Stream Ecological Integrity

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Streams and rivers provide important services to humans, and therefore, their ecological integrity should be a societal goal. Although ecological integrity encompasses structural and functional integrity, stream bioassessment rarely considers ecosystem functioning. Organic matter decomposition and ecosystem metabolism are prime candidate indicators of stream functional integrity.

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1. Introduction

Like all ecosystems, streams and rivers can be characterized by both their structure and function. Ecosystem structure refers to the physical characteristics of the ecosystem (e.g., water quality and channel form) and the composition of biological communities, while ecosystem functioning refers to the processes, such as those that control energy and matter fluxes in the ecosystem, including organic matter decomposition and ecosystem metabolism [1]. The European Water Framework Directive recognizes that “ecological status is an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters,” but it only considers structural elements for the evaluation of the ecological status of streams and rivers: biological elements (aquatic flora, benthic invertebrates, fish), hydromorphological elements (hydrological regime, river continuity, channel morphology), chemical and physical elements (nutrients, pH), and specific pollutants (Directive 2000/60/EC [2]). Similarly, assessments in the United States focus on invertebrates, water quality parameters, and geomorphological classifications [3]. Since ecological integrity includes both structural and functional integrity, bioassessment of streams and rivers focusing solely on structural elements provides an incomplete and potentially misleading picture of the overall ecological integrity. This is of concern because structure and function can respond differently to environmental change [4][5][6], and there can be alterations in functioning (e.g., organic matter decomposition) without noticeable alterations in structure (e.g., benthic invertebrate community composition) [7][8]. Additionally, ecosystem functions are closely linked to the ecosystem services upon which human societies depend [9][10], and therefore, evaluating ecosystem functioning is critical to understanding impacts on ecosystem services. The recent New Zealand National Policy Statement for Freshwater Management 2020 reflects this need and recognizes ecosystem health as a compulsory value to be protected, noting that it specifically incorporates five elements: water quality, water quantity, physical habitat, aquatic life, and importantly, ecosystem function [11].

Many biologically mediated ecosystem functions can potentially be used in stream bioassessment [12]. Here, we focus on two processes for which there is significant background information on their sensitivity to environmental stressors and that have been most often studied in the context of stream bioassessment: organic matter decomposition and ecosystem metabolism [1][13]. Organic matter decomposition connects riparian vegetation and aquatic communities via the instream cycling of energy and nutrients of terrestrial origin, while ecosystem metabolism is an integrative measure of organic carbon production and consumption. Both functions integrate environmental conditions over time, and across multiple trophic levels and multiple levels of biological organization, such that changes in a single level may be reflected in altered process rates [1][13]. Additionally, both organic matter decomposition and ecosystem metabolism are partly carried out by organisms that are not usually considered in bioassessment, namely, heterotrophic microorganisms, and these functions can therefore reflect changes in the microbial community structure and activity that are not detected in standard bioassessment programs. Furthermore, organic matter decomposition and ecosystem metabolism do not depend on the presence of a specific taxon, but rather on functional groups (e.g., invertebrate shredders), potentially allowing for large spatial scale comparisons that are not complicated by biogeography [10]. However, these functions will only be useful bioassessment tools if they respond predictably and sensitively to environmental change and anthropogenic stressors and can discriminate between different types of human impacts [14].

2. Incorporation of Functional Indicators into Official Bioassessment Programs

Many stream and river researchers have called for the use of functional indicators in ecosystem bioassessment since the turn of the millennium [1][10][12][13][15][16][17]. In fact, there is a growing number of studies that report on the use of functional indicators in ecosystem bioassessment, but their uptake in standard regional or national bioassessment programs has generally been slow. This is perhaps changing.

