: feeding type "grazer/scraper".



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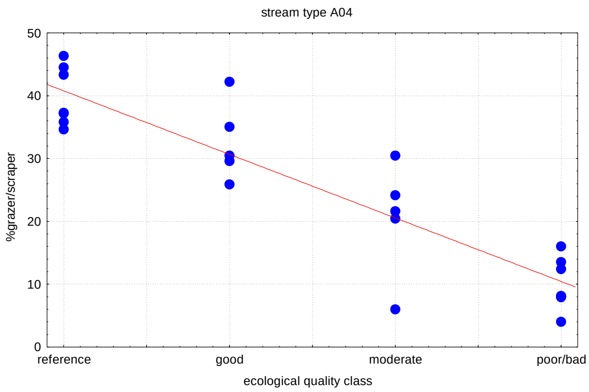

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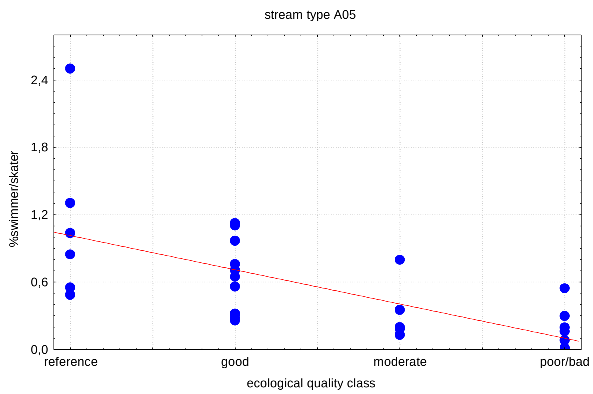
Figure 4: Different types of ecology-based metrics (% individuals) and their response to environmental stress expressed in ecological quality classes; a: locomotion type "swimmer/skater", b: current preference "indifferent", c: stream zonation preference "epirhithral", d: substrate preference "lithal".



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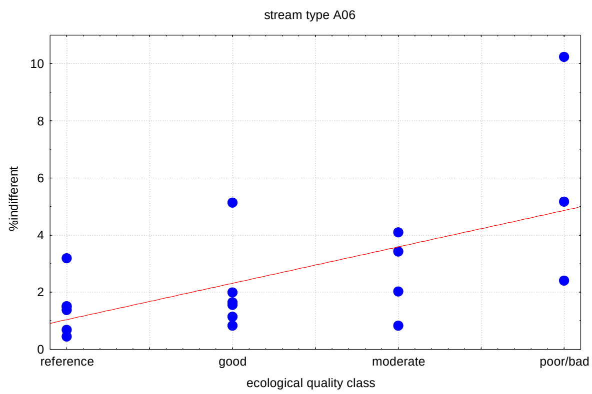

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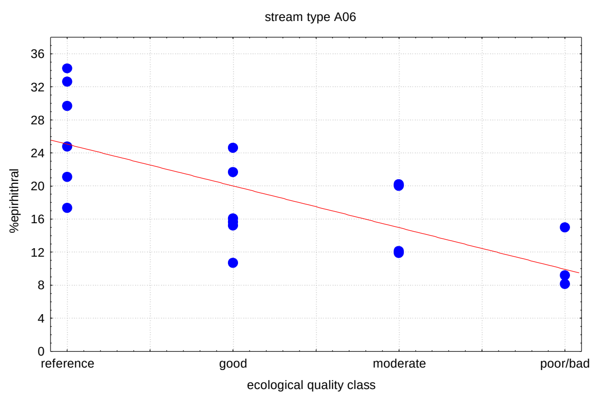

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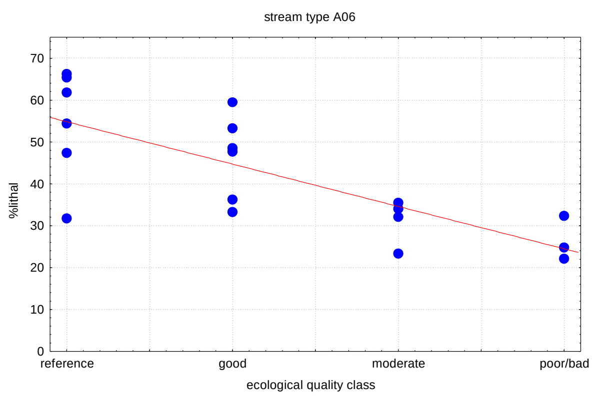

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