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Modelling macroinvertebrate and fish biotic indices: From reaches to entire river networks

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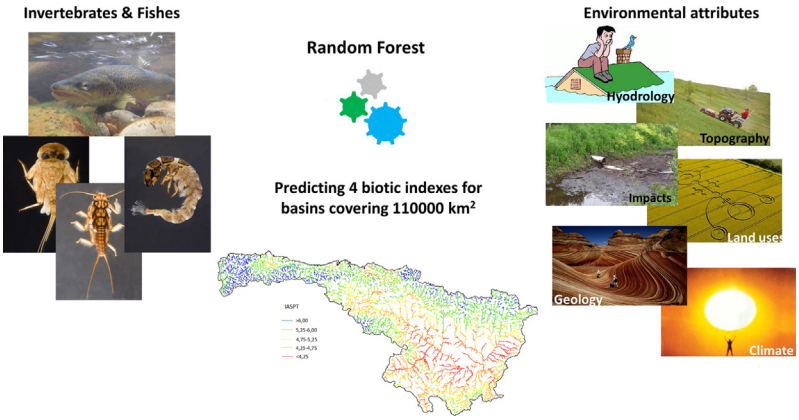
HIGHLIGHTS

- Invertebrate and fish indices were predicted across whole river networks (110,000 km^2).
- Models were done with the Random Forest analysis using 25 predictor variables.
- Invertebrate and fish metrics showed similar spatial patterns.
- All indices were mainly driven by the same environmental factors.
- Indices were higher in the Atlantic region than in the Mediterranean one.

GRAPHICAL ABSTRACT



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ABSTRACT

We modelled three macroinvertebrate (IASPT, EPT number of families and LIFE) and one fish (percentage of salmonid biomass) biotic indices to river networks draining a large region (110,000 km^2) placed in Northern and Eastern Spain. Models were developed using Random Forest and 26 predictor variables (19 predictors to model macroinvertebrate indices and 22 predictors to model the fish index). Predictor variables were related with different environmental characteristics (water quality, physical habitat characteristics, hydrology, topography, geology and human pressures). The importance and effect of predictors on the 4 biotic indices was evaluated with the IncNodePurity index and partial dependence plots, respectively. Results indicated that the spatial variability of macroinvertebrate and fish indices were mostly dependent on the same environmental variables. They decreased in river reaches affected by high mean annual nitrate concentration (>4 mg/l) and temperature (>12 °C), with low flow water velocity (<0.4 m/s) and aquatic plant communities being dominated by macrophytes. These indices were higher in the Atlantic region than in the Mediterranean. This study provides a continuous image of river biological communities used as indicators, which turns very useful to identify the main sources of change in the ecological status of water bodies and assist both, the integrated catchment management and the identification of river reaches for recovery.

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1. Introduction

The ecological status assessment of aquatic ecosystems in Europe, according to the Water Framework Directive (WFD), requires the evaluation of their different components: 1) biological communities, 2) water physico-chemical characteristics and 3) hydromorphological conditions (in order of importance; European Commission, 2000). Macroinvertebrate communities are commonly used to evaluate water quality deterioration, mainly because of their broad response to different water quality stress gradients (Álvarez-Cabria et al., 2010) and the efficient results they provide (Bonada et al., 2006). Fish communities are also commonly used as bioindicators, but in this case mainly in order to analyse the hydromorphological conditions of rivers and streams (flow regime and longitudinal connectivity; e.g. Schmutz et al., 2016). However, in many cases, a wide variety of human impacts are simultaneously affecting fluvial ecosystems (water quality and hydromorphological conditions), changing the structure and composition of biological communities in a different way than a single alteration would, due to concomitant effects (Piggott et al., 2012). Therefore, understanding the effects of multiple anthropogenic stressors is essential to disentangling the response of biological communities and their associated indices. For instance, this is the case of catchments that are severely affected by agriculture. This land use has been identified as highly responsible for water quality deterioration in Europe, because the excessive use of fertilisers increases the risk of eutrophication (Lowicki, 2012). Moreover, agricultural landscapes are usually affected by deforestation, which increases the incidence of solar radiation on soils and the transference of heat to rivers and streams (Binkley and Fisher, 2013). Furthermore, the agricultural activity not only changes water quality (eutrophication and water temperature), but it also causes major changes in the hydromorphological elements of fluvial habitats. Thus, catchments dominated by agricultural land uses are more affected by sediment inputs than forested ones, especially where natural riparian vegetation has been removed or altered (Piggott et al., 2012; Burdon et al., 2013). Moreover, the use of infrastructures for crop irrigation, such as reservoirs, modifies the natural hydrologic and hydraulic properties of rivers and streams, changing the longitudinal distribution of fishes and other aquatic communities.

