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Review Paper

Ecological integrity of rivers, biondication and aquatic macroinvertebrates

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Abstract

The main objective is to clarify the concept of ecological integrity of rivers and explore the state of knowledge on the bioindication of ecological integrity based on macroinvertebrates. The work is based on a literature search and analysis of scientific publications, theses, dissertations and reports that deal with bioindication. According to this analysis, ecological integrity is schematised according to three main inseparable categories, namely chemical, physical and biological integrity, which define the general quality of an aquatic environment. Disturbance of the environment modifies each facies of this ecological integrity, which affects the structural and functional organisation of the organisms that reside there. The immediate response of populations to this environmental change evokes bioindication concept of aquatic ecosystems. Abiological response that justifies the use of bioindicators, including macroinvertebrates which are the most used. Effective monitoring of the ecological integrity of rivers involves the use of bioindicators that can reveal their ecological quality. Bioindicators are valuable tools that should be considered in aquatic ecosystem monitoring programs and environmental policies.

Keywords: Ecological health, habitats, biomonitoring, conservation.

Introduction

Freshwater ecosystems are home to 9.5% of the species currently described by scientists[1]. They provide a large number of functions from which human populations benefit. As a result, they are among the most exploited ecosystems on the planet[2]. The vulnerability of rivers is reinforced by the strong link that these systems have with their watersheds. As a result, they are often directly impacted by human activities in place in their watersheds[3]. In rural areas, the intensification of agricultural activities is the major cause of the degradation of aquatic ecosystems[4]. Agricultural activities in watersheds have serious ecological impacts for rivers and deeply alter the persistence of fundamental ecological processes[5,6]. Indeed, the use of chemical fertilizers, pesticide application, cultural practices and industrial discharges have a muted negative impact on aquatic biological communities. Anthropogenic actions deteriorate communities, cause intoxication, induce biocenotic disturbances and sometimes even lead to the extinction of some species[7,8].

Monitoring the integrity of these aquatic ecosystems is now largely based on measurements of biological communities. Fish, benthic macroinvertebrates, zooplankton, phytoplankton, macrophytes, bacteria and birds are used to assess the responses of aquatic systems to anthropogenic disturbances. Of these aquatic bioindicators, macroinvertebrates are the most widely used. They are valuable bioindicators of the health of aquatic ecosystems where they can be used to detect early warning signs of potential environmental problems, identify cause and effect between environmental disturbances and biological and ecological impacts[9,10,11]. Bioindication is therefore an advantageous method for assessing ecological integrity compared to methods involving measurements of pollutants or chemical compounds.

This review aims to clarify the concepts of ecological integrity and river bioindication. It presents the usefulness of macroinvertebrates in bioindication and the interest in conserving the ecological integrity of rivers.

Clarification of concepts

Ecological integrity: Ecological integrity is a concept used to indicate the general ecological state of aquatic ecosystems. This theme also refers to the ecological health of lakes and rivers.An aquatic ecosystem with high ecological integrity, or excellent ecological quality, is one where human impact is minimal and which has not been altered by human activity[5,12]. Considers that an environment with integrity is at its full intrinsic potential, its condition is stable, its ability to counteract the effects of disturbances is maintained and it requires minimal external support for its management. In a river, this means that ecological processes, such as production, decomposition, nutrient dynamics and organism movements, will be identical to those found naturally in a river of the same region[5].

Ecological integrity in aquatic ecosystems is schematized according to three ecological aspects. It is made up of chemical, physical and biological integrity. Physical integrity expresses the physical compartment of rivers. Hydrology, geomorphology, sediment dynamics and riparian vegetation determine the diversity of aquatic habitat[13]. Physical integrity describes a watercourse whose physical characteristics provide quality habitat and ensure the ecological conditions necessary for the development of the biocenosis[5].Finally, chemical integrity characterizes the chemical elements of water and sediments[13].

