Hierarchical Classification of Rivers: A proposal for eco-geomorphic characterization of Spanish rivers within the European Water Frame Directive

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ABSTRACT: River classification has an important role in fluvial management and conservation. The European Water Frame Directive (WFD) promotes river classification as a first step to define river-type specific reference communities. In this paper, several previous classification schemes are briefly reviewed, and a hierarchical river classification approach is proposed for the Spanish rivers within the WFD. Biogeographic provinces, watershed, river segments and river reaches are successively classified according to main factors determining biological communities in river ecosystems.

1 INTRODUCTION

1.1 Many classification approaches have been proposed for rivers and streams, serving a wide range of purposes, including scientific research, river management and river restoration and conservation. Although many authors have been developed river classsification systems based on biological features (see Naiman, 1998) presenting a comprehensive scheme of river functioning (e.g. Cummins, 1974), the classification systems based on physical criteria (geomorphic and hydrologic factors) represent a wider frame to explain the river system, being based on channel morphology and physical processes related to flow regime characteristics, which ultimately determine biological communities and potential response (Ward, 1989; Montgomery, 1999).

The implementation of the Water Frame Directive (WFD) in the European Community (OJEC, 2000) requires an effort of river classification among the State Members, with the aim of characterizing ecoregions and surface water body types within each river basin district. Furthermore, each State Member shall ensure the establishment of type-specific reference conditions, the evaluation of ecological status of rivers, and the assessment of measures to prevent further deterioration and protect and enhance the status of aquatic ecosystems.

In Spain, some river classification attempts have been done in different regions until now, according to the WFD. Bonada *et al.* (2002) have proposed a river typology for the Mediterranean rivers, differentiating 9 ecotypes based on nine physical criteria, by means of clustering of stations by the K-means method and a discriminant analysis. They use a non hierarchical scheme, where descriptors at different spatial scale and ecological meaning (e. geology, distance to source, shape of lateral slope channel, etc.) are taken together at the same level, in a single-scale approach. For the Catalonian rivers, ACA (2002) has differentiated 5 "fluvial regions" and 10 "fluvial management subregions", responding to hydrological and geological criteria, arranged in a non hydrological-processes-based scheme. Finally, Ollero *et al*. (2003) have proposed a methodology to classify the rivers of Aragón, using topographic, hydroclimatic and morphological criteria to obtain 13 different river types. They arrange the descriptors from ecoregion characteristics (altitude and location) to fluvial reach characteristics (valley shape and specific discharge) in a hierachical scheme, although they do not consider some valuable criteria identifying habitat types (e.g. substratum) and patterns of flow regime. Each of these classification systems represent different approaches producing different river types with a distinct nomenclature. That seems to be not appropiate for integrating river types in a common classification framework for the Spanish rivers.

In this paper, a multiple-scale river classification system is proposed, following a hierarchical squeme of ecoregion, watershed, river segment and reach. The classification system includes main landscape components determining watershed characteristics and dynamics: geology, topography and climate, and major factors controlling biological communities in rivers: channel morphology, flow regime, bed forms and riparian vegetation, representing an useful sys-

tem to characterize the wide range of physical habitat types of the Spanish rivers.

2. RIVER CLASSIFICATION SCHEMES

Several comprehensive historical reviews of river classification schemes have been made by Naiman (1998), Rosgen (1996), Thorne (1997) and more recently by Kondolf *et al*. (2003), explaining the evolution of concepts and approaches in river classification.

2.1. Classifying single-scaled, channel reaches

Main references in a single-scale approach classification should include Leopold and Wolman (1957) straight, meandering and braided types classification; Schumm (1977) stable, depositing and eroding streams differentiation; and more recently, Rosgen (1994; 1996) seven major stream types definition, according to channel slope, shape and pattern.

2.2. Hierarchical approach: River classification in the context of the watershed

In the context of the watershed promoted by Hynes (1975), bench marks in river classification development are the works of Frissell *et al*. (1986), which present a new integrative approach based on how the stream systems are organized in a nested hierarchy of drainage basins, incorporating, on successively lower levels, stream segment, reach, pool-riffle and microhabitat subsystems; Amorós & Petts (1993), which consider the fluvial hydrosystems as four dimensional systems, under the asymmetrical control of small scale features by larger scale factors, in a decreasing geographic consideration of watershed, river segment, reach and unit; and lately Montgomery & Buffington (1997), who have defined river types according to channel morphology, explained in a hierachical physical processes based classification system.

