Hydrobiologia (2006) 566:33–37

M.T. Furse, D. Hering, K. Brabec, A. Buffagni, L. Sandin & P.F.M. Verdonschot (eds), The Ecological Status of European Rivers: Evaluation and Intercalibration of Assessment Methods
DOI 10.1007/s10750-006-0072-9

Stream and river typologies – major results and conclusions from the STAR project

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Key words: environmental assessment, river, stream, typology, Europe, water framework directive

Abstract

The EU Water Framework Directive uses abiotic variables for classifying streams and rivers into types. For rivers, the EU Water Framework Directive fixed typology i.e. 'System A' typology are defined by ecoregions, size based on the catchment area, catchment geology and altitude. Within any given part of the WFD typology, it is assumed that biological communities at undisturbed sites will be broadly similar and will therefore constitute a type-specific biological target and a way to stratify the spatial variability in stream and river monitoring and assessment. The data collected for the STAR project cover 13 countries and include 22 stream types. A total of 233 sites were fully sampled for all biological quality elements (fish, macrophytes, benthic macroinvertebrates, and diatoms) in the study. Analysing the STAR macroinvertebrate dataset in relation to environmental and biogeographical variables resulted in three major groups of stream types that correspond to three major landscape types in Europe: Mountains, Lowlands and Mediterranean. Similar results were found when analysing all four biological quality elements (fish, macrophytes, benthic macroinvertebrates, and diatoms) sampled in the STAR project. The studies also showed that the stream types using the WFD 'System A' descriptors are probably less useful at finer scales and it is suggested that a stream typology should take three main parameters as a starting point, i.e., climate (temperature), slope (current velocity) and stream size. Existing site-specific multivariate RIVPACS-type predictive models were also compared to both null models and the WFD 'System A' physical typology as methods of predicting macroinvertebrate reference conditions. It was concluded that the multivariate models are more effective in predicting reference conditions primarily because they make use of continuous rather than categorical predictor variables and because the multivariate RIVPACS-type models are not constrained by the use of a limited number of variables.

Introduction

In environmental assessment studies of environmental impact, the objective is to separate the change generated by anthropogenic stress from the natural spatial and temporal variability (Johnson, 1998). If the natural variability is large and the anthropogenic induced change is small it will be difficult to detect a real change in the measured variable(s) caused by the pollutant (Johnson, 1998). Geographical classifications (e.g., by ecoregions) can be a useful tool in partitioning natural spatial variability, thereby optimizing monitoring, assessment, and conservation programs. Simply put, by using geographical classification sampling is more cost-effective (less samples are needed to detect anthropogenic stress) and a water quality baseline for each geographic area can be defined.

A renewed interest in regionalization in the environmental assessment of fresh waters (mainly in the USA and Europe) is largely a result of government agencies wanting to shift their efforts in resource management from single issues (a particular stream or lake) to a more holistic approach (e.g., aquatic systems nested in catchments or ecoregions) (Omernik & Bailey, 1997). The use of a typology to classify streams has also become an accepted part of ecological assessment (Wright et al., 1999; Hering et al., 2004), but the underlying factors (variables) determining the typology differs strongly among approaches.

The EU Water Framework Directive (European Commission, 2000) uses only abiotic variables for classifying streams and rivers into types (Annex II, section 1 of the WFD), whereas other approaches such as the RIVPACS predictive model (e.g., Wright et al., 1984) uses biotic variables, and others uses combinations of biotic and abiotic variables (e.g., Reynoldson et al., 1997). For rivers, the EU Water Framework Directive fixed typology i.e., 'System A' typology is defined by ecoregions (according to Illies, 1978), size based on the catchment area (small 10–100, medium 100–1000, large 1000–10,000 and very large >10,000 km^2), catchment geology (calcareous, silicious, and organic), and altitude (lowland, <200, mid-altitude 200–800 and high altitude >800 m.a.s.l.). Within any given part of the WFD typology, it is assumed that biological communities at undisturbed sites will be broadly similar, and will therefore constitute a type-specific biological target and the typology is thus a way to stratify the spatial variability in stream and river monitoring and assessment.