Biological systems that are present at a specific location reflect their ability to persist in the physical and chemical environment of their region[12]. An environment characterised by an assemblage of organisms similar to that produced by long-term evolution in the environment therefore shows high biotic integrity[5]. The notion of ecological integrity is related to the capacity of an system to keep a community of organisms in equilibrium, well integrated, capable of adapting to change and having, for a given ecoregion, a specific composition, diversity and functional organisation comparable to that of a natural ecosystem[12,14]. Ecological integrity thus refers to the level of organisation of the whole community and is directly associated with the evolutionary context. The integrity of a system can thus be assessed according to the characteristics of the components and processes important in maintaining its genetic and ecological organisation[5,14-16].

Biomonitors and Bioindicators

The term biomonitoring refers to the use of biological indicators to quantify the pollution status of a given environment based on measurable parameters[17]. The organisms used in a biomonitoring program are called biomonitors and are defined by Kaiser, J.[18] as organisms from which certain changes, or characteristics, can be measured, making it possible to assess the degree of contamination of an environment and the consequences for the health of other organisms or the entire ecosystem. Biomonitors therefore provide information on quantitative aspects of environmental quality. Biomonitoring then reflects "the systematic use of living organisms or responses to determine the state or changes in the environment"[19,20]. Markert, B.[21]elaborate and clarify biomonitoring as a method of observing the impact of external factors on ecosystems and their evaluation over a period of time, or on the observation of differences between one place and another. Therefore, a biomonitor is also a bioindicator in itself, but the reverse is not always true[17].

The various species that underpin the production of resources and ecological services in an ecosystem are controlled by physical, chemical, biological and hydrological factors. Any change in these factors has an impact on the species. Some species with high sensitivity are used to detect disturbances (pollution, habitat modification, climate change, etc.). These are so-called bioindicators that provide information on the health of habitats[18]. Modifications in the environment can decrease or increase the population level of the bioindicator depending on whether they positively or negatively affect different life parameters of these organisms at the behavioural, morphological, tissue or physiological level[9,22]. Altering the reproductive physiology of a bioindicator could, for example, cause a decrease in its population. Banaru, D. and Perez, T.[23] define a bioindicator as an organism or set of organisms that, by reference to life parameters, makes it possible to characterise the state of an ecosystem or an ecocomplex in a practical and reliable way and to highlight their natural or induced changes as early as possible. Bioindicators are a real tool because of their ability to characterise the state of an ecosystem under environmental stress, as well as to detect or predict significant changes that may occur within the same ecosystem[9,18,22,24]. A bioindicator can be an individual, a part of an individual or even a community of individuals containing information on the quality of the environment. Given the non-specificity of the responses of most organisms to environmental stress, the task of a bioindicator is more to highlight the physiological effects affecting organisms under the influence of stressful environmental conditions than to directly measure the concentrations of the different pollutants involved[25]. Bioindication, thus referring to the use of a single taxon or communities of animal and plant species to determine risks or effects on an ecosystem, is a tool used to assess environmental conditions[26]. It is then summarised as the capacity of organisms or a set of organisms to reveal by their presence, absence or demographic behaviour the characteristics and evolution of an environment[9].

Sentinel species: A sentinel species is a bioindicator that is particularly sensitive to one or more pollutants likely to cause disturbances or changes in a given environment[18]. Because of their sensitivity, these species have the capacity to highlight early signs of alteration in the natural environment even before the effects are felt within the affected environment. They therefore act as a kind of alarm signal for the entire ecosystem[17]. Sentinel species, also called ecological sentinels, have a sensitivity that serves as an early indicator of changes in the ecosystem environment.

Ecological niche: The concept of niche in ecology can be viewed from several angles. First, the niche can be understood as a description of the habitat requirements of a species[27]. Here, the ecological niche is defined by the role that a species can play in nature, determined by the characteristics of its habitat, its diet. This concept is mainly associated with[28], who first introduced the term. Secondly, the niche can be seen as an ecological function of the species[27]. Hence the emphasis on the functional roles of species by Elton, C.[29]. Thirdly, the niche can be appropriated as the position of the species in a community[27]. Thus, Hutchinson, GE.[30] proposed a more formal quantitative concept based on a set of theories. The notion of ecological niche[30] can be understood through life history traits. For a given taxon, each trait then constitutes one of the dimensions of the hyper volume corresponding to the taxon's Functional Trait Niche (FTN) [31]. The potential of the "trait" approach is so great that[32] recommend reconsidering the entire ecology of communities from this point of view. The ecological niche thus becomes one of the founding concepts of bio-indication. By definition, the ecological niche of a species corresponds to all of the characteristics of its habitat: its diet, interspecific relations and activity rhythms, as well as its place in food webs and its reproductive needs[33]. The concept of ecological niche thus reflects the functional relationship between a species and its ecosystem, determined by the combination of its tolerance limits with respect to different biotic and abiotic factors[22]. The disturbance of these conditions results in an imbalance that translates into a modification of the ecological, physiological or morphological parameters of the bioindicator.

