Ecological Indicators 84 (2018) 459–469

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Application of lithotopo units for automatic classification of rivers: Concept, development and validation

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A R T I C L E I N F O

Keywords:
Lithotopo unit
Geoecology
Water Framework Directive 2000/60/EC
Fluvial geomorphology
Classification system

A B S T R A C T

River classification is one of the recommendations of the European Water Framework Directive 2000/60/EC, which establishes that classifications should be carried out according to different variables hierarchically organized from a smaller to a larger scale. We suggest incorporating into the Directive's hierarchical system a geoecological unit (lithotopo unit) that discriminates rivers with similar geomorphological features and ecological funtionality. The lithotopo units are not an alternative to the Directive typology, they are a complement intended to improve it.

Our method is divided into two stages, the first focused on the development of LTUs and the second on their validation. We applied the concept of lithotopo units to a 30,000 km^2 region in the NW of the Iberian Peninsula (Spain) using a Geographic Information System and field work. Seven kinds of lithotopo units were identified for the study area, each with its own geomorphological processes and dynamics, and, as a consequence, particular associated habitats. Cartographic validation was done through the analysis of 122 sample sites distributed in eight basins. Of the five validation variables originally employed, specific stream power and median grain size are the two that yielded the best results. Each kind of lithotopo unit displays a range of values of specific stream power and median grain size that is internally homogeneous but different from that of the other units. The methodology thus produced, which can be applied to other regions, is transparent, objective and quantitative.

1. Introduction

Fluvial systems are formed by a wide range of elements with multiple non-linear interactions on different spatial and temporal scales (Knighton, 1998; Rice et al., 2010a; Wheaton et al., 2011; Stoffel et al., 2013). The geomorphological elements of a river system (Newson, 2002; Blue and Brierley, 2015) are key influences on the biological component that often motivates fluvial assessment and restoration (Frissell et al., 1986; Palmer et al., 2010). Fluvial geomorphology processes drive the creation and development of habitats and control ecological processes, and are thus fundamental to the quality of the fluvial ecosystem (Newson and Large, 2006; Vaughan et al., 2009). Therefore, an ecological understanding of fluvial systems requires a solid understanding of its geomorphological dimensions (Fryirs and Brierley, 2012).

In many countries, recent decades have witnessed important changes in environmental law and policy as a result of fluvial conservation and restoration initiatives (Kondolf and Micheli, 1995; Poff et al., 2003; Rohde, 2004; Wohl et al., 2005; González del Tánago and García de Jalón, 2007; Palmer et al., 2007; Brierley and Fryirs, 2008; Magdaleno, 2008; Beechie et al., 2010; González Briz et al., 2015). In Europe these changes led to several influential regulations, including Habitats Directive 92/43/EC, Water Framework Directive 2000/60/EC (henceforth WFD), Floods Directive 2007/60/EC, and Environmental Quality Standards Directive 2008/105/EC. The WFD proposes river classification as one of its recommendations to help improve the ecological status of river systems. This takes into account different variables and features in a hierarchical organization from smaller to larger

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http://dx.doi.org/10.1016/j.ecolind.2017.08.043
Received 19 April 2017; Received in revised form 17 August 2017; Accepted 18 August 2017
Available online 17 September 2017

scale, and facilitates the establishment of reference conditions for each river type. The WFD suggests two systems of characterization (A and B) based on different variables or features. System A, which is obligatory, is intended to locate the river within its biogeographical setting. It includes variables related to basin level hydrological processes to establish a common regional European typology. System B includes additional optional factors in order to further characterize rivers on different spatial scales.

The WFD recognizes that geomorphological principles are vital for river ecology. However, the proposed hydrogeomorphological variables are optional and insufficient (Ollero et al., 2003). Article 4 of the WFD states that Member States should: "*achieve good surface water status at the latest 15 years after the date of entry into force of this Directive*". Now, after 15 years under the Directive, this goal has not been fulfilled in many European rivers. We believe that this is, in part, due to (i) lack of involvement of geomorphologists in the administration and management agencies, (ii) medium-high requirements of time and data, (iii) absence of simple automated classifications, and (iv) that the use of hydrogeomorphological variables remains optional (Newson, 2002; Blue and Brierley, 2015). It should be noted that WFD is a management tool and as such should be able to be applied by technicians without the need for specialized scientific knowledge. Although there are widely used geomorphological classifications like the Rosgen (1994, 1996) and Montgomery and Buffington (1997, 1998) classifications, as well as the River Styles Framework (Brierley and Fryirs, 2005), these generally require time, observations, and expertise for their application.

The present study aims to develop a simple geomorphological classification tool that can be applied rapidly and adjusted to fit tight budgets. We propose adopting a different level of spatial organization: geoecological units called lithotopo units or LTUs (Montgomery, 1996) that identify areas with similar topography and lithology, and thus analogous geomorphological processes. The inclusion of LTUs as an obligatory descriptor within System A would make it possible to organize river management according to geomorphological criteria. We tested this classification in the Galicia region of Spain (Fig. 1) to establish a protocol for the development of LTUs that is transparent, objective and quantitative. Finally, we evaluated the validity of basin scale identification of LTUs using channel-scale variables.

