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River ecosystem processes: A synthesis of approaches, criteria of use and sensitivity to environmental stressors

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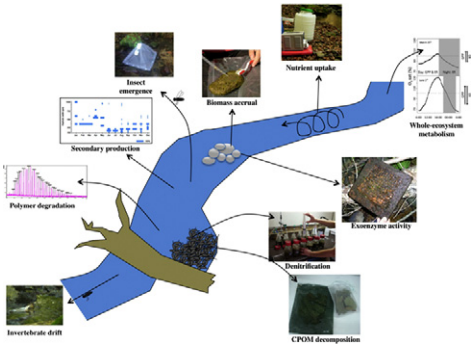
HIGHLIGHTS

- River ecosystems should be assessed by their structure and functioning.
- Ecosystem functioning is rarely taken into account.
- A synthesis of river ecosystem processes is proposed.
- Approaches, criteria of use and sensitivity to stressors are described.
- Our synthesis contributes to a more functional view in river research and management.

GRAPHICAL ABSTRACT



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ABSTRACT

River ecosystems are subject to multiple stressors that affect their structure and functioning. Ecosystem structure refers to characteristics such as channel form, water quality or the composition of biological communities, whereas ecosystem functioning refers to processes such as metabolism, organic matter decomposition or secondary production. Structure and functioning respond in contrasting and complementary ways to environmental stressors. Moreover, assessing the response of ecosystem functioning to stressors is critical to understand the effects on the ecosystem services that produce direct benefits to humans. Yet, there is more information on structural than on functional parameters, and despite the many approaches available to measure river ecosystem processes, structural approaches are more widely used, especially in management. One reason for this

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discrepancy is the lack of synthetic studies analyzing river ecosystem functioning in a way that is useful for both scientists and managers. Here, we present a synthesis of key river ecosystem processes, which provides a description of the main characteristics of each process, including criteria guiding their measurement as well as their respective sensitivity to stressors. We also discuss the current limitations, potential improvements and future steps that the use of functional measures in rivers needs to face.

1. Introduction

Ecosystem structure refers to the physical features of the ecosystem and the organisms (*i.e.* microbes, plants and animals) that inhabit it. Ecosystem functioning, on the other hand, refers to the set of processes that regulate the fluxes of energy and matter in ecosystems as a consequence of the joint activity of these organisms (Tilman et al., 2014). Thus, ecosystem structure and functioning can be viewed as the two sides of a same coin. In the case of rivers, structure encompasses variables such as channel form, water characteristics, or composition of the biological communities, whereas functioning refers to processes such as metabolism, organic matter decomposition and secondary production (Sandin and Solimini, 2009). Although structure and functioning influence each other, their relationship is not straightforward, and often one cannot be automatically inferred from the other (Cardinale et al., 2012). Furthermore, environmental stressors can affect structure and functioning in contrasting ways (Fig. 1) (Sandin and Solimini, 2009).

The concept of ecosystem functioning is gaining popularity among environmental scientists and managers alike (Jax, 2010). This interest is based on a number of reasons, among which two stand out. Firstly, one can be directly interested in ecosystem functioning, as it is the backbone of ecosystem services (Millennium Ecosystem Assessment, 2005), some of which can be translated into monetary benefits (Quintessence-Consortium, 2016). For instance, the capacity of rivers to retain nutrients contributes to water purification, a relevant regulating service (Loomis et al., 2000). Likewise, fish production can be a key provisioning service for the local communities as well as a source of income derived from recreational angling (Hernández-Morcillo et al., 2013). In this sense, management actions may be fully or partially focused on fish production, metabolism and nutrient cycling (Bunn et al., 2010; Kupilas et al., 2016; Lepori et al., 2005). Secondly, ecosystem functioning can be viewed as an integral component of ecological status. This is, for instance, the case of the EU Water Framework Directive (EC, 2000), which defines ecological status as "an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters".

Traditionally, many methods have been developed to characterize ecosystem structure, and incorporated into environmental assessment protocols. Despite the growing demand, however, much less progress has been made to develop and standardize methods to measure ecosystem functioning, or to incorporate them into the assessment of river ecological status (Palmer and Febria, 2012). Functional indicators of ecological status are still in their infancy (Bunn et al., 2010; Young et al., 2008) and are not the focus of this paper; still, we hold that promoting the measurement of ecosystem functioning will favor their development and implementation.

While researchers and managers recognize the importance of ecosystem functioning, water authorities remain in general reluctant to measure river ecosystem processes. The main reasons for reluctance are the widespread consideration of being too expensive, difficult to perform or interpret, or simply that these measurements yield results not directly applicable to management. We oppose to these objections, and hold that there is sufficient scientific knowledge to provide suitable and efficient functional measures, that may be tailored to the needs of the water authorities. Although some processes are complex to measure or require very specific equipment, others are not, and measurements could be performed straightforward in combination with the structural variables commonly assessed.

The aim of this paper is to present a synthesis of key river ecosystem processes. We provide a description of the main characteristics of each process, including criteria guiding their measurement as well as their respective sensitivity to stressors. We also discuss the current limitations, potential improvements and future steps that the use of functional measures in rivers needs to face. Our ultimate purpose is to contribute to the adoption of a more functional perspective in river research and management.

2. Classification of processes

The list of processes that can be measured in rivers is very long, and ranges from purely physical processes to others more biologically mediated (Palmer and Febria, 2012). Here, we focus exclusively on

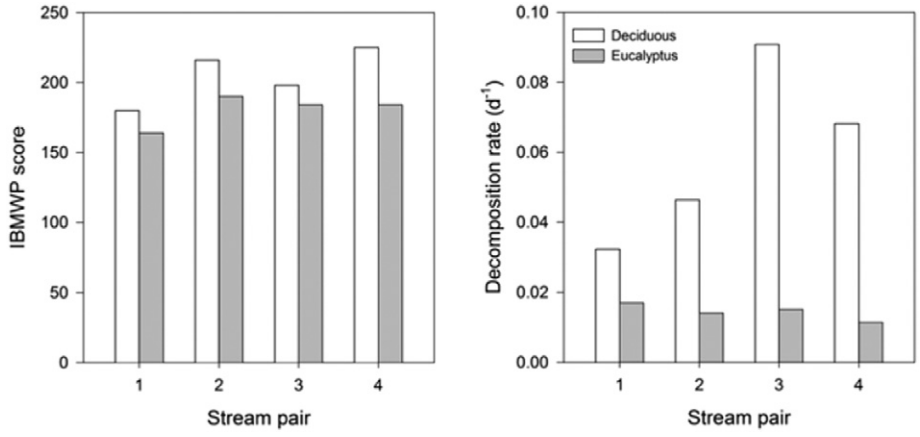

Fig. 1. Differential response of structural and functional metrics to an environmental stressor in 8 paired streams (*i.e.* pairs are very similar streams) in the northern Iberian Peninsula. Half of them were surrounded by native deciduous vegetation, the other half by Eucalyptus plantations. The small differences in IBMWP (Iberian Biological Monitoring Working Party) (left panel), an invertebrate-based biotic index, between deciduous and Eucalyptus streams, contrast with strong differences in decomposition rate of alder leaves measured in coarse mesh bags (right panel). Unpublished data provided by Elosegi et al.