UNIVERSITY OF SWAZILAND

MAIN EXAMINATION PAPER 2018

TITLE OF PAPER : AQUATIC CONSERVATION

COURSE CODE : BIO618

TIME ALLOWED : THREE HOURS

INSTRUCTIONS :
1. ANSWER ANY TWO (2) QUESTIONS
2. EACH QUESTION CARRIES FIFTY (50) MARKS

SPECIAL REQUIREMENTS: NONE

THIS PAPER IS NOT TO BE OPENED UNTIL PERMISSION HAS BEEN GRANTED BY THE INVIGILATORS

QUESTION 1

Identify the major zones in a lotic system and how key variables, such a flow patterns, substrate and physicochemical properties influence these systems and associated biota.

[Total marks = 50]

QUESTION 2

Elucidate on the basis and advantages of biological monitoring. Using the article provided as background, discuss the three main taxa used in biological monitoring and explain why an integrated approach is more effective than a single index?

[Total marks = 50]

QUESTION 3

Freshwater ecosystems are under unprecedented pressure. Identify the major threats to freshwater systems and their biodiversity and deliberate on how these arise as well as mitigation measures for restoration and management of freshwater habitats.

[Total marks = 50]

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Biomonitoring and Bioindicators Used for River Ecosystems: Definitions, Approaches and Trends

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Abstract

In this paper, we present a review on concepts, current use and anticipated future directions of biomonitoring approaches and bioindicators used for river ecosystems. Periphyton, benthic macroinvertebrates and fish are the most common indicators in river biomonitoring, which can be used separately or contemporaneously. Their importances in the ecosystems and advantages for biomonitoring have been described in detail. Commonly used biomoniting approaches include diversity, biotic indices, multimetric approaches, multivariate approaches, functional feeding groups (FFGs) and multiple biological traits. Among these techniques, biotic indices and multimetric approaches are most frequently used to evaluate the environment health of streams and rivers. However, functional measures have been increasingly applied as a complementary approach to reflecting ecological integrity. Furthermore, recent researches have demonstrated the efficiency of molecular techniques on enhancing the taxonomic resolutions and detecting the genetic diversity in river biomonitoring.

Keywords: River Ecosystem; Biomonitoring; Bioindicators; Review

1. Introduction

1.1. Background

Since streams and rivers are among the most endangered ecosystems worldwide [1-3], there are urgent demands for comprehensive methodological approaches to evaluate the actual state of these ecosystems and to monitor their rate of changes [4]. Physical, chemical and bacteriological measurements commonly form the basis of monitoring,

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because they provide complete spectrum of information for proper water management [5]. However, in running waters, where changes in hydrology are rapid and difficult to estimate, they cannot reflect the integration of numerous environment factors and long-term sustainability of river ecosystems for their instantaneous nature. Biomonitoring has been proven to be necessary supplementary to those traditional monitoring techniques [6]. Aquatic organisms, such as diatoms [7-10] and benthic macroinvertebrates [4-5], can serve as bioindicators to integrate their total environment and their responses to complex sets of environmental conditions [11]. They offer the possibility to obtain an ecological overview of the current status of streams or rivers.

1.2. Conceptual Issues

Biomonitoring, or biological monitoring, is generally defined as "the systematic use of living organisms or their responses to determine the condition or changes of the environment" [12-14]. Indeed, measurements (endpoints) used for river ecosystems may be selected from any level of biological organization (suborganismal, organismal, population, community, and ecosystem). However, the historical focus has been on ecological methods and higher levels of organization, e.g. populations, communities, and ecosystems. Therefore, the term of biomonitoring used in this paper tends to follow Markert et al. [15]: "Biomonitoring is a method of observing the impact of external factors on ecosystems and their development over a period, or of ascertaining differences between one location and another." Compared to the former definition, the latter is considered to reflect the ecological content of biomonitoring better.

According to Markert et al. [15-17], a bioindicator is "an organism (or part of an organism or a community of organisms) that contains information on the quality of the environment (or a part of the environment)". An "ideal" indicator at least should have the characteristics as follows: (a) taxonomic soundness (easy to be recognized by nonspecialist); (b) wide or cosmopolitan distribution; (c) low mobility (local indication); (d) well-known ecological characteristics; (e) Numerical abundance; (f) suitability for laboratory experiments; (g) high sensitivity to environmental stressor (s); (h) high ability for quantification and standardization [4, 18-19].