2. Methodology

2.1. Study site

The study area covers a ~30,000 km^2 portion of the NW Iberian Peninsula (Fig. 1). The tests were made analyzing sample sites distributed across eight river basins (Anllóns, Arnoia, Cabe, Lea, Lor, Lérez, Pambre and Sor), which cover almost 12% of Galicia (Table 1). In these basins, dendritic drainage patterns predominate, though some areas exhibit trellis morphology.

The average precipitation in Galicia is 1200–1300 mm/year, although it varies substantially due to relief effects (Martínez-Cortizas and Pérez-Alberti, 1999). High runoff and streamflow for this portion of the Iberian Peninsula (Pérez-Alberti, 2000) reflects high levels of precipitation and perennial base flow.

Drainage basins were chosen for inclusion in the validation study based on the application of a reach diversity index (see Horacio, 2014). This index measures the diversity of reaches of a river considering (i) the abundance of different types according to a variable, and (ii) the distribution of the reaches in the space, that is to say, by their continuity or fragmentation. Calculation of the geomorphological diversity of Galician rivers was carried out over 20 km river lengths using the following geomorphological variables: incision ratio of the valley, amplitude of the valley, lithology, sinuosity of the river reach, slope of the valley, and density of faults and fractures. The assessment was conducted using a Geographic Information System and correspondence analysis. The application of that study revealed that the eight basins analysed are representative of the diversity of geomorphological environments in Galicia.

The geological history of the NW of the Iberian Peninsula produced a morphological expression that Hernández-Pacheco (1949) described as resembling piano keys made up of *horst and graben* terrain, with a gradual inclination from east to west (Solé, 1983). This configuration reflects trans-tensional or transpressive regimes associated with strike-slip faults (de Vicente and Vegas, 2009; de Vicente et al., 2007; de Vicente et al., 2011). The five main geomorphological features of Galicia consist of: mountain ranges, grabens or depressions, upland surfaces, faults and fractures, and the fluvial network (Pérez-Alberti, 1993). The first four are morpho-structural features (see profile A-B in Fig. 1), while the fluvial network reflects the main features of the relief (Martín-Serrano, 1991).

The Galician fluvial network is antecedent and bears a close relationship to regional tectonic development and evolution since the Cenozoic (Pérez-Alberti, 1982). From a tectonic perspective, Galicia hosts two kinds of rivers or reaches: those that follow the tectonic grain of structures (Pérez-Alberti, 1993), and those that follow the course of their tertiary ancestors and passively follow subsequent alpine tectonic modifications (Vidal-Romaní, 1996). The deep incision of the fluvial network derives from intense fragmentation of the old igneous craton on which Galicia rests (Martín-Serrano, 1991). This process gave rise to striking topographic contrasts characterized by a combination of sectors with pronounced elevation differences and others with little relief. Gorges occur in all lithologies, and sinuous rivers are apparent in both alluvial plains and plutonic massifs.

Lithologically, over 85% of the surface of Galicia rests on granitoid and metamorphic rocks (schist, gneiss and slate; Table 1). The former comprises 37% of the surface and the latter 49%. The eastern strip of Galicia is dominated by slate with quartzite bands (e.g., Lor River). In the central-western sector there is a combination of sedimentary deposits with schists and granitoid rocks (e.g., Lea River). The SW sector of Galicia is covered mostly by granitoids (e.g., Lérez River). All together, the basins selected for the validation of the LTUs (see Fig. 1) cover the lithological diversity in Galicia. The Cabe River basin, in particular, is a synthetic expression of the diversity of the lithological as well as geomorphological environments that exist in Galicia.

2.2. Conceptual framework

The LTU protocol shown in Fig. 2 is designed to be used within the limits of a geomorphological province – a region with similar land forms, hydrologic, erosional and tectonic processes over areas greater than 1,000 km^2 (Montgomery and Buffington, 1998). In this sense, Galicia is considered an independent geomorphological province (Pérez-Alberti, 1993). The LTUs are delimited on the same level as river basins (50–500 km^2) (Montgomery and Buffington, 1998). However, LTUs differ from river basins in that they identify sectors in which different geomorphological processes influence ecological processes (Montgomery, 1996; Brierley et al., 2006; Wheaton et al., 2011). While river basins provide a logical basis for resource management, their spatial limits do not generally coincide with the underlying lithological framework. Taking the river basin as the standard unit in the sense established by the WFD can mean that some basin reaches may have more in common inside a LTU that crosses several basins than inside several LTU forming one single basin (Fig. 2). In this study the river basin is regarded as the first level of spatial organization (Newson, 2002) internally structured according to LTUs (Montgomery, 1996; Omernik and Bailey, 1997; Brierley and Fryirs, 2005). In contrast to other classifications with a greater biological orientation (Pennak, 1971; Wright et al., 1984; Holmes, 1989; Jowett and Duncan, 1990; Naiman, 1998; Wright et al., 1998), the hierarchical classification of Montgomery and Buffington (1998) has a clear hydrogeomorphological focus compatible with using LTUs to facilitate regional comparison of fluvial systems.