Different Scales of Analysis in Classifying Streams: from a Multimetric Towards an Integrate System Approach

Cortes, R. M. V.(1)[1], Oliveira, S. V.(1), Cabral, D. A.(1), Santos, S.(1) & Ferreira, T.(2)[2]

(1) UTAD, Depart. Florestal.

(2) Inst. Sup. Agronomia, Depart. Florestal.

Abstract

Two different approaches to define the ecological status of several catchments (NW Portugal) are compared. At a coarser scale, all the stream network was classed using GIS according to several variables related to: a) biotic indicators, such as native and exotic fish species, benthic biotic index and characteristics of the riparian corridor); b) chemical indicators of contamination, where an estimation of industrial and urban organic loads and water quality was included. This methodology is preceded by a typological classification so that a determination of the ecological status can be made separately of each of the physical units integrated in the watercourse. More specifically, sites monitored on the basis of invertebrate fauna were classed and the most relevant metrics were selected through multivariate procedures. Both methods can be seen as

---

[1] Universidade deTrás-os-Montes e Alto Douro, Depart.amento Florestal, Apart. 202, 5001-911 Vila Real, Codex, Portugal. E-mail: rcortes@utad.pt; Tel: 351259350269; Fax: 351259350480.

[2] Instituto Superior de Agronomia, Departamento Florestal, Tapada da Ajuda, 1349-017, Lisboa, Portugal. E-mail: terferreira@isa.utl.pt; Tel: 351213653487; Fax: 351213645000.

complementary and produced similar indications at different scales of analysis. In the first case, a management orientated technique, we can identify the main typological gradients and the relative pristine segments of the most disturbed ones. Such an assessment of the entire catchment of grate use in the 2nd case in order to define the sampling sites for multimetric systems in river health assessments.

Introduction

Biosurvey techniques are commonly used to detect aquatic life impairments and to assess their relative severity. However, additional environmental information is needed to identify the source of disturbance, such as chemical and hydrological data sets and habitat description. Biosurveys may be used within a planning or management framework to prioritize water quality problems or to document recovery following mitigation or rehabilitation measures (Barbour *et al.*, 1999). The actual assessment of the biological condition tries to characterize the overall integrity of a river system, and the term “river-health” has been used even though it meaning remains obscure (Norris & Thoms, 1999). Assessment of river health involves comparisons between sites that are thought to be similar in the in lack of degradation. Classification of stream sites is essential to define the reference sites in each ecoregion, and it can be achieved by multivariate analysis or predictive models (*e.g*. Wright *et al.*, 1984, Moss *et a*l., 1987, Parsons & Norris, 1996), or by studying geomorphical features (*e.g.* Hughes & Larsen, 1988, Omernik, 1995). Such comparisons can be based on a multimetric approach, i. e, by using potential measures (metrics) that are relevant to the ecology of streams. According to Barbour *et al.* (1999) representative metrics should be selected from each of the following 4 categories: a) richness measures; b) composition measures; c) tolerance measures; d) trophic or habit measures. Therefore this methodology relies exclusively on the use of stream biota (one or more communities). These indicators, according to Herlihy *et al*. (1997), must be: a) biologically relevant; b) implementable on national and regional scales; c) robust (repeatable and quantitative); d) sensitive to disturbance.

However, as pointed out by Davies *et al.* (2000), stream managers often require information about other features, e. q. physical ones, that need to be improved to enhance the biological condition. Moreover, a number of authors have argued for a more oriented catchment approach. Such an approach should assimilate the hierarchical framework for stream habitat classification proposed by Frissel *et al*. (1986), which emphasizes a stream's relationship to its watershed across a wide range of scales in space and time, from the global channel network to the micro-habitat level. For instance, Lorenz *et al*. (1997) have proposed that the assessment of a functioning river ecosystem requires spatial integration of water quality, hydrology and geomorphology (to describe the structure of the river channel), riparian zones (including floodplains) and ecological information on species. This concept may be considered similar to the habitat assessment model of Davies *et al.* (2000) that establishes the links between larger-scale locational characteristics and local scale habitat features. But, while there is no doubt that human activities such as land use and water resource development, alter the physical, chemical and biological processes of river ecosystems, most assessment methods fail to integrate anthropogenic indicators with the other biotic or abiotic descriptors of a river system condition.

Which approach is more useful? Should we adopt bioassays based on biota, such as the multimetric procedures, which imply a previous development of regional reference sites, but are more precise at a local level? Or, is it more convenient to fallow an integrated view of the whole catchment, including geomorphological analysis at appropriate spatial scales and indicators of disturbance (physical, biological, human influences…)? Are both assessment practices totally independent or do they complete and validate each other? These are the type of questions we should like to investigate in the present work, where both methods and concepts are compared in some catchments in the North of Portugal.