The EU Water Framework Directive also allows each member state to adopt an alternative characterization 'System B' with five obligatory factors (altitude, latitude, longitude, geology and size), and an additional 15 optional factors (e.g., distance from river source, mean water depth, and mean substratum composition). No specific categories of value ranges are suggested for each factor in 'System B' and the member state is left to decide how many of the optional factors they wish to use. In consequence a very extensive set of stream types could be defined by individual Member States for each ecoregion within their territorial limits, since with e.g., 'System A' each ecoregion has a theoretical maximum of 4 (size)$\times$3 (altitude)$\times$3 (geology) = 36 types, which means that within a country such as Sweden containing three (Illies) ecoregions, the maximum number of theoretical stream and river types is 108, but in reality only some of these types do exist, mainly because altitude is strongly related to ecoregion.

River and stream types

The data collected for the STAR project cover 13 countries (Austria, Czech Republic, Denmark, France, Germany, Greece, Italy, Latvia, Poland, Portugal, Slovakia, Sweden and UK). The sampling included 22 stream types, where five were defined as being of the STAR project type "Core stream type 1" (mid altitude, 200–500 m.a.s.l. and with a "small" catchment area 10–100 km^2), seven were of the STAR project type "Core stream type 2" (lowland, <200 m.a.s.l. and "medium" catchment areas 100–1000 km^2), whereas ten other stream types were defined as STAR project type "Additional stream type" (having a different characterisation). Core and additional stream types could also be defined as either calcareous, siliceous or, occasionally, organic but, with a few exceptions, sites within a type sampled by a partner were all in the same geological category. These stream types sampled in the project are situated in 11 Ecoregions according to Illies definition (Illies, 1978; as used in the Water Framework Directive), these were regions 3, 4, 6, 7, 8, 9, 10, 14, 15, 16 and 18. Within these 22 types, 263 sites (streams or rivers) were sampled for macro-invertebrates in each sampling season (see Furse et al., 2006). All of these 263 sites were also subject to hydromorphological surveys and 252 were sampled for phytobenthos, 251 for macrophytes and 249 for fish. A final total of 233 sites were fully sampled for all biological quality elements.

Testing of the WFD typology

As part of the STAR project, the amount of variation in benthic macroinvertebrate composition explained by differences in stream types was tested in the six countries where at least two types were sampled. The amount of variation in macroinvertebrate community composition explained by type differed between 16.0% in the Czech Republic and 67.9% of the total explained variation in Greece (Sandin, Friberg, Furse, Clarke & Larsen unpublished). In comparison, the difference between two sampled seasons explained between 11.6% of the total explained variation (in Greece) and 56.0% of the total explained variation in Latvia. The pre-defined stress gradient (here divided into sites pre-defined as having a high or good ecological status versus those pre-defined as having a moderate, poor or bad ecological status [see Furse et al., 2006]) explained between 15.3% (in Greece) and 55.3% of the total explained variation in France (Sandin, Friberg, Furse, Clarke & Larsen unpublished). Stream type, differences between seasons, and the pre-defined stress gradient were always statistically significant explanatory variables. When looking at these comparisons one must of course take into account the fact that e.g., differences in how much variation is explained by type in relation to the other factors in dependent on how large differences there are in types analysed.

Analysing the STAR macroinvertebrate dataset in relation to environmental and biogeographical variables resulted in three major groups of stream types that correspond to three major landscape types in Europe: Mountains, Lowlands, and Mediterranean (Verdonschot, 2006a). This author suggests that the three major groups probably represent the major combination of geomorphological and/or climatological conditions of the sampled sites and that the driving forces behind these differences are most probably climate (temperature), slope (current velocity) and stream size, where benthic macroinvertebrates respond to the driving forces of these three major factors. Similarly, Pinto et al. (2006) also concluded that the biotic data (in this case all four sampled biological quality element) could be divided into three main groups, i.e., Mediterranean, mountain, and lowland streams or rivers.

