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Can we predict biological condition of stream ecosystems? A multi-stressors approach linking three biological indices to physico-chemistry, hydromorphology and land use

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ABSTRACT

We built a corpus of models capable of explaining the variability of the biological indices used in the French surveillance monitoring network and also predict the ecological status of non-monitored water bodies. Benthic macroinvertebrates, diatoms and fish indices have been used to determine the ecological status of 1100 sites of the monitoring network distributed homogeneously over national territory.

The pressures taken into account to explain and predict ecological status cover three spatial scales: catchment, reach, site. The set of predictive data cover three types of pressure: land use pressure, hydromorphological pressure and physico-chemical pressure measured at catchment, reach and site scale, respectively.

We showed that the parameters characterising the load of nutrients and organic matter had a predominant effect on the three biological compartments, and that land use variables played an integrating role of the different pressures acting on rivers and explained a major part of their degradation. On the contrary, we also showed that it was more difficult to characterise the role of the hydromorphological descriptors measured at the intermediate scale of the reach due to the difficulty of characterising the links between scales.

The three predictive models developed demonstrated good performances to evaluate biological condition and are of great interest for managers as it permits using a set of pressure data to successively predict the status of water bodies for which biological monitoring data are unavailable.

1. Introduction

One of the main expectations of society regarding ecology is the capacity to determine the status of environments and above all to diagnose the causes of the degradations that affect them. How can this status be defined? What should be measured? What biological, chemical and hydromorphological parameters should be taken into account? Over recent years, strong societal and political ambitions have developed, manifested for example in attention being given to the status of water through the Clean Water Act in the United States in 1972 and the European Framework Directive on Water in 2000. The objective is to ensure the good ecological condition of water. To respond to these questions, governments have set up programmes for the monitoring of water status in order to establish a coherent and comprehensive overview of water status within each river basin district.

However, none of the existing regulations require systematic monitoring of each water body in the framework of systematic observation networks. For example, the monitoring network in France covers approximately 25% of the water bodies of the territory with 1500 sites. This leaves 4500 water bodies for which the classification of ecological status must be done without monitoring data being available. What is more, this situation is by no means unique in Europe since both technical constraints and economic reasons have led the member states to opt for only partial monitoring of their water bodies (Kristensen and Christiansen, 2012).

In order to answer the above questions, reliable and reproducible methods are required to predict the ecological status of non-monitored water bodies objectively and uniformly for all the

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water bodies of a country. However, the spatial coverage of most ecological research is relatively limited, which implies the need to develop tools capable of extrapolating knowledge to larger scales and new territories (Miller et al., 2004).

Works to model status indicators emerged at the beginning of the 2000s in countries that base the evaluation of ecological status according to the RIVPACS system, such as the United Kingdom (Wright et al., 1998). The reference conditions have been modelled as a function of natural environmental descriptors. Many other countries have adopted this system: MEDPACS in Spain (Poquet et al., 2009), the Mondego model in Portugal (Feio and Poquet, 2011), PERLA in the Czech Republic (Kokeš et al., 2006), SWEPAC DRI in Sweden (Johnson and Sandin, 2001) and AusRIVPACS in Australia (Smith et al., 1999).

On the contrary, very few research has focused on the development of predictive tools that permit evaluating non monitored water bodies. Donohue et al. (2006) built a model to predict ecological status based on populations of benthic macroinvertebrates using catchment land use data and water chemical quality indicators of 797 sites in Ireland. In Denmark, Kristensen et al. (2012) developed a model capable of predicting the presence of fish assemblages as a function of catchment land use and chemical and morphological data measured at site level on 335 sites.

This type of research has also been conducted outside the European Union. In the USA in particular, where several authors have published works on the development of models to predict ecological status (again based on benthic macroinvertebrate populations) on the basis of catchment land use (Brown et al., 2012; Carlisle et al., 2009; Maloney et al., 2009; Waite et al., 2010). Brown et al. (2012) developed a predictive model using the boosted regression tree (BRT) method to predict ecological status based on macroinvertebrate populations using catchment land use data, and river corridor and environmental descriptors. They worked on a dataset consisting of 159 sites distributed in Southern Coastal California. Maloney et al. (2009) compared five types of predictive method (classification and regression trees, random forest, conditional random forest and ordinal logistic regression) to predict ecological status based on the macroinvertebrates of 1561 sites of Chesapeake Bay (Maryland). The predictive variables were composed of land use variables and environmental descriptors. Carlisle et al. (2009) used Random Forests to predict the biological status of 920 sites distributed over the whole of the USA, again using macroinvertebrates as status indicators. The predictive variables were also based on land use data and other general environmental descriptors. Waite et al. (2010) used multiple linear regression to model several metrics based on macroinvertebrates, measuring the ecological status (biological condition) for 299 sites in Oregon and Southern Coastal California. The predictive variables were land use variables measured on the scale of the catchment, the river corridor and environmental descriptors.