Methods

Study area

This study took place in NW Portugal along five catchments: Âncora, Lima, Neiva, Cávado and Ave (Figure 1), the first and the third basins being the smallest. The Lima River is the longest one having its source in Spain. All the main rivers have flows regulated by dams, for hydropower purposes, particularly Lima River, where the second most important Portuguese dam located near the border with Spain. This area is characterized by narrow and steep valleys of granite bedrocks, but with a relatively high run-off, the consequence of an average yearly rainfall value of 1900 mm, which reaches about 2800 mm in the headwaters in the neighboring country. Most of the population lives in the coastal zone, and this province has the largest human population density of the country. Therefore, many impacts associated with urbanization are here present (emphasized by the fact that the domestic sewage treatment plants barely reach a level of 40%), in contrast with the eastern areas, with their steeper valleys and the remnants of native vegetation (the only national park of the region is situated precisely on the upper parts of the Lima and Cávado basins). Land use is predominately agricultural in the generally more flat, western zones, but the Ave basin has the highest concentration of industry (mainly textile factories) with obvious consequences for the contamination of the middle and lower reaches.

Assessment of the ecological status of the aquatic ecosystems

a) Biological integrity

A total of 34 sites were defined, for benthic collections, habitat characterization and water quality analysis. These stations were monitored in the spring of 1999. A kicking procedure sampling method, using a hand-net, with constant effort at each site, was used to collect the invertebrates, which were identified in most cases, to species level. We investigated an array of invertebrate attributes (potential metrics) thought to be useful in the assessment of the biological conditions. This array covered the four categories mentioned in Barbour *et al*. (1999). The metrics used appear in Table1 together with the environmental descriptors. Several parameters expressing the habitat characteristics were quantified from the forms used for the River Habitat Quality (Raven *et al*., 1998).

To explore the degree of ecological importance of the 37 metrics included, several multivariate analyses, namely Redundance Analysis (RDA) and Canonical Analysis (CA), were performed through the packages CANOCO (ter Braak & Smilauer, 1998) and STATISTICA (Statsoft, 1998). Data (metrics and environmental descriptors) were previously transformed by linear methods for the chemical variables and by non-linear methods for taxa abundance. RDA was the technique selected to determine the relationship between the individual metrics and the environmental attributes. This procedures uses both sets of data (taxa and site descriptors) and it may be considered a restricted type of Principal Components Analysis performed for species data, but where the axes are linearly related to the environmental parameters. Additionally, RDA also used new variables representing interactions between individual variables describing typology. Redundant variables were eliminated prior to CA, and this technique was also used to link both sets of data and primarly to know the association (redundance) between biotic and abiotic descriptors.

b) Classification coupling biological and physical features

We based the assessment of disturbance for the entire drainage network on a previous river classification of the geomorphic characteristics. Stream geomorphic units (GUs) were studied under a hierarchical perspective linking variables that determine physical watershed features. Such parameters were: stream order (Strahler concept), simplified geological classification, topography (slope mapping) and precipitation (this variable defines the hydrological regimen) - Table 2. A Geographic Information System (GIS) combined these different types of data, where the segments < 2Km were discarded.

At a macro-scale of the watershed we also used GIS to integrate land use with instream conditions, and to produce a final index of global stream quality called KT. We relied on seven primary data layers (with discrete and continuous variables) divided into two groups (Table 3):

- KA (biotic integrity variables): biotic index based on benthic fauna, structure of the riparian corridors, number of exotic fish species and number of native fish species.
- KB (variables defining environmental stressors): water quality, contamination load from urban source and contamination load from industrial activities.

We combined these data layers to identify the different state of conservation of the fluvial network in the three catchments. ARCVIEW © was the GIS software used to overlay the distinct data layers to perform the final spatial assemblage.

To calculate KT we took into account that the final value had to independent of the number of variables with available information and of the relative range of variation in each case. In fact, this index combines the site information (ex: biotic index or water quality), which is extended to the defined segment (GU), with continuous characterization (ex: estimated loads defined for all the GUs at a district level). The following formula was established, and it integrates a double standardization, to compensate for the above mentioned character of available data at the individual physical units, where n is the number of variables in each segment and s the standard deviation:

$$\mathrm{KT} = \sum\left(\frac{\mathrm{KA_i} - \overline{\mathrm{KA_i}}}{s\left(\overline{\mathrm{KA_i}}\right)}\right)\Big/ \mathrm{nA_i} + \sum\left(\frac{\mathrm{KB_i} - \overline{\mathrm{KB_i}}}{s\left(\overline{\mathrm{KB_i}}\right)}\right)\Big/ \mathrm{nB_i}$$

The KT classes allow us to prioritize eligible areas for restoration or for preservation.