2. Bioindicators Used for River Ecosystems

Bioindicators need to not only indicate the long-term interaction of several environmental conditions, but also react to a sudden change of the important factor(s). There are several alternations for indicators of biomonitoring in streams and rivers, however benthic macroinvertebrates, periphytons and fishes are the most frequently utilized. Their efficacy when used separately has been demonstrated by many studies, e.g., Whitton and Rott [20], Vis et al. [21], Prygiel et al. [22], and Coste et al. [23] for periphyton, Rosenberg and Resh [4], Lenat and Barbour [24], Statzner et al. [25], and Buffagni et al. [26] for benthic macroinvertebrates, Fausch et al. [27], Joy and Death [28], Oberdorff et al. [29], and Pont et al. [30] for fish. In other studies, nevertheless, two or more assemblages have been used contemporaneously for monitoring river ecosystems, such as in Soininen and Könönen [6], Scuri et al. [31], Carlisle et al. [32], Birk and Hering [33], and Torrisi et al. [34].

2.1. Periphyton

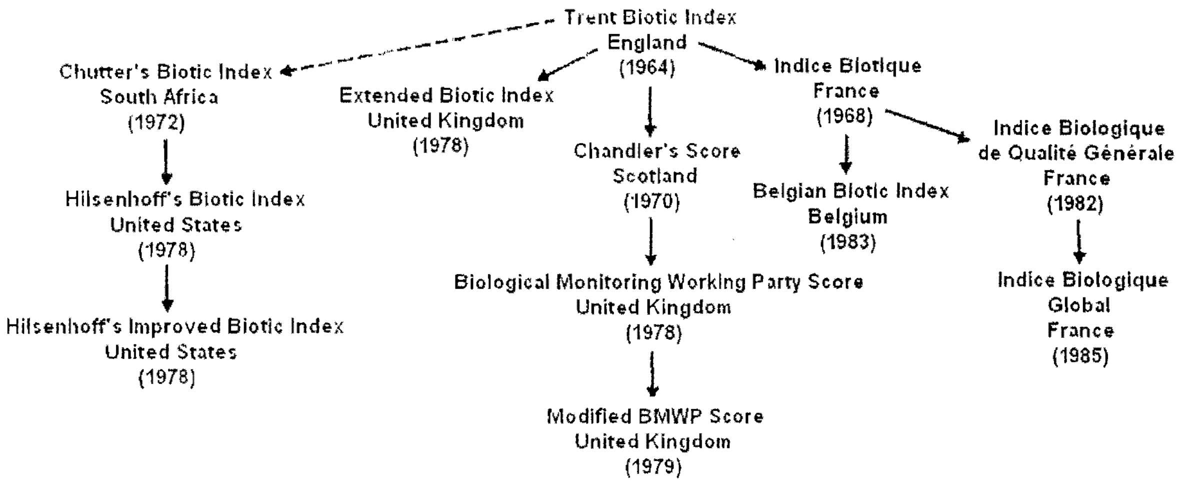
Periphytons are valuable indicators of environmental conditions in streams and rivers. As primary producers, periphytons act as important foundation of food webs in river ecosystems [9, 35-36]. Periphytons generally have rapid reproduction rates and very short life cycles and therefore can be expected to reflect short-term impacts and sudden changes in the environment [37-38]. Because the assemblages usually attach to substrate, their growing and prospering can respond directly and sensitively to many physical, chemical and biological variation occurring in the stream (or river) reach, including temperature, nutrient levels, current regimes and grazing etc.[37, 39-45].

Periphytons, especially diatoms, have been preferred for river biomonitoring purposes by many authors [20, 46-55]. Taxa richness and diversity [56-59], assemblage similarity [60-61], taxonomic composition [62], Chlorophyll a [63-65] and biomass [46] have all been reported as measures to indicate the environmental stress. Furthermore, many biotic indices based on species- specific sensitivities and tolerances have been developed to infer specific or general environmental conditions in streams and rivers. Most of them are indicators of organic pollution ([66], see review [67]). Several biotic indices also have been successfully applied in many studies to estimate the status of river ecosystems, mainly in central and northern European rivers [55, 68-70].