New Zealand has been quick to adopt ecosystem functions for inclusion in bioassessment programs and is a model for their inclusion elsewhere. Recent changes in New Zealand's national environmental policy have recognized ecosystem health as a compulsory value of freshwater ecosystems and ecological functions as a key component of ecosystem health, alongside water quality, water quantity, habitat, and aquatic life [11]. Ecosystem metabolism has been included in this policy as one of the compulsory attributes to be measured, giving ecosystem metabolism a similar status to structural indicators based on fish, macroinvertebrates, macrophytes, deposited sediment, dissolved reactive phosphorus, and DO. Local government agencies in New Zealand, who are responsible for environmental bioassessment and reporting, have shown an interest in the use of functional indicators for some time and helped to fund the development of the framework presented in Young et al. [13]. The inclusion of ecosystem metabolism in recent policy changes has led to an increase in interest and demand for guidance on measurement approaches and more resources will be required to implement the policy changes.

Using the criteria described in Young et al. [13], the analysis of metabolism measurements as part of regular regional bioassessment and reporting programs has identified sites ranging from poor to good ecosystem health [18][19][20][21][22]. Ecosystem metabolism has also been considered a useful tool for assessing the effectiveness of stream restoration [23]. Increases in shading from riparian plantings are expected to reduce GPP back to baseline levels. Reductions in inputs of organic waste are expected to reduce rates of ER back to baseline levels, while the restoration of riparian zones is expected to result in more natural levels of organic matter inputs, potentially increasing rates of ER in streams that are organic matter deficient. However, Doehring et al. [24] found no consistent evidence of changes in ecosystem metabolism among 11 pairs of sites with and without riparian buffers. They considered that the scale of riparian plantings (between 196–1600 m in length) was insufficient to affect stream metabolism, given that the buffers represented only a small proportion (0.1–1.7%) of the total upstream stream length.

The value of including organic matter decomposition in monitoring programs has been recognized in New Zealand, but it has been difficult to encourage the use of further functional indicators when bioassessment budgets are already stretched. Initial trials of leaf litter decomposition as an indicator of stream functional integrity were hampered by leaf litter availability and the perceived variability in leaf litter chemical composition, even within a single species. Subsequent trials of standardized substrates (wood sticks and cotton strips) showed more promise, but the results were sometimes difficult to interpret [25][26][27].

In South East Queensland, Australia, freshwater bioassessment incorporates 22 indicators across five indicator groups, including ecosystem metabolism, with regular bioassessment at over 120 stream sites throughout the region [15]. GPP is primarily influenced by water chemistry and riparian condition, while ER reflects the water and sediment chemistry. The bioassessment information is used to develop report cards that summarize the ecosystem health of stream sites for local politicians and the wider community and have been instrumental in growing awareness among the public of the connections between land management and the health of the region's waterways [15].

In France, the national agency for water and aquatic ecosystems (ONEMA) seems to be open to the incorporation of leaf litter decomposition into bioassessment programs. Colas et al. [28] reported the case where practitioners of water agencies collaborated with researchers to test the use of leaf litter decomposition as an indicator of hydromorphological disturbance and water chemical quality. For this, Alnus glutinosa leaves were enclosed in fine- and coarse-mesh bags and incubated in 82 stream sites distributed throughout France. According to the authors, the interaction between the researchers and river managers promoted the direct transfer of a bioassessment tool based on leaf litter decomposition to stakeholders, which may promote its inclusion in future bioassessment programs [28].

In other places, however, the incorporation of indicators of stream functional integrity in bioassessment programs is hindered by multiple factors. For instance, in Portugal, the effort to implement structural indicators is already considerable (in terms of the budget and human resources), there is still much to do (for instance, extend bioassessment to all water bodies), and it is already very difficult to meet the deadlines of the Water Framework Directive. Thus, providing additional effort to incorporate functional indicators is not feasible at present.

Despite the difficulties in incorporating indicators of stream functional integrity in large scale bioassessment programs, these can be particularly useful in bioassessment programs at smaller scales. Examples include the evaluation of the effects of stream restoration practices [29][24][30][31][32][33] or of particular point source pollution (pesticide spill [34], wastewater treatment plant [35][36]).

In conclusion, organic matter decomposition and ecosystem metabolism have been shown to be widely effective in detecting the environmental changes caused by anthropogenic activities. Therefore, these two functions have great potential as indicators of stream functional integrity. Incorporating these functions in stream bioassessment programs is an essential step toward the improvement of the management and conservation of running water ecosystems.

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