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ENVIRONMENTAL DRIVERS OF BENTHIC COMMUNITIES: THE IMPORTANCE OF LANDSCAPE METRICS

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Abstract

The distribution of aquatic communities is dependent on processes that act at multiplescales. This study comprised 270 samples distributed over 2 years and used a nested sampling design to estimate the variance associated with three spatial scales: basin, site and microhabitat. Habitat assessment was made using River Habitat Survey. The derived Habitat Quality Indices and the benthic composition were crossed with landscape metrics and types of soil use, obtained from GIS data, using multiple non-parametric regressions and distance-based redundancy analysis. Invertebrate variation was mainly linked with intermediate scale (site) and landscape metrics were the main drivers determining local characteristics. The aquatic community exhibited a stronger relationship with landscape metrics, especially patch size and shape complexity of the dominant uses, than with habitat quality, suggesting that instream habitat improvement is a short-term solution and that stream rehabilitation must address the influence of components at higher spatial scales.

Keywords: landscape metrics, soil use, macroinvertebrates, habitat, spatial scale

1. Introduction

The hierarchy theory indicates that small scale physical and biological features are hierarchical nested by variables on larger spatial scales, which means that in-stream conditions are constrained and controlled by successive larger-sale factors, interacting as filters along those scales (Frissell et al. 1986; Poff, 1997). Lotic biological assemblages occurring at a given site are a subset of the potential pool of colonizers that have passed through a system of filters related to the environmental variables and their modification by human action (Boyero, 2003; Bonada et al., 2005). This is the case of geology, climate and landscape-level factors such as land use or vegetation patterns that have been shown to influence local habitat condition and therefore the composition of benthic fauna (Roth et al. 1996; Lammert & Allan, 1999; Joy & Death, 2004). More recently, studies tended to focus on analyzing the dependence of hydromorphological characteristics on catchment level features and land-use, in particular whether reach or catchment scale vegetation constitute suitable predictors of in-stream features (Allan, 2004; Buffagni et al., 2009; Sandin, 2009). There is a strong need to develop habitat assessment strategies that integrate different complementary spatial scales from microhabitat level (including hydraulics) to the assessment of river corridor condition and surrounding land use (Cortes et al., 2009). These aspects have been already incorporated into methodologies proposed in different field surveys (e.g. Raven, 1998). There is no doubt that the spatial hierarchy of fluvial ecosystems is a crucial aspect to consider, since identifying the relationships between different levels allows associations to be made between habitat features, processes and communities. This knowledge is essential for improving the implementation of appropriate management and monitoring measures (Sandin, 2009), as the effect of multiple human pressures on aquatic habitats is spread over several spatial scales (Hughes et al., 2008).

The main objective of this work was to assess the influence of environmental attributes expressed at different scales on stream communities, particularly macroinvertebrates, and to determine how the habitat descriptors are shaped by higher spatial scales, namely landscape patterns.

2. Methodology

A hierarchical nested design was used for sampling benthic communities. In this study it was considered 4 catchments (Rivers Olo, Corgo, Pinhão and Tua), 15 sites distributed by the river network, 3 transects in each site and 3 micro-habitats (replicates) in each site. All catchments are located in the Douro basin (Northern Portugal) and are subjected to distinct natural conditions (such as high gradient streams ranging from 1100 m to 50 m of altitude). Furthermore, there are preserved areas, like the Olo and Tua catchments, contrasting with other areas influenced by an intensive agriculture (specially vineyards), located in the downstream sectors of rivers Corgo and Pinhão (Figure 1).