Interest of bioindication

Physico-chemical monitoring collects simple and punctual measurements; it is a basic practice of water quality monitoring, which has been completed and perfected with the evolution of techniques[34]. However, measuring these parameters alone does not provide a comprehensive view of the health of the aquatic ecosystem. Indeed, the assessment of water chemistry, even at frequent intervals, is subject to uncontrolled temporal variability[34].

Bioindication refers to the assessment of environmental quality using bioindicators, i.e. living organisms known for their ability to reflect the state of ecosystems and to identify problems and risks to them. Environmental assessment methods using biological indicators often have the advantage of being inexpensive compared to traditional methods involving measurements of pollutants or chemical compounds. The use of bioindicators generally avoids the use of expensive technological equipment and saves time[17]. In addition, another important aspect of using biological indicators is that they contain information on exposure to all the different contaminants integrated over time, unlike instrumental measurements that can only provide a static, point-in-time picture of the situation[17].

Environmental quality monitoring based exclusively on physico-chemical parameters does not allow conclusions to be drawn on the health of the ecosystem, because it does not assess the quality of the habitat and is limited to the study of pollutants. In addition, this method does not allow for the integration of synergistic, additive or antagonistic effects of various pollutants on organisms[35]. Bioindicators, because of their bioaccumulation capacity, provide early detection of pollutants or disturbances. Furthermore, bioindicators provide information on the bioavailability of pollutants rather than their total concentration in the environment[22].

Importance of conservation of the ecological health of rivers
Freshwater ecosystems perform a wide range of functions related to biological and hydromorphological processes. Aquatic communities play an essential role in the matter and energy cycles. Autotrophic primary producers ensure energy transfer along the trophic chain and are the guarantors of the maintenance of secondary production, particularly fish production[3]. In nutrient-poor systems, the energy at the base of food webs comes from allochthonous organic matter. This resource becomes accessible to consumers through the joint action of physical leaching processes and biological actors[3].

As a major component of the environmental, rivers perform important ecological functions[36]. They improve landscape diversity, help to connect distant biotopes and, when their water quality is good and they maintain some natural dynamics, provide many diverse habitats for many animal and plant species. Changes in habitat character between terrestrial and aquatic conditions allow terrestrial and aquatic organisms to use the same space at different times while benefiting from different sources of nutrients[37]. Rivers thus provide a significant increase in biodiversity and ecosystem productivity[37,38]. A river is not just a body of water in constant motion. From its source to its mouth, it forms a continuous and complex ecosystem, in which all its components, both aquatic and terrestrial, are interdependent. Rivers, through the land-aquatic transition zones, actively participate in the exchange of energy between terrestrial and aquatic systems[37].

Beyond the importance of the biodiversity that rivers host, they provide many services to riparian populations[5,36,37]. These aquatic ecosystems perform fundamental functions in the life process of communities. Portable water supply, for example, is an essential service provided by these systems. Ecosystems which provide full services to populations and which offer several advantages (commercial, sports, recreational) have good ecological integrity[5,39]. Freshwater ecosystems can also generate other indirect services that are sometimes difficult to quantify, but which are very beneficial to the well-being of the population. Cultural and religious services, climate regulation, effects mitigation of climate change, water decontamination, etc. are provided by these systems which ensure important ecological and socio-economic roles for communities[40]. The socio-economic impacts of reduced ecological integrity are therefore numerous. These include reduced cultural diversity and quality of life, economic deprivation and environmental injustice[12]. Human societies depend on freshwater and the various resources and services associated with it[5].

