Riverscaping basin management – Understanding multiple stress effects and their future impact on biotic quality

Approche à grande échelle de la gestion des bassins - Comprendre les effets multiples de stress et leurs impacts futurs sur la qualité biotique

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RÉSUMÉ

Les systèmes fluviaux sont affectés par plusieurs facteurs de stress, de nature diverse, qui ont tendance à ne pas agir isolément, mais à interagir. En raison de leur nature directionnelle, hiérarchique et dendritique unique, les rivières posent un problème de conservation et de gestion. Une pression donnée affectant un segment n'est pas spatialement limitée car elle affecte le plus souvent l'ensemble du réseau fluvial aval. L'objectif de ce travail est de fournir une approche à grande échelle de la gestion des bassins en analysant l'effet des facteurs de stress isolés et interactifs, et des variables environnementales sur plusieurs éléments biotiques (poissons, macroinvertébrés, diatomées et macrophytes). Pour cela, une étude de cas dans le bassin de la Sorraia (centre du Portugal), un système méditerranéen en situation de pénurie d'eau et de pollution organique, a été retenue. Une combinaison de modélisation basée sur les processus (SWAT - Soil and Water Assessment Tool) et de modélisation empirique (BRT – Boosted regression trees, RF – Random Forests et GLMM - Mixed Generalized Linear Models) a été appliquée. Cette approche peut être appliquée à la prévision des impacts des changements climatiques futurs, et à l'évaluation de l'efficacité des plans de gestion. Cette méthodologie semble utile pour déterminer la gestion efficace des ressources et la planification de la conservation des réseaux fluviaux.

ABSTRACT

River systems are affected by several stressors, diverse in nature, that tend not to act isolated, they interact. Due to their unique directional, hierarchical and dendritic nature, rivers pose a conservation and management conundrum. A given pressure affecting one segment is not spatially limited as it most often affects the whole downstream river network. The objective of this work is to provide a wide scale approach to basin management by analyzing the effect of isolated and interacting stressors and environmental variables in several biotic elements (fish, macroinvertebrates, diatoms and macrophytes). For that, a case study in the Sorraia basin (Central Portugal), a Mediterranean system under water scarcity and organic pollution, was chosen. To develop the proposed framework a combination of process based modelling (SWAT – Soil and Water Assessment Tool) and empirical modelling (BRTs – Boosted Regression Trees, RFs – Random Forests and GLMM – Mixed Generalized Linear Models) was applied. This approach can be further applied in the prediction of the impacts of future climate changes, and to assess the effectiveness of management plans. This methodology seems to be helpful for determining effective and resource efficient management and conservation planning of river networks.

KEYWORDS

River basin management, Process based modelling, Empirical modelling, Climate change, Multiple Stressors

1 INTRODUCTION

Europe's water resources and ecosystems are impacted by various stresses (Herring et al., 2010) that affect ecological and chemical quality, water availability and ecosystem functions. In addition, future climate changes will, predictably, lead to an increase in the impact of stresses on rivers. When several stresses affect a system, interactions may occur, these interactions may have different impacts on the ecological and chemical quality of rivers. There are still few studies that deal with the combination of several impacts, which creates a lack of mechanistic understanding of the interaction of stresses. This diminishes our ability to predict responses to changing environments, risk assessment, management, impact mitigation, and ecosystem restoration.

In this work we selected a case study from the Sorraia Basin (Central Portugal) to develop a conceptual model of Basin functioning and merged process and empirical modelling in order to define biotic quality of several elements (Macrophytes, Fish, Macroinvertebrates and Phytobenthos). This study will facilitate a precise definition of the ecological status of the water bodies, but following a basin-wide approach that will allow a general understanding of the processes that operate in the basin, making possible the implementation of effective management and restoration policies.

2 MATERIALS AND METHODS

2.1 Study area

The Sorraia River Basin has an area of 7730 km² and a length of 155km. Drains into the Tagus estuary and is the tributary of the Tagus with the largest area of the basin. About half of the Sorraia watershed is covered by cork oak forests and the other half is covered by the largest irrigation area in Portugal (about 15 500 ha). It is affected by water abstraction which augments the already stringent environmental conditions of its Mediterranean climate.

2.2 Process based modelling

The model used in this work is the SWAT (Soil and Water Assessment Tool) model (Neitsch et al., 2005), a semi-distributed basin model in which a great effort and knowledge was placed in the crop database (with growth parameters of about 100 species) and vegetation growth model. The SWAT model divides the river basin into subareas that are assumed to be homogeneous - hydrological response units (HRUs). In this case, SWAT allowed to run the entire Sorraia watershed on a daily basis. The SWAT model was applied to the Sorraia basin using the ArcSWAT interface, which is an ArcGIS extension from ESRI. The GIS maps available for topography, land use from EO (Earth Observation data) are adapted to the SWAT classification and the soils of the study area were used.

2.3 Empirical modelling

We used a stepwise analytical procedure, closely following the steps proposed in Feld et al. (2016) to analyze the impacts of multiple stresses on aquatic biomonitoring data. After checking the quality and consistency of the data, we performed a first exploratory analysis using two regression techniques, Boosted Regression Trees (BRT) and Random Forests (RF). We quantified and tested the effects of individual and multiple stresses through Generalized Linear Models (GLM) or Generalized Mixed Linear Models (GLMM), when more than one sampling occasion was available for each location.

