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Land use at the reach scale as a major determinant for benthic invertebrate community in Mediterranean rivers of Cyprus

Stefania Erba [a,*], Giorgio Pace [a,b], Daniele Demartini [a,c], Davide Di Pasquale [a,d], Gerald Dörflinger [e], Andrea Buffagni [a]

[a] CNR – IRSA, Water Research Institute, Via del Mulino 19, 20861 Brugherio (MB), Italy
[b] Freshwater Ecology and Management Group, Departament d'Ecologia, Universitat de Barcelona, Av. Diagonal 643, 08028 Barcelona, Catalonia, Spain
[c] Prothea Srl-Via Gran Sasso, Via Zaccaria 4, 20122, Milano, Italy
[d] CNR-ITC – Istituto per le Tecnologie della Costruzione, Via Bassini 15, 20133 Milano, Italy
[e] Water Development Department, Ministry of Agriculture, Natural Resources and Environment, Nicosia, Cyprus

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ABSTRACT

The European Water Framework Directive (WFD 2000/60/CE) requires the quantification of anthropogenic pressures for evaluating the risk of failing environmental objectives when setting river basin management plans and for biological data interpretation when assessing ecological status.

Many studies emphasized the close relationship between biological communities (e.g., fishes and invertebrates) and land use. The need for evaluating the impact of non-natural land use at different spatial scales is often stated, and relatively small spatial scales can be particularly relevant to understand biotic community changes. Abiotic descriptors derived for the reach scale can thus be used to evaluate the success of restoration measures, and their selection and testing is urgent for river management purposes. In this context we describe a new index, which allows quantification of land use modification at the reach scale, the 'Land Use Index - reach' (LUIr). The LUIr was developed on the basis of data gathered in the field with the CARAVAGGIO method (river habitat survey technique). A full description of the index is presented. In addition, jointly with a series of environmental descriptors developed for the quantification of general or specific anthropogenic stressors (*sensu* WFD), the effectiveness of the new index (LUIr) in describing environmental gradients as perceived from benthic invertebrates has been evaluated for Mediterranean rivers in Cyprus. The multiple regression analysis performed (all subset regression and relative importance) revealed that among the set of environmental descriptors the LUIr resulted to be the factor best explaining the variation of biological metrics. Additionally, the analysis highlighted that the biological metrics more influenced by land use at the catchment level (LUIc) are those estimating the overall diversity and are consequently more influenced by factors at larger scale. The descriptor derived by physico-chemical parameters was in a few cases selected by regression analysis as the most important factor in explaining variation of biological metrics. The descriptors able to detect variation of other habitat features (i.e., habitat modification, habitat diversity and lentic–lotic character) resulted as weak predictors in the models. Our results support the conclusion that the LUIr index can be a useful and cost-effective tool to interpret invertebrate community variation. Moreover, as urgently requested by WFD, LUIr can be used to set and check effectiveness of measures for the improvement of aquatic ecosystems, particularly for Mediterranean streams where agricultural land use is one of the main anthropogenic pressures.

1. Introduction

Freshwater ecosystems have provided an important source of supplies and services for human beings since the beginning of civilization. Accordingly, these ecosystems were subjected over the time to a wide range of human stressors, sometimes acting directly on river ecosystems and other times indirectly affecting the river compartment, including hydromorphological alteration, accumulation of organic compounds and other contaminants and alteration in the natural land uses (Tockner et al., 2010). River ecosystems are affected by multiple human impacts and, thus, the achievement of a good ecological status through effective river

* Corresponding author. Tel.: +39 039 21694204; fax: +39 039 2004692.
E-mail address: erba@irsa.cnr.it (S. Erba).

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management needs to address the link between the observed effects and the range of anthropogenic stresses.

In particular, the global transition from undisturbed areas to human-dominated landscapes (agricultural and urban development) has strongly impacted the physical features of lotic ecosystems by (i) changing hydrological regimes (Poff et al., 2006), (ii) clearing riparian vegetation and opening canopy, (iii) altering the timing, amount, and kind of inputs of water, light, and organic matter (Post and Kwon, 2000). Therefore, investigators increasingly recognized that human actions at the landscape scale are a principal threat to the ecological integrity of river ecosystems (e.g., Lammert and Allan, 1999; Sponseller et al., 2001; Collier and Quinn, 2003; Roy et al., 2003; Harding et al., 2006; Urban et al., 2006) and made the quantification of land use/land cover a valuable indicator of the state of ecosystems (Meyer and Turner, 1994).

However, several difficulties in delineating "pathways of influence" based on empirical analyses of land use and stream responses are still recognized. According to Allan (2004) our understanding of the relationships between anthropogenic land use and the ecological integrity of streams is complicated by (i) covariation between anthropogenic and natural gradients, (ii) uncertainties concerning the importance of legacies and thresholds and (iii) the issue of scale.