3.HIERARCHICAL RIVER CLASSIFICATION PROPOSED FOR SPANISH RIVERS

Integrating the main concepts of river classification proposed by the different authors previously cited, a river-type characterization system at different hierarchical levels is proposed for the Spanish rivers, providing a framework for assessing reference conditions and ecological status within the WFD. Spain contains a much wider range of eco-geomorphic river types than many other European countries, and their characterization should be based on a broad and integrative approach of different hydrological and geomporhological processes.

Table I summarizes the successive criteria of channel characterization at different spatial scales proposed by the Spanish rivers, following the hierarchical scheme of characterizing fluvial habitats that determine natural fluvial communities, response and potential, presented in Figure 1.

Table I: Classification levels and criteria at different spatial scales.

- Ecoregion
  - Biogeographic province
- Watershed
  - Size
    - Small (<100 km^2)
    - Medium (100-1000 km^2)
    - Large (1000-10.000 km^2)
    - Very large (10.000–25.000 km^2)
    - Great river (>25.000 km^2)
  - Geology
    - Siliceous
    - Calcareous
    - Clay material
    - Organic
- River segments
  - Morphologic characteristics (adapted from Rosgen, 1996)
    - Steep mountainous rivers (A, A+)
    - Moderately gradient, sinuous rivers (B)
    - Low gradient, meandering rivers (C, E)
    - Braided (D) and Anastomosed (DA) rivers
    - Entrenched low gradients, meandering stable channels (F)
    - Entrenched on moderate gradients, unstable channels (G)
  - Flow regime
    - Permanent
      - Precipitation based regime
      - Ground water based regime
    - Non-permanent
      - Ephemeral
      - Temporal
        - With hyporheic flow in summer
        - Without hyporheic flow in summer
- Channel reaches
  - Bed morphology (modified from Mont. & Buffington, 1997)
    - Cohesive
      - Bedrock
      - Clay
    - Non cohesive (Alluvial)
      - Cascade reaches
      - Step-pool reaches
      - Plane-bed reaches
      - Pool-riffle reaches
      - Dune-ripple reaches
      - Bars and/or islands (see Thorne, 1997)
  - Riparian vegetation
    - Woody Vegetation community types
    - Bank shrub and herbaceous units
    - Aquatic plant formations
- Other particular characteristics
  - Travertine substratum
  - Karstic formations

Gypsum substratum
Saline waters
Others

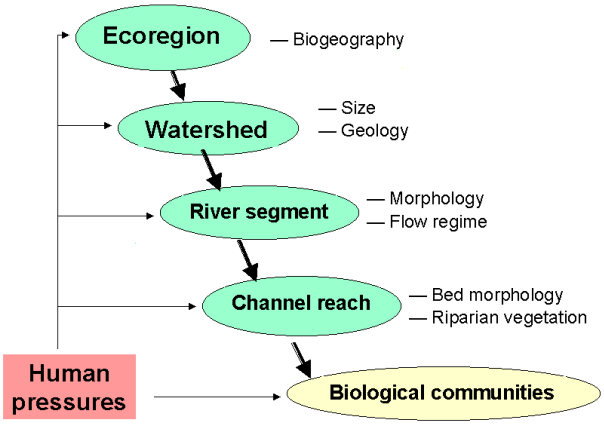

Figure 1. Hierarchical scheme of physical factors determining biological communities in rivers.

Ecoregion: Biogeographic Provinces

Ecoregions represent units of landscape classification with relative homogeneity in their ecosystems (Omernik, 1995). Within the WFD, Wasson *et al.* (2002) have differentiated 22 hydro-ecoregions (HER-1) attending to differences in physical factors: climate, geomorphology (altitude, watershed slope, thalweg slope) and geology, folloging the approach of US EPA (Lotspeich, 1980, Frissell *et al*., 1986).