Results

RDA treated both sets of data simultaneously. The cumulative variance of the metrics-environment relation explained by the first two axes was 51.8 % of the total variance, which implies a strong contribution to reduce the overall variability (the eigenvalues of the1st and 2nd axes were, respectively, 0.322 and 0.145). However, all the variables related to the substrate composition showed a strong multicollinearity, since they presented values of inflation factor > 20 (Jongman *et al.*, 1987). A partial RDA ordination was performed, where each drainage basin was considered as a covariable. Both of the first two axes showed a similar proportion of variance (51.1 %), and after fitting the covariables it was calculated that these represent only 10.6 % of the total variance. Therefore, we may conclude that the metrics did not reflect important differences between each catchment. A further RDA analysis was used, including two extra variables (interactions) describing the typological variation: distance to source x width and distance to source x depth. The objective was to detect the 10 most easily explained environmental parameters, which was accomplished through the “forward selection” procedure (ter Braak & Smilauer, 1998). The resulting diagrams appear in Figures 2 and 3, where arrows represent the sites attributes, with a proportional length to the effect of the variable on the ordinations. Such selected variables accounted for about two--thirds of the variance explained by all variables. The eigenvalues of axes 1 and 2 were 0.265 and 0.103 (cumulative variance of the two axes: 69.2 %) and the inflation factors of each of these variables were below 10, showing the absence of multicollinearity. Figure 2 illustrates that this analysis can discriminate between the most disturbed reaches and the most preserved ones, whereas Figure 3 facilitate to extract the most relevant metrics responsible for such separation. Thus, when characterizing the less impacted sites we find: intolerant taxa and Trichoptera, Plecoptera, Ephemeroptera and EPT taxa. On the opposite side of this environmental gradient we found increasing numbers of tolerant species and a high proportions of Oligochaeta, Gastropoda and Crustacea + Mollusca.

CA gave a global view of the metrics effectiveness as a bioassessment tool. Here, to avoid the multicollinearity between metrics expressed either as numbers or percentages, only the independent variables were included in the analysis, together with total abundance and H’ (resulting in a total number of 20 tested metrics). For the same reason, only 12 site descriptors with no overlap information were considered: depth, current, width (average values), conductivity, sand, silt, dominant substrate, riparian and macrophytic cover, riparian integrity, disturbance level and banktop soil use. The canonical R was highly significant ($p < 0.001$) and the first root displayed an eigenvalue of 0.993. The total redundancy of the environmental variables and metrics was notoriously high, respectively, 65.11% and 46,82 %. Such a strong redundance between both data sets allows us to infer a marked overall correlation between the community and the environment descriptors. Figure 4 expresses clearly, for the first root, the strong affinity between the canonical coefficients of the variables belonging to each set, displayed by a linear relation.

On the basis of the typological classification of the streams draining the studied catchments, 44 GUs were established. As can be observed in Figure 5, the physical structural complexity is not apparently different along the longitudinal gradient. However, from an inter-basin perspective it is possible to conclude that the Ave catchment is relatively more homogeneous. The classification of the GUs, for the quantification of the index of conservation KT, through the variables included in KA and KB, enabled us to distinguish between the relatively more preserved eastern areas, corresponding to the higher reaches, and the overpopulated and industrialized downstream parts (Figure 6). A relative exception is the Ave basin, where the disturbance sources are spread throughout the whole area, including the main stream and the tributaries. This index is also sensitive to regulation impacts, which can be seen from the lower degree of the quality classification of the main stem of the River Lima basin.

Discussion

We observed a general coincidence between both spatial scale analyses. That is, the finer resolution from the discrete classification of sites based on metrics has common features with the one orientated towards a global perception of the entire catchment. In fact, the division between the most disturbed sites *versus* the least modified ones (potential reference sites) obtained by multivariate analysis of biota composition (exclusively the benthic invertebrate taxa) agrees with the classification of the entire network super--imposed on a previous determination of the geomorphological units calculated by an integrator approach which includes indicators of biota disturbance (fishes, invertebrates, riparian cover) and of the water quality and human activities over the watershed (sewage effluents). Naturally, this last method is more useful for catchment planning and for assessment of cumulative effects, but it needs a larger amount of data. Indeed, this technique, even if apparently displaying more information, is only a valid procedure if there is extensive information for all the variables contributing to the KT calculation. In reality, we discovered a relatively stronger contribution of the continuous variables for the final KT, in spite of the standardization procedure. We believe that the use of convenient weighting factors for each variable may overcome this aspect.