2.2. *Benthic Macroinvertebrate*

Many countries have a long history of using macroinvertebrates to monitor the ecological status of river ecosystems [71]. Benthic macroinvertebrates are key components of aquatic food webs that link organic matter and nutrient resources (e.g., leaf litter, algae and detritus) with higher trophic levels [72]. These organisms have mostly sedentary habits [73] and are therefore representative of site specific ecological conditions. With the sensitive life stage [74] and relatively long life span [75], they have the ability to integrate the effects of short-term environmental variations. Besides, these assemblages are made up of many species among which there is a wide range of trophic levels and pollution tolerances [73, 75-76], therefore providing strong information for interpreting cumulative effects. Community structure of the assemblages frequently changes in response to environmental disturbances in predictable ways, which is the basis for development of biocriteria to evaluate anthropogenic influences [77]. These responses have been summarized by Gray [78] into three categories, including reduction in diversity, retrogression to dominance by opportunistic (e.g. shorter life-cycle, faster reproducing) species and reduction in individual size of dominating species. For example, in streams and rivers polluted by organic matters [5, 79-80] or heavy metals [78, 81-86], species richness and diversity of the macroinvertebrate community strongly reduces for the direct and indirect impact of contaminants; and, Chironomidae commonly possesses the dominant status at the expense of other more sensitive groups, such as stoneflies (Ephemeroptera), caddisflies (Plecoptera) and mayflies (Trichoptera).

Studies on the potential use of benthic macroinvertebrates as bioindicators for river ecosystems have been widely reported in literatures [4, 87-94]. Benthic macroinvertebrates, especially aquatic insects, have been traditionally used in the biomonitoring of stream and river ecosystems for various environmental stress types, such as organic pollution [95-98], heavy metals [82, 86, 99], hydromorphological degradation [26, 100-101], nutrient enrichment [71, 102-106], acidification [107-110] and general stressors [38, 111-112]. Indeed, the assemblages constitute the basis of most biomonitoring program currently in Europe and North America. Many countries (or states or water authorities) even have developed their own biotic indices (e.g. Netherlands [113], France [114], Belgium [115], Denmark [116], U.K [117], Switzerland [118] and U.S.A. [119]; see Fig.1).



2.3. Fish

As highly visible and valuable components of the freshwater ecosystems, fish communities have been applied to monitor river ecosystem health for a long time [27, 120-121]. Fish are the top of the aqutic food web and are consumed by humans, which makes them important for assessing contamination [38]. Due to their relatively long life cycle and mobility, they can be good indicators of long-term (several years) effects and broad habitat conditions [38]. In addition, with wide range of trophic level, including the highest level occupied by top predators, community structure of fish assemblage is reflective of integrated aquatic environment health [122-125].

Fish communities respond significantly and predictably to almost all kinds of anthropogenic disturbances, including eutrophication, acidifition, chemical pollution, flow regulation, physical habitat alteration and fragmentation, human exploitation and introduced species [122-123, 126-130]. Their sensitivities to the health of surrounding aquatic environments form the basis for using fishes to monitor environmental degradation [27]. Over the last 30 years, a variety of fish-based biotic indices have been widely used to assess river quality, and the use of multimetric indices, inspired by the index of biotic integrity (IBI) [122-123], has grown rapidly [131].

3. Common Approaches Used for Biomonitoring of River Ecosystems

There are several different biomonitoring techniques currently employed in river ecosystems. The selection of an appropriate technique depends on the issues being addressed and available resources. Potential biomonitoring methods include diversity indices, biotic indices, multimetric approaches, multivariate approaches, functional feeding groups (FFGs) and multiple biological traits.

Bioaccumulation and toxicity of contaminants in indicator species also remain an important component of several river monitoring programs. However, they are not described here since our focus has been on the ecological approaches to measure ecosystem status. In addition, ***the saprobic systems*** have been once used (in Europe) primarily to indicate oxygen deficits caused by biologically decomposable, organic pollution in running waters, on the basis of Saprobic values of indicator species (mainly bacteria, algae, protozoans and rotifers, but also some macroinvertebrates and fish). However, by the mid-1970s, these indices have been rejected by most European countries for their limits [132-134].