3 RESULTS AND DISCUSSION

All GLMM models using Ecological Quality Ratio (EQR) indicators showed R^2 values above 0.2. The EQR Fish presented the model with the best Goodness-of-fit (R^2m = 0.56), followed by the macroinvertebrate EQR (R^2m = 0.39), by the EQR Macrophytes (R^2m = 0.36) and finally by the EQR Phytobenthos (R^2m = 0.29). Among the selected models, the predictors of land-use were the most frequently selected for inclusion in the models (except RQR Fish).

In general, stresses were less related to biotic elements than to environmental variables. But the stresses related to land-use had more relation with the biotic elements than the hydrological and nutrient stresses. This may have occurred because soil use variables can be seen as a proxy for

multiple stresses, thus explaining the stronger effect observed. However, we cannot completely rule out the existence of other major stresses that were not considered in this analysis (due to lack of data or difficulty in integrating into the modeling strategy followed), such as channeling water lines, damming, transboundary barriers, industrial pollution). Furthermore, land-use stresses being a proxy for multiple pressures may have exerted an effect on the biotic elements in such a way that the otherwise significant effect of a stress is not detected on the scale of the response variable. Overall, three models included terms of interaction, but in all cases, the interactions show that the two variables have an opposite interaction. The combined effect appears to be less than the sum of the isolated effects.

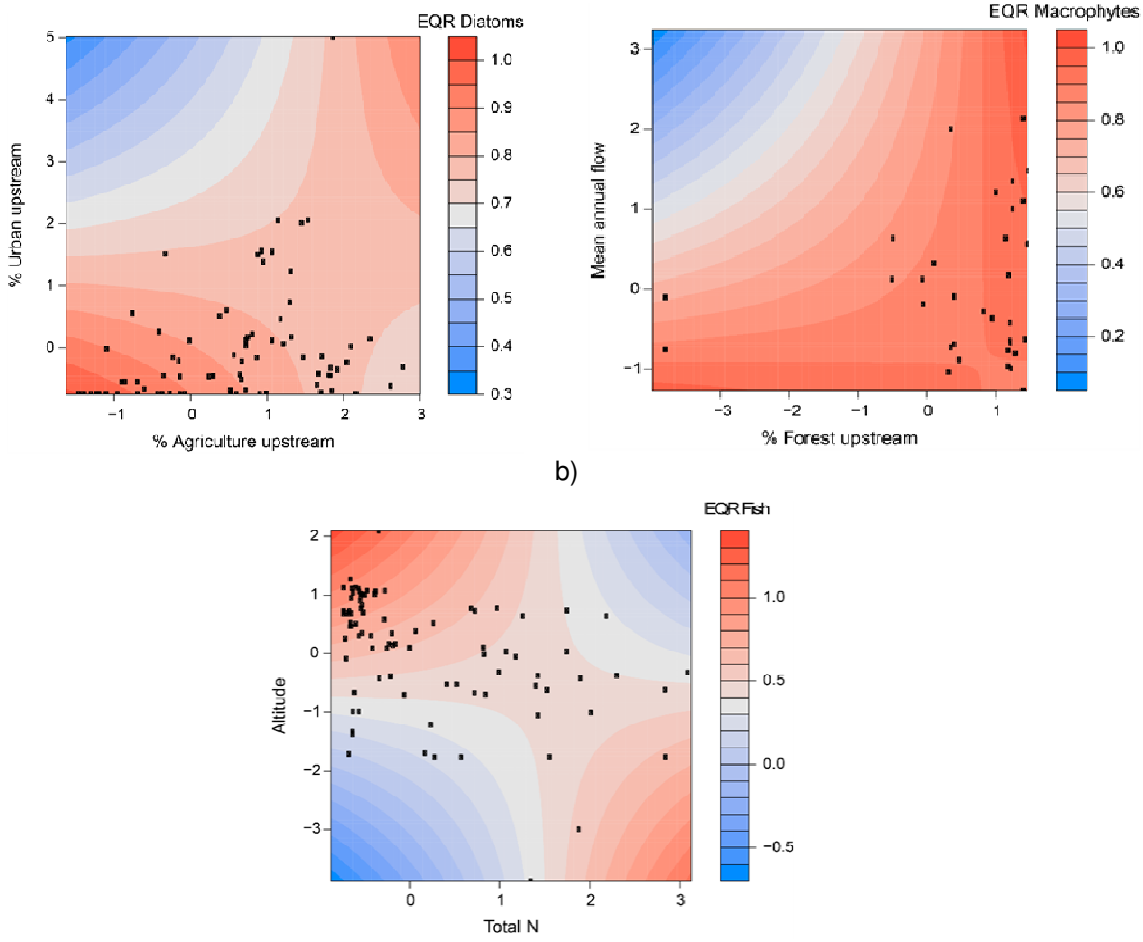

Fig.1 - Partial response of combined effects of the interacting predictor variables included in the Generalized Linear Model for the Ecological Quality Ratio of the Portuguese biotic integrity index for a) Phytobenthos (diatoms), b) Macrophytes and c) Fish.

This study demonstrates, using a case study, how the interconnection between process-based models and empirical models can be made for model establishments with predictive capacity of the ecological status of the water bodies. These models and this method can be applied to anticipate future impacts of climate change and can even be used to test the effectiveness of measurement plans. It is thus a very useful tool for river basin planning and management, allowing for changes and adapting management measures to achieve the objectives of the Water Framework Directive.

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