These initial predictive tools demonstrate that it is possible to predict ecological status efficiently on the basis of pressure variables. Nonetheless, they take little account of the multiple spatial scales that structure both the pressure and longitudinal functioning of rivers. Indeed, a river is organised hierarchically as a function of several interlinked scales: catchment, reach, mesohabitat and microhabitat (Allan, 2004; Allan and Johnson, 1997; Frissell et al., 1986; Poff et al., 1997). In addition, the degradation of ecological status results from several types of pressure: punctual discharges (more or less episodic), diffused pollutions, changes of solid and liquid flows, artificial structures and breaks in connectivity (Borchardt and Richter, 2003). According to the DPSIR concept (driving forces, pressures, status, impact and response) (Kristensen, 2004), human activities (agriculture, urbanisation) generate combined pressures (chemical discharges, physical changes) and constitute driving forces that change the abiotic components of the ecosystem (physico-chemistry, hydromorphology). These changes then affect biological communities and thus ecological status.

In this framework of analysis, some works have focused on understanding the links between biological condition and pressures in a multiscale context. Land use, hydromorphology and physic-chemistry have been linked one after the other to biotic indices based on macrophyte communities (Feld, 2013), diatoms (Dahm et al., 2013), fish (Feld, 2013; Marzin et al., 2012; Marzin, 2013) and macro-invertebrates (Feld, 2013; Marzin et al., 2012; Sponseller et al., 2001; Sundermann et al., 2013; Wasson et al., 2010).

Feld (2013) showed that not all biological groups respond in the same way to pressures and that lotic fauna was more correlated than lotic flora to the land use indicators measured on the scale of a catchment such as riparian corridor, with a more marked correlation for mountain rivers than for plain rivers. In line with Sponseller et al. (2001) and Wasson et al. (2010), it has also been shown that the riparian corridor plays a major protective role for the ecological functioning of a river and that taking into account specific regional geographical characteristics, in particular geographical entities such as eco-regions, is essential for good river management. Dahm et al. (2013) and Sundermann et al. (2013) used more categories of pressure variables at different spatial scales to explain ecological status and showed that physico-chemistry and land use had a greater effect than hydromorphology on the status indicators of all the biological groups.

More generally, these studies have highlighted the links that exist between each of these pressures and biological indices. Some have shown that the links between pressures and biological indices are influenced by the scale at which the pressure is taken into account. Thus a catchment, reach and riparian corridor are scales that have a considerable structural effect on the pressures affecting ecological status (Marzin et al., 2013; Wasson et al., 2010).

Our objective is to take into account this knowledge on the organisation of spatial scales and on the links between pressures and ecological status in determining the ecological status of non-monitored water bodies.

To this end, we built a corpus of models capable of explaining the variability of the biological indices used in the survey network and also predict the ecological status of non-monitored water bodies in France. Benthic macroinvertebrates, diatoms and fish indices have been used to determine the ecological status of 1100 sites of the monitoring network distributed homogeneously over French territory. The pressures taken into account to explain and predict ecological status cover three spatial scales: catchment, reach, site. The set of predictive data cover three types of pressure: land use pressure, hydromorphological pressure and physico-chemical pressure measured at catchment, reach and site scale, respectively.

This permits answering the following questions:

- What are the pressures with the greatest influence on ecological status measurement tools? In what way? With what intensity?
- How can the ecological status of non-monitored water bodies be predicted?

2. Materials and methods

2.1. Biological data

We used the data of 1100 sites from the French monitoring network for the period 2008–2009 (Fig. 1). These sites are distributed in 22 hydro-ecoregions and cover every size of river. The benthic macro-invertebrate data were collected in conformity with a standardised common protocol (AFNOR, 2009). The biological index calculated on the basis of these fauna lists is the I2M2