Such difficulties are exacerbated considering that the influence of anthropogenic stress on environmental evaluation can be scale dependent (e.g., Townsend et al., 2003; Buck et al., 2004). Some authors emphasized that local scale variables (e.g, local instream habitat and physico-chemical conditions at reach) may be more important in smaller streams (Buck et al., 2004; Roy et al., 2003; Heino et al., 2004). In contrast, other studies (Allan et al., 1997; Lammert and Allan, 1999) attributed greater importance to larger-scale variables (e.g., catchment geology). Moreover, according to Strayer et al. (2003) the most effective spatial perspective differed among the ecological response variables and was linked to the mechanisms thought to control each variable. For example, broad spatial perspectives were found most effective in estimating aquatic plant species richness, suggesting that plant propagules can be transported over long distances, even during single flood events (Nilsson et al., 1993). In contrast, local or streamside corridor perspectives were useful in estimating macroinvertebrate species richness, which may be controlled by more local processes such as shading and loading of leaf litter and wood into the channel, and provision of egg-laying sites (de Szalay and Resh, 2000; Sponseller et al., 2001). Thus, understanding and predicting the effects of land-use change on stream and river ecosystems are difficult scientific problems and major challenges not only for contemporary ecology (Strayer et al., 2003), but also for regular bioassessment.

The Water Framework Directive (WFD EC/2000/60, European Commission, 2000) constitutes a milestone for aquatic ecosystem management in Europe as the evaluation of the ecological status is mainly based on biological communities. The WFD requires also the quantification of the anthropogenic pressures affecting the aquatic biota, also including diffuse pollution sources, so that links can be established between pressures and changes in biological communities. Thus, there is a major challenge to measure the different human impacts in a meaningful way for the aquatic biota, to factor out cause–effect relationships. Different methods have been developed to quantify environmental impacts and relate them to biological communities and, those related to changes in river physical habitat attributes can be assessed by a wide range of methods (e.g., Raven et al., 2000; Tiner, 2004; Buffagni et al., 2009, 2010; Monaghan and Soares, 2010).

Many tools have been developed for the quantification of land use impacts. However, the large majority of these tools are focused on the riparian buffer and upstream catchment areas (watershed land cover). The quantification of land use change at reach scale is still poorly investigated, despite several studies (King et al., 2005; Migliaccio et al., 2007; Springe et al., 2006) having demonstrated that some biological communities (e.g., macroinvertebrate and diatoms) were even more strongly predicted by environmental factors quantified at the reach scale (e.g., variation in substrate size and ion concentrations).

Based on this premise, we propose here a robust and easily applied index to evaluate the degree of land use variation at the river reach scale. The features considered for the calculation of the index have been assessed by using river habitat survey techniques, here namely the CARAVAGGIO method (Buffagni et al., 2005, 2010, 2013).

Therefore, the main goals of our study were: (i) to describe a new index to quantify the deviation of land use from natural conditions at the reach scale (LUIr), and (ii) to test and validate the relevance of this index for river communities (here macroinvertebrates) in Cyprus rivers.

Specifically, the effectiveness of the new index (LUIr) was evaluated jointly with a series of environmental descriptors quantifying other general or specific anthropogenic stresses. The analyses carried out allow us to identify the environmental descriptors most closely related to the variation in river benthic communities expressed by indices devoted to ecological status quantification (*sensu* WFD). In addition, we analyzed the relative importance of each individual predictor (environmental indices) in explaining biological variation within a set of biological metrics. Studies of this kind are particularly useful for Mediterranean streams, where such information is lacking and agricultural land use is one of the main anthropogenic pressures (EEA, 2009).

2. Material and methods

2.1. Study area

In the present paper we investigated 40 sites distributed on 8 rivers of Cyprus Island (East Mediterranean). Each site was sampled only during one sampling occasion between November 2005 and October 2006. The studied rivers were all perennial, belonged to the official intercalibration type R-M4 of the WFD (EC, 2008) and were comparable in terms of flow regime and overall environmental features (Erba et al., 2009), thus representing one stream type (*sensu* WFD). Mean catchment area and altitude of the investigated river sites were respectively 59 km^2 and 548 m asl; the predominant catchment geology was mixed (i.e., not siliceous). Moreover, streams were selected covering the whole quality range present in the geographic area from undisturbed and nearly natural sites (reference sites) to human-impacted sites. Ten river stretches were selected as reference sites on the basis of the quantification of the following anthropogenic pressures: land use, water physico-chemical parameters, hydromorphological alteration. None of the previous pressures, in the selected reference sites, were significant according to criteria specified in Nijboer et al. (2004) and Erba et al. (2009).

2.2. Biological data

Macroinvertebrates were sampled quantitatively following a multi-habitat scheme according to the AQEM and STAR sampling protocols (Buffagni et al., 2004). A riffle pool sequence was firstly identified in each site and 10 sampling units were collected from the pool area and 10 from the riffle area. The sampling units collected in pools were merged and the same was done for riffle