Macroinvertebrates: main bioindicators in aquatic environments

In the field of aquatic bioindication, several categories of bioindicators are used: benthic macroinvertebrates, zooplankton, phytoplankton, macrophytes, bacteria, fish and birds. The intrinsic characteristics of these animal and plant communities are used to assess the health of the ecosystems and to illustrate possible disturbances to their ecological integrity. Analysis of species diversity, composition, abundance and distribution reveals ecological imbalance within the ecosystem. Among these categories of bioindicators, macroinvertebrates have characteristics that make them the most widely used bioindicators for assessing and monitoring aquatic ecosystems health.

Characteristics of macroinvertebrates: Macroinvertebrates are organisms that are visible to the naked eye and are very heterogeneous, grouping together several phyla such as insects, molluscs, crustaceans and worms, which inhabit the bottom of rivers and lakes[41]. Their habitat is very diverse. They live in or near the bottom of streams and water bodies for most or part of their lives[42]. They are found under stones, in sand, gravel in litter, plant roots.

The main orders of aquatic insects belonging to this category of organisms are: Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera, Megaloptera, Hemiptera, Odonata and Lepidoptera[9].

Macroinvertebrates are an important link in the aquatic food chain. They are also the most important source of food for several species of amphibians, birds and fish. They also participate in the transfer of matter and energy to nearby terrestrial ecosystems[43]. Benthic organisms also influence nutrient cycles in aquatic ecosystems through feeding, excretion and burrowing in sediments[44]. Filter-feeding organisms consume fine suspended particles and make them accessible to other organisms via their feces[3]. Bioturbation, favoured by burrowing organisms, leads to mixing and oxygenation of sediments, which accelerates nutrient cycling[43,3]. Macroinvertebrates must therefore be present in sufficient quantity and diversity to maintain a balanced, functional and healthy river ecosystem[9].

Macroinvertebrates are widely used in bioindication because they are very abundant, diverse and colonise a wide variety of habitats. They are easy to sample and their collection has little impact on the biota in place. The size of these organisms is adequate for sampling and identification. They are mostly large enough to be observed directly at the sampling site. However, their size is not large enough to allow them to be collected, transported and preserved in large quantities with simple and light equipment[9].

Influencing factors: Macroinvertebrates are strongly affected by habitat modification, organic matter, and the quality and diversity of the river bottom[5]. The structure of benthic assemblages changes when their environment is disturbed, which allows a better characterisation of the spatio-temporal distribution of pollution. The high diversity of macroinvertebrates covers a wide range of responses to environmental factors. Thus, the response to disturbances varies among species. For example, Chironomidae and Oligochaetes tolerate very low oxygen concentrations in the water, whereas may fly larvae need well-oxygenated water to live[3]. Furthermore, the essentially sedentary lifestyle of sedentary macroinvertebrates provides a representative picture of their local habitat conditions[45]. Moreover, the generally long life span of these organisms gives them the status of integrators of the synergistic effects of various disturbances[46]. They integrate the cumulative and synergistic short-term effects (up to a few years) of multiple physical (habitat modifications), biological and chemical disturbances in the watercourse. Individuals at the most sensitive stages respond rapidly to disturbances, while the overall effects will be observable at the community level, over a long time scale.

Conclusion

Freshwater ecosystems provide many of the functions from which human populations benefit. As a result, they are among the most exploited ecosystems on the planet. The degradation of the ecological integrity of rivers is reinforced by the strong link that these systems have with their catchment areas. Effective management of the ecological integrity of these vulnerable ecosystems requires eco-monitoring based on the use of organisms that can reveal their health. These organisms are bioindicators of the health of aquatic ecosystems and can be used to detect early signs of potential environmental problems and to identify the causes and effects of environmental disturbances. Macroinvertebrates are the most widely used bioindicators because of their strong ability to characterise the state of an ecosystem under environmental stress, as well as to detect significant changes in the environment. The great diversity of macroinvertebrates covers a wide range of responses to environmental disturbances.

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