For the case of Spanish rivers, we advocate the use of biogeographic provinces defined by Rivas Martínez *et al*. (2002), based on terrestrial vegetation, which ultimately reflects the influence of climate, geomorphology and geology, together with soil conditions and historical features. The last two are determining factors of hydrological processes in the watersheds, and have relevance on fluvial regimes, conditioning fluvial habitats and communities. The Spanish biogeographic provinces (Fig. 2) represent an integrated landscape regionalization, which clearly differentiates thermo-pluviometric regions, altitude and slope conditions, geology and soil properties, geographic constraints, etc... which are related to many of the classification optional descriptors suggested in system B of the WFD. The nomenclature of biogeographic provinces facilitates the geographic location of river sites, and the same geographical regionalization scheme is being used for the interpretation and evaluation of European Habitat Directive for conservation and management purposes (Rodwell *et al*., 1997).

Watershed

Within each biogeographic province, different size and geological complex watersheds can be recognized, which have a clear influence on their hydrological and ecological conditions. The size corresponds to the drainage area at the end of the considered channel reach, and the geology should be weighted according to the percentage of area occupied by different lithologies. Additional classes have been considered apart from those included in the WFD, which take into account the ecological differences of the biggest rivers (>25.000 km^2), and the wide extension of Spanish territory on clay, silty-clay Tertiary materials.

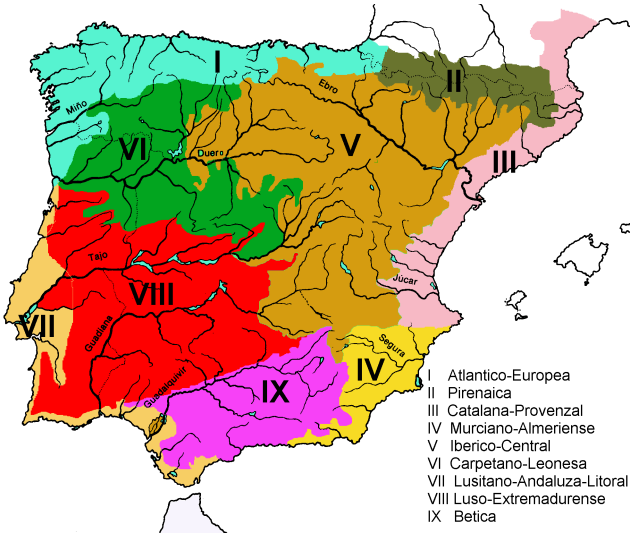

Figure 2. Biogeographic Provinces of Rivas Martínez *et al.* (2002) within the Spanish Iberian basins.

River segment

Considering the confluence of tributaries as a main hydrologic discontinuity factor, we propose defining river segments using the numerical classification of Spanish rivers made by MOP (1965). Each river segment should be characterized by its morphological condition, using Rosgen types at level I, from air-photographs and digital maps with a resolution at least of 25 x 25 m.

Natural flow regimes in Spanish rivers are very diverse. We propose to characterize them firstly by the permanency of flows, according to Poff & Ward (1989), and successively by the pattern of seasonal fluctuations and intensity of dryness.

River reach

To ultimately characterize river reaches, field surveys are needed to assess the bed morphology patterns and the riparian vegetation. Montgomery & Buffington (1997) channel reaches are considered for alluvial, non-cohesive substratum rivers, whereas cohesive rives are differentiated, with bedrock or clay material. Thorne (1997) river reaches types ac-

cording to bar and islands characteristics are further recommended for D and DA river segments.
Riparian vegetation is characterized by main woody vegetation community types along the transversal profile of channel and riparian areas, following similar approaches to those of Garilleti & Lara (2002).

Application

The hierarchical classification scheme is prepared to be treated by GIS at different scales, where each characterization criteria can be cartographied independently.
Not all the theoretical possible combinations can occur in natural conditions, as some of the criteria are mutually dependent (biogeographic province and geology; morphology of channel and bed, etc...); at the same time, according to the objectives and expertise, some of the criteria can be further detailed, adding new characteristics and subclasses at different levels, in an open-tree classification scheme.
At regional scale, river segment types can be enough to distinguish operational river sites in which to define reference or potential communities, whereas in some basins with a lot of river data (i.e. Ebro Basin), a channel reach scale can be attained, always within a common integrated multiple-scale approach.
The characterization system proposed includes most of the hydromorphological elements for classifying ecological status of rivers defined in the WFD, and can be very useful identifying physical causes and consequences of river degradation at local scale.

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