The study by Verdonschot (2006a) also showed that the stream types using the WFD 'System A' descriptors are probably less useful at finer scales and he also suggests that a stream typology should take the three main parameters as a starting point. Next streams with comparable major environmental conditions can be mapped and reference conditions can be defined as such. Verdonschot (2006a) also concluded that, the geographic descriptors (e.g., ecoregions) did not fit well within the benthic macroinvertebrate typology testing.

Earlier, Verdonschot & Nijboer (2004) tested if the typology suggested in the WFD was useful for developing an assessment system for macroinvertebrates in streams. They concluded that the major macroinvertebrate distribution patterns in European streams follow climatological and geomorphological conditions and are well distinguished in terms of stream types. Thus, the WFD typology was useful for the development of type-specific assessment systems for streams using macroinvertebrates. Furthermore, it was shown that large-scale factors affected the macroinvertebrate distribution even on a very fine scale. On the other hand Sandin & Johnson (2000) concluded that large-scale variables such as an ecoregional delineation is not sufficient for stratifying streams or rivers for monitoring and assessment based on benthic macroinvertebrates. Testing differences in taxonomic composition among sites or streams between types (based on abiotic data) is clearly also dependent on taxonomic resolution used in the study (Verdonschot, 2006b), the finer the taxonomic resolution used, the more distinctive the types become. In this study it was also shown that species (or 'best available') taxonomic level performed better at a practical (fine) scale in comparison to family-level taxonomy. Another complication is that human stress diminishes the natural differences between stream communities and typologies should therefore be based on reference conditions (Verdonschot, 2006b). If the reference condition criteria used within different stream or river types differ, when defining references used for comparisons, types that are in reality distinct might seem to be similar enough to merit them to be joined into a common type.

Finally, a different approach was taken by Davy-Bowker et al. (2006). These authors used existing site-specific multivariate RIVPACS-type predictive models already in place in Great Britain (RIVPACS), Sweden ($\mathrm{SWEPAC}_{\mathrm{SRI}}$) and the Czech Republic (PERLA) and compared them to both null models and the WFD 'System A' physical typology as methods of predicting macro invertebrate reference conditions. They conclude that the multivariate models are more effective in predicting reference conditions primarily because they make use of continuous rather than categorical predictor variables (that have been selected for their value as good correlates of macroinvertebrate community composition) and because the multivariate RIVPACS-type models are not constrained by the use of a limited number of variables (Davy-Bowker et al., 2006). A further problem with a priori typological approaches such as the WFD 'System A' as demonstrated by Davy Bowker et al. (2006) is that they usually utilise variables gathered solely at large geographical scales, whereas their analysis shows that substratum composition, width and depth, all of which are local scale variables measured at the time of sampling, can also be strong correlates of macroinvertebrate community composition. The importance of both large-scale and local factors as determinants of macroinvertebrate communities should therefore not be overlooked when setting up montoring and environmental assessment systems in streams and rivers. Similar conclusions were reached by Heino et al. (2003) based on a study of macroinvertebrate diversity in headwater streams.

Conclusions

- Stream type, differences between seasons, and the pre-defined stress gradient were always statistically significant explanatory variables when testing their relation to the benthic macroinvertebrate community composition.
- Analysing the STAR macroinvertebrate dataset in relation to environmental and biogeographical variables resulted in three major groups of stream types that correspond to three major landscape types in Europe: Mountains, Lowlands, and Mediterranean.
- Similarly, it was concluded that the biotic data (in this case all four sampled biological quality element) could be divided into three main groups, i.e. Mediterranean, mountain, and lowland streams or rivers.
- The driving forces for benthic macroinvertebrates are most probably climate (temperature), slope (current velocity), and stream size.
- Testing differences in taxonomic composition among sites or streams between types (based on abiotic data) is clearly also dependent on taxonomic resolution used in the study, the finer the taxonomic resolution used, the more distinctive the types become.
- It was also concluded that multivariate (RIVPACS type) models are more effective in predicting reference conditions than either null models or WFD 'System A' typology primarily because they make use of continuous rather than categorical predictor variables.

Acknowledgements

STAR was funded by the European Commission, 5th Framework Program, Energy, Environment and Sustainable Development, Key Action Water, Contract no. EVK1-CT-2001–00089.

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