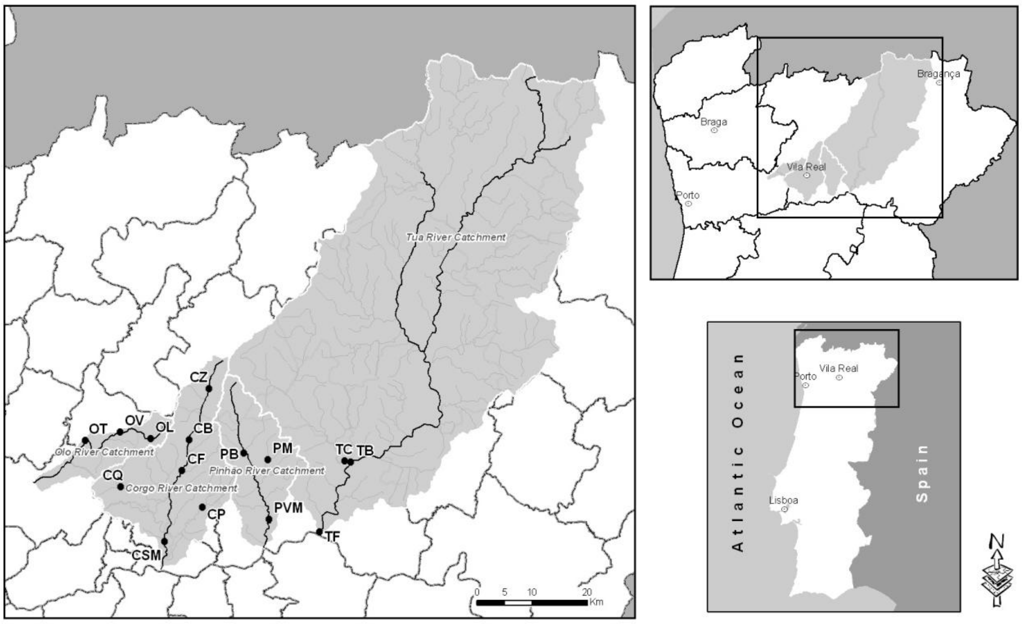

Figure 1: Location of the 15 study sites along the Olo, Corgo, Pinhão and Tua rivers, all from the Douro catchment, Northern Portugal. Study sites are spread along the longitudinal axis of the main rivers, but the Tua catchment, which was only sampled in the lower section.

Invertebrates sampling was made in 2006 and 2007 in these micro-habitats using surber samples. Invertebrates were identified to genus level to most of the families (except Diptera and Oligochaeta).The relationship between large scale variables and the benthic fauna was assessed using both species composition and species traits. The environmental variables considered covered two levels of observation:

a) At landscape and soil use scale the data was obtained from Corine Landcover and it was considered a circle of 1km radius around each site. In the first case we used a set of metrics that can be grouped in patch metrics of density and size, edge, shape and of diversity and interspersion. These metrics were further applied to each type of soil use originating a total of 48 variables (Table 1).

b) At the aquatic habitat and river corridor scale it was applied the River Habitat Survey methodology (RHS - Raven et al., 1997, 1998). Ten transects or "spot checks" were made at 50m intervals along the 500m reach and discrete descriptions obtained (e.g. cover channel substrate, flow type, aquatic vegetation types, bank vegetation structure, artificial modifications). Continuous observations or “sweep up” along the 500m reach characterized features and modifications not described at the spot-checks (e.g. natural and man-made features, or riparian vegetation). Two habitat indices, derived from the RHS were determined: 1) Habitat Quality Assessment (HQA), that is an expression of the habitat quality (e.g., physical habitat, vegetation cover, the use of marginal land), and 2) Habitat Modification Score (HMS) that quantifies the extent of artificialization (e.g. weirs, bank protections) along the channel.

Table 1: Environmental descriptors used for describing landscape-land use and habitats at each of the 15 sites included in the Rivers Olo, Corgo, Pinhão and Tua, The landscape metrics were applied to the different soil use types resulting in a total of 48 landscape variables.

Landscape metrics	Soil use variables	Habitat descriptors
PATCH DENSITY AND SIZE METRICS	Agriculture land, except vineyards (area in m^2 and %)	**ARTIFICIAL FEATURES**
Number of patches	Vineyards (area: m^2 and %)	Habitat Modification Score (HMS)
Total edge	Coniferous woodland (are: m^2 ; %)	**HABITAT QUALITY**
Patch size stands dev.	Broadleaf woodland (area: m^2; %)	HQA flow
	Mixed woodland area (area: m^2; %)	HQA channel
SHAPE METRICS	Urban area (area in m^2 and %)	HQA bank features
Mean shape index	Scrub & shrubs (area in m^2 and %)	HQA bank vegetation structure
Mean patch fractal dimension	Water surface including reservoirs and wetlands (area in m^2 and %)	HQA point bars
Weighted mean patch fractal dimension		HQA in-stream channel vegetation
		HQA land use
		HQA trees
		HQA special features