Understanding the mechanisms that drive the variability of biotic indices is sometimes a difficult task, because this variability is influenced by the complex interplay between a wide array of anthropogenic stressors and the natural factors affecting river ecosystems (Álvarez-Cabria et al., 2010). Moreover, the high natural spatial variability of biological communities and the scarcity of data hamper the evaluation of large water bodies and the development of River Catchment Management Plans, which are usually based on the values of biotic indices calculated from biological communities sampled in few sites. In this regard, results from biotic indices representing a given river reach (100 m length) are then used to evaluate the integrity and the ecological status of large, and sometimes highly variable, water bodies (see European Commission, 2000). Carrying out field surveys to estimate the variability of the structure and composition of the biological communities, and the subsequent biotic indices, within the water bodies of a river network is not possible due to the high costs and intensity of such surveys. The absence of spatial continuous data for these biological communities makes it difficult to assess the river ecosystem integrity without making very rough assumptions as to "representativeness" of the selected river reach for surveying within the water body. Data modelling might be an effective solution to complete this lack of data, because it allows predicting the different biotic indices to all river network in relation to different types of anthropogenic impacts and natural factors.

In this study, we defined a virtual watershed (sensu Barquín et al., 2015) as a framework to incorporate the environmental and biological information of a large area (110,000 km^2) situated in Spain (Europe). We used this digital framework to investigate how natural and anthropogenic factors, acting at catchment and sub-catchment scale, affected the variability of three biotic indices based on macroinvertebrate communities (the Iberian Average Score per Taxon: IASPT, the Ephemeroptera, Plecoptera and Trichoptera number of families: EPT and the Lotic Invertebrate Index for Flow Evaluation: LIFE) and one index based on fish community (the percentage of salmonid biomass). Thus, our main objective was to model these biotic indices for all the reaches in the whole river network. We chose these biotic indices because they represent the structure and composition of two different biological communities and they were proposed and designed to assess the integrity of different fluvial ecosystem components (water quality; IASPT and EPT and hydromorphological conditions; LIFE and percentage of salmonid biomass). The second objective was to identify the most important variables that define the variability of these biotic indices. Most reviewed models in the literature analyse the variation of biotic indices estimated from only one type of biological community; such as diatoms (Teittinen et al., 2015), invertebrates (Erba et al., 2015), macrophytes (Demars et al., 2012) or fishes (González-Ferreras et al., 2016). However, to date we have not found many studies that model the response of biotic indices calculated from different communities in the same study area (but see Clapcott et al., 2016, who modelled biotic indices calculated from fish, invertebrate and algal communities). Thus, we are especially interested in determining whether biotic indices designed to evaluate different impact types (e.g. organic enrichment or low flow) and calculated from different biological communities (macroinvertebrates and fishes), show similar or different spatial patterns, as well as exploring how they are affected by the different natural and anthropogenic factors.

2. Methods

2.1. Study area

The study area (110,000 km^2) is situated in northern and eastern Spain and includes river catchments managed by three different regional water agencies (Confederación Hidrográfica del Cantábrico: CHC, Agencia Vasca del Agua: URA and Confederación Hidrográfica del Ebro: CHE). The study area can be grouped into two large territories (Fig. 1).

1. The first one (25,000 km^2) is managed by the CHC and URA agencies. Rivers and streams from this territory drains into the Atlantic Ocean (Cantabric Sea; Fig. 1). This region contains small-medium sized catchments (from 30 km^2 to 5000 km^2) with high slopes. In this area climate varies from thermo-temperate Atlantic climate, on the coast, to an oro- and supra-temperate climate in the interior (Rivas-Martínez et al., 2004). Average annual precipitation is 1300 mm. Broad-leaved forest, shrubs and grasslands occupy 80%, while agriculture only reaches 10% of this region. On average, the population density is 100 inhabitants/km^2.
2. The second territory (85,000 km^2), managed by the CHE agency, is occupied by the Ebro catchment and drains into the Mediterranean Sea. This region has an average of 32 inhabitants/km^2, and it is characterised by a Meso-mediterranean and Supra-mediterranean climate, with average annual precipitation of 650 mm (from 300 mm in the central area, to 1700 mm in the Pyrenees mountain range). Snow is abundant in winter and early spring (Bejarano et al., 2010). Agriculture covers 50% of the Ebro catchment.

2.2. Biological and environmental information

The biological database was completed with information from the water agencies indicated above. We compiled information from macroinvertebrate communities surveyed in 1077 river reaches, with 436 belonging to CHC, 204 to URA and 437 to CHE. Invertebrates were sampled following the protocols of these 3 water agencies. Samples were taken

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