Nevertheless, GIS allows for great flexibility in defining restoration goals (Rusell *et al.*, 1997), and offers a meaningful way of data summarization and presentation. KT classification is a flexible procedure, as the variables selection may depend on existing data. Also, it may be constantly improved by adding new sources of information, which may overcome a lack of precision of some variables. In fact, as more variables are included in the KT determination its final value becomes less dependent on a particular parameter (for instance, in the present work the number of sampling stations for aquatic fauna is probably insufficient). Certainly other variables reflecting changes on a large scale could be more important, when analysing modifications at a basin perspective, than point or local descriptors. A variable that probably should be considered is land cover: Roth *et al.* (1996) found that stream biotic integrity was correlated with this variable at a catchment scale, and that local riparian vegetation was a weaker predictor of stream conditions. This is not surprising because Omernik *et al*. (1981) had already shown that stream nitrate and phosphorous concentrations were strongly related to watershed land uses, but not to land near the margins. But this observation is true also for validation of metrics, which generally rely on local features (this potential bias is also underlying this work…) but needs to be correlated, not only with local indicators of physical habitat degradation but also with measures of anthropogenic influence at the landscape scale (Klauda *et al*., 1998).

Thus, the multimetric system is clearly more precise in concerning assessment of ecological functioning of the streams, and may be adopted as a tool for the Water Directive (Framework for Community Action in the Field of Water Policy), but it is very dependent on the local characteristics of the streams (reach or segment). Moyle & Marchetti (1999) and Moyle & Randall (1998) stress this characteristic by considering that indices of biotic integrity (IBI) are typically site-specific measures, and that watersheds evaluation needs distinct watershed-wide metrics. All types of metric procedures need, however, a previous definition of the reference points. Theses should be discriminated by the ecoregions and ecotypes, and in each of these geographical areas such points should be representative of pristine conditions (or regional reference sites). Our approach satisfies that objective: by defining the geomorphological units (GUs), followed by their classification according to the human impacts (KT) we provide a useful tool for the definition of the reference sites. By coupling KT and GUs classifications we may have also the underlying geomorphic context or the potential response of the channel segment to disturbance. This method allows for a series of spatial scales - from the reach, that is, the sampling site through the valley segments to the whole watershed. Frissel & Ralph (1998), consider that the most effective monitoring designs should include, precisely designated functional controls following this hierarchical approach.

Therefore, the KT evaluation could be the process to carry out before the location of sites for bioassessment. This is an essential aspect of IBI application and it is not uncommon that this index it is not correlated with habitat degradation because of a lack (or deficient selection) of reference sites, as pointed out by Shields *et al*. (1995) and, as a consequence, IBI classes are ecologically meaningless. Another approach, similar to IBI, is the use of biological traits of organisms, such as size, reproductive and dispersal potential, feeding habits, etc, as disturbance measures across ecoregions. A detailed description of traits and their categories may be found in Usseglio-Polatera *et al*., (2000). Statzner *et al*. (2001) applied these functional analyses on a large scale, covering many water types across Europe. From our perspective, the assignment of benthic taxa to those groups requires a detailed knowledge of their ecology, which is virtually absent for many endemic species in Mediterranean areas, besides being more laborious and potentially producing redundant information.

In conclusion, both techniques developed here may be used together, moreover with multi-purposes objectives, involving assessment of stream functioning and planning at different scales. It is both practical and technically advisable, that the selection of sites for biological monitoring be based on a general characterization of the geomorphological patterns, displayed at the catchment level coupled with the evaluation of the relative magnitude of the disturbance factors along the defined river segments.

Bibliography

Barbour, M.T., Gerritson, J., Snyder, B.D. & Stribling, J.B. (1999): Rapid bioassessment protocols for use in stream and wadeable rivers: Peryphiton, benthic macroinvertebrates and fish. *EPA 841-B-99-002*. U.S. Environmental Protection Agency, Washington.

Davies, N.M., Norris, R.H. & Thoms, M.C. (2000): Prediction and assessment of local stream habitat features using large-scale catchment characteristics. - *Freshwater Biology*. **45**: 343-370.

Frissel, C.A., Liss, W.J., Warren, C.E. & Hurley, M.D. (1986): A hierarchical framework for stream habitat classification: viewing streams in the watershed concept. - *Environmental Management*. **10**: 199-214.

Frissel, C.A. & Ralph, S.C. (1998): Stream and watershed restoration. 599-625. *River Ecology and Management*. - R.J. Naiman & R.E. Bilby (eds.), Springer, New York.