A nested permutational MANOVA from resemblance matrix based on the Bray-Curtis coeficient was used to test the significance of benthic composition from the different spatial levels (catchment, site and transect). Multiple non-parametric regressions from distance-based linear models (DISTLM) were established between invertebrate taxa and the environmental variables by using the following independent variables (separately): habitat quality indices, soil use variables and landscape metrics (Table 1). Ordination techniques using distance-based redundance analysis (dbRDA) were established between benthic fauna, but expressed as metrics sensitive to contamination and soil use and landscape metrics. The biological metrics were extracted from Varandas & Cortes (2009) since they proved to be the most sensitive to disturbance in catchments of North Portugal (Table 2). Multivariate analyses were carried out using the package PERMANOVA for PRIMER (Anderson et al., 2008).

Table 2: List of invertebrate metrics selected (Oliveira & Cortes, 2009). Acronyms are indicated in bold.

Invertebrate metrics			
Families of Predators	**fP**	% Shredders	**%Shr**
Fam. of Ephem., Plecop., Trichop.	**fEPT**	% Scrapers	**%Scr**
Families of Swimmers	**fSwi**	% Filterers	**%Fil**
Families of Clingers	**fCling**	% Gatherers	**%Gath**
% Rheophilous	**%Rhe**	% Predators	**%Pred**
Genus of shredders	**gShr**	% Limnophilous	**%Lim**
Genus of Filterers	**gFil**	% Omnivorous	**%Omn**
Families of Gatherers	**fGath**	% organisms with branchial respiration	**%br**
% Intolerants	**%Int**	% organisms with cutaneous respiration	**%cr**
Index	**IBMWP**	% organisms with aerial respiration	**%ar**
Index	**FBI**	% organisms parasites	**%Par**

Results

The results of the MANOVA for benthic composition are presented on Table 3, separately for each year, and showed that site produced the significant differences for both years ($p < 0.05$) whereas differences between catchments were less evident.

Table 3: Hierarchical MANOVA performed separately for both years of field study (2006 and 2007)

Source of variation (2006)	**df**	**Mean squares**	**Pseudo-F**	**P**
Catchment	3	16625	1.482	**0.044***
Site	11	11157	5.415	**0.001***
Transect	30	2062	1.439	**0.001***
Residual	90	1433		
Source of variation (2007)	**df**	**Mean squares**	**Pseudo-F**	**P**
Catchment	3	11771	1.290	0.115
Site	11	9122	4.859	**0.001***
Transect	30	1178	1.065	0.182
Residual	90	1763		

Multiple non-parametric regressions (DISTLM) between macroinvertebrate taxa and habitat quality illustrated the greater importance of landscape metrics in shaping benthic composition, in particular the fractal dimension of hardwood forest, agriculture patches and number of vineyard patches, followed by soil use (agriculture; $p < 0.05$) (Table 4).

Table 4. Multiple non-parametric regressions, using AIC criterion, between benthic invertebrate communities, habitat indices, land uses and landscape metrics.

MODEL with RHS indices; R2= 0.218			
Variables selected (Best model 2 var.)	**AIC**	**Pseudo-F**	**P**
HQA flow type	109.60	1.22	0.269
HQA vegetation channel	109.26	2.03	0.380
MODEL with Land use variables; R^2= 0.313			
Variables selected (Best model 2 var.)	**AIC**	**Pseudo-F**	**P**
Agriculture area	107.75	3.09	**0.04***
Hardwood forest	107.31	2.12	0.22
MODEL with Landscape metrics; R2= 0.978			
Variables selected (Best model 13 var.)	**AIC**	Pseudo-F	**P**
Area weighted patch fractal dimension of agriculture	106.93	4.00	**0.01***
Total edge hardwood forest	106.19	2.40	0.05
Patch size standard deviation of mixed forest	105.98	1.75	0.11
Number of patches of vineyard	105.22	2.01	**0.02***
Mean fractal dimension area patch of hardwood	104.63	1.70	0.07
Number of patches of agriculture	103.51	1.85	0.07
Area weighted patch fractal dimension of mixed forest	101.24	2.30	**0.03***

The dbRDA ordinations, grouping biological and environmental data are represented on Figure 2, with separate plots for biological and environmental variables. The 1st axis reflected the longitudinal variation, where the landscape variables linked to the natural cover (forest and shrubs) define the sites located upstream and the ones associated with the vineyard influence more the lower reaches. On the first sites we may notice the presence of less disturbed communities reflected by higher values of the biotic index, EPT, shredders and intolerant fauna, whereas this pattern is replaced downstream by a dominance of organisms with branchial and cutaneous respiration, belonging to trophic groups with mainly filterers and gatherers. Concerning the relation between benthic fauna and soil use it was also detected a longitudinal gradient related to soil use from natural areas (e.g. hardwood forest) to agriculture (including vineyards).

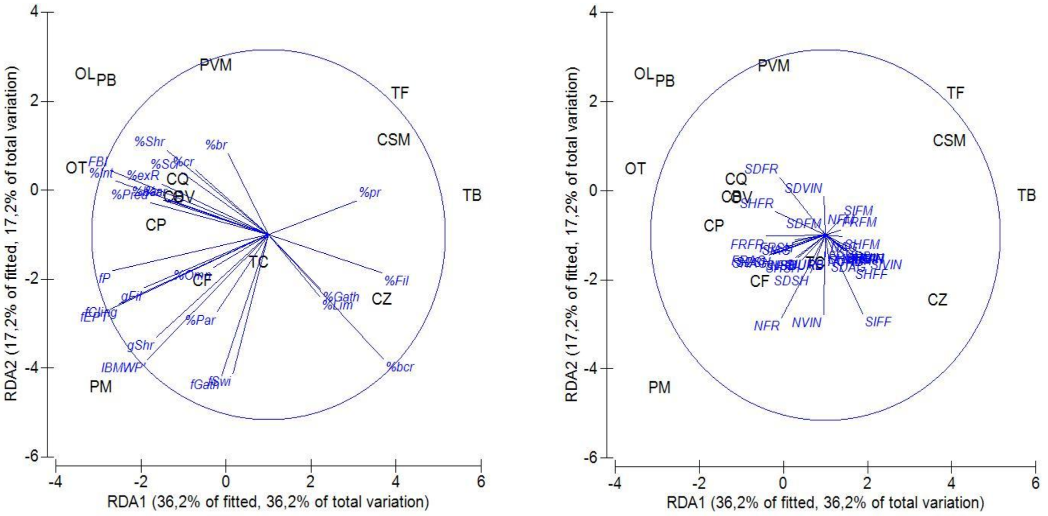

Figure 2: Redundance analysis (dbRDA) between invertebrate metrics and landscape metrics. The left diagram represents the biological metrics and on the one on the right represents the landscape patterns. Acronyms for landscape metrics: **N** number of patches; **SD-** patch size standard deviation**, SI-** mean shape index**, SH-** mean patch fractal dimension**, FR-** area weighted mean patch fractal dimension**;** the last letters represent vegetation types: **VIN** vineyard; **AG** agriculture; **FF** broadleaf forest; **FR** coniferous forest; **FM** mixed forest; **URB** urban area (see Table 2 for the biological metric codes)

Discussion

Many studies using environmental variables determined at different spatial levels, attempt to extract the relevant scales that lend structure to aquatic communities such as benthic macroinvertebrate assemblages (Roth et al., 1996; Lammert and Allan, 1999). Lowe et al. (2006), who made a revision on patterns and processes across multiple scales of stream-habitat organization, emphasize the fractal network structure of stream systems at a landscape scale and mention the need to understand how the spatial configuration of habitats within a network affect fluxes of individuals and materials. The same authors conclude that broader use of multiscale approaches to explore population and community dynamics and species-ecosystem linkages in streams will produce research results that are applicable to management and conservation challenges. This study found that landscape metrics provided a powerful tool for assessing both macroinvertebrate dynamics, instream habitats and also the river corridor. It was also found that soil use descriptors were associated with the typological functioning of the river system displayed by the longitudinal succession of benthic assemblages.

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