Herlihy, A., Kaufamnn, P., Reynolds, L., Li, J. & Robison, G. (1997): Developing indicators of ecological condition in the Willamete Basin: An overview of the Oregon Prepilot Study for EPA’s EMAP Program. 275-282. *River Quality,* *Dynamics and Restoration*. - A. Laenen & D.A. Dunette (eds.), Lewis Publishers, CRC Press, Boca Raton.

Hughes, R.M. & Larsen, D.P. (1988): Ecoregions: An approach to surface water protection. - *Journal of the Water Pollution Control Federation*. **60**: 486-493.

Klauda, R., Kazyak, P., Stranko, S. & Southerland, M. (1998): Maryland biological stream survey: a State Agency Program to assess the impact of anthropogenic stress on stream habitat quality and biota. - *Environmental Monitoring and Assessment*, 51: 299-316.

Jongman, R. H., ter Braak, C.J. F. & Tongeren, O.F.R. (1987): Data Analysis in Community and Landscape Ecology. - Pudoc, Wageningen, The Netherlands.

Lorenz, C.M., Van Dijk, G.M., Van Hattum, A.G.M. & Cofino, W.P. (1997): Concepts in river ecology: Implications for indicator development. - *Regulated Rivers: Research & Management*. **13**: 501-516.

Moyle, P.B., & Marchetti, M.P. (1999): Applications of indices of biotic integrity to California streams and watersheds. 367-380. *Assessing The Sustainability and Biological Integrity of Water resources Using Fish Communities*. - T.P. Simon (ed). CRC Press, Boca Raton, FL.

Moyle, P.B. & Randall, P.J. (1998): Evaluating the biotic integrity of watersheds in the Sierra Nevada, California. - *Conservation Biology*. **6**: 1318-1326.

Moss, D., Furse, M.T., Wright, J.F. & Armitage, P.D. (1987): The prediction of the macroinvertebrate fauna of unpolluted running-water sites in Great Britain using environmental data. - *Freshwater Biology*. **17**: 41-52.

Norris, R.H. & Thoms, M.C. (1999): What is river health?. - *Freshwater Biology*. **41**: 197-209.

Omernik, J.M., Abernathy, A.R. & Male, L.M. (1981): Stream nutrient levels and proximity of agricultural and forest land to streams: some relationships. - *Journal of Soil and Water Conservation*. **36**: 227-231.

Omernik, J.M. (1995): Ecoregions: a spatial framework for environmental management. 49-62. *Biological Assessment Criteria: Tools for Water Resource Planning and Decision-Making*. - Lewais Publishers, Boca Raton, FL.

Parsons, M. & Norris, R.H. (1996): The effect of habitat specific sampling on biological assessment of water quality using a predictive model. - *Freshwater Biology.* **36**: 419-434.

Raven, P.J., Holmes, N.T.H., Dawson, F.H., Fox, P.J.A., Everard, M., Fozzard, I.R. & Rouen, K.J. (1998): River Habitat Quality. - Environment Agency, Bristol, U.K.

Roth, N.E., Allan, J.D. & Erickson, D.L. (1996): Landscape influences on stream biotic integrity. - *Landscape Ecology*. **3**: 141-156.

Russell, G.D., Hawkins, C.P. & O'Neill, M.P. (1997). The role of GIS in selecting sites for riparian restoration based on hydrology and land use. - *Restoration Ecology*. **4**: 56-68.

Shields Jr., Knight, S.S. & Cooper, C.M. (1995): Use of biotic integrity to assess physical habitat degradation in warmwater streams. – *Hydrobiologia*. - **312**: 191-208.

Statsoft. (1988): STATISTICA for Windows (Computer Program Manual). - Statsoft, Inc.: Tulsa, Oklahoma, USA.

Statzner, B., Bis, B., Dolédec, S. & Usseglio-Polatera, P. (2001): Perspectives for biomonitoring at large spatial scales: A unified measure for the functional composition of invertebrate communities in European running waters.

ter Braak, C.J.F. & Smilauer, P. (1998): CANOCO: Software for Canonical Community Ordination - version 4. - Wageningen, The Netherlands.

Usseglio-Polatera, P., Bournaud, M., Richoux, P. & Tachet, H. (2000) : Biological and ecological traits of benthic freshwater macroinvertebrates: relationships and definition of groups with similar traits. *Freshwater Biology*. **43**: 175-205.

Wright, J.F., Moss D., Armitage, P.D. & Furse, M.T. (1984): A preliminary classification of running water sites in Great Britain based on macroinvertebrate species and the prediction of community type using environmental data. - *Freshwater Biology*. **14**: 221-256.