3.1. Diversity Indices

As traditional biomonitoring approaches, many diversity indices have been developed to describe responses of a community to environment variation, combining the three components of community structure, namely *richness* (number of species present), *evenness* (uniformity in the distribution of individuals among the species) and *abundance* (total number of individuals present) (e.g., Shannon-Wiener Index [135], Simpson Index [136], Margalef Index [137]; see review [5]). The assumption is that undisturbanced environments are characterized by high diversity or richness, an even distribution of individuals among the species, and moderate to high counts of individuals. The best use of diversity-related indices in river and stream monitoring is probably as an indicator of changes in species composition when comparing impacted and reference assemblages [57]. Many criticisms have been made against the usefulness of diversity indices when employed separately in assessment of river systems [5], and now these indices are preferred to be used together with other metrics (see *3.3 Multimetric Approaches* below).

3.2. Biotic Indices

Biotic approach, as defined by Tolkamp [138], combines the relative abundance on the basis of certain taxonomic groups with their sensitivities or tolerances into a single index or score. The sensitivity and tolerance of indicator assemblages to a number of environmental characteristics, such as organic pollution, heavy metals, pesticides, eutrophication and pH, are known to differ among species. Therefore, these species-specific pollution indications can be used to infer environmental conditions in a habitat. Biotic indices of macroinvertebrate and periphyton are widely used in European countries. To take benthic macroinvertebrate for an example, numerous biotic index and score systems have been developed [5] (as illustrated in Fig.1). Commonly used biotic indices for macroinvertebrates include Trent Biotic Index (TBI) and Extended Biotic Index (EBI), Chandler's Score System, Biological Monitoring Working Party Score System (BMWP) and ASPT (Average Score per Taxon), Hilsenhoff's Biotic Index (HBI) etc. Among these indices, BMWP and its derivative, IBMWP, are recommended by the Water Framework Directive and widely used in the European Union.

3.3. Multimetric Approaches

Multimetric indices represent a means to integrate a set of variable or metrics, which represent various structural and functional attributes of an ecosystem (such as taxa richness, relative abundance, dominance, functional feeding groups, pollution tolerance, life history strategies, disease, and density), therefore provide robust and sensitive insights into the responses of an assemblage to natural and anthropogenic stressors [27, 112, 122, 139-140]. Since Karr [122] first introduced Index of Biotic Integrity (IBI) on the basis of fish assemblages, similar indices have been developed for benthic macroinvertebrates [141-143], fish [144-146], periphyton [50, 147]. By now, multimetric approaches for benthic macroinvertebrates have been the most widely used approach for river biomonitoring in USA [140] and recently used in other parts of the world as well [148-150].

3.4. Multivariate Approaches

Multivariate approaches have been initially introduced to assess the biological status of rivers within the UK, with the development of RIVPACS (River Invertebrate Prediction and Classification System) [151]. Multivariate approaches adopt statistical analyses to predict site-specific fauna patterns, which are expected in the absence of major environmental stress; and, the biological evaluations are then performed by comparing the observed fauna at the site with the expected fauna [152-153]. Multivariate approaches have been proven to be effective for biomonitoring. Several predictive models using multivariate techniques are widely used, such as RIVPACS and it derivative, AusRivAS (Australian Rivers Assessment System) [154], BEAST (Benthic Assessment Sediment) [155-156], or the recent ANNA (Assessment by Nearest Neighbor Analysis) [157]. In recent studies, except for macroinvertebrate, multivariate approaches have been developed for periphytons and fishes (e.g., Joy and Death [28]).

3.5. Functional Approaches

It is generally recognized that adequate characterization of ecosystems requires information on both structure (pattern) and function (process) [158]. Thus, although assemblage structure and composition has been successfully used in studies of impairment, there has been a recent renaissance in the use of function analyses as a complementary approach to reflecting ecological integrity.

3.5.1 Functional Feeding Groups (FFGs)

Analyses of Functional feeding groups (FFGs) are the key components of river continuum concept (RCC) [159] and have been applied to assess ecosystem-level processes in rivers and wetlands [160-162]. In river biomonitoring, FFGs measures have been used in the forms of single feeding groups (as absolute or relative abundance), ratios between two groups, or composite index that includes several trophic aspects [e.g., the Index of Trophic Completeness (ITC) [163]. In recent years, these measures have been combination with other metrics and applied in biomonitoring approaches (see *3.3 Multimetric Approaches* above, e.g. "Benthic Index of Biotic Integrity" [141], "Florida Stream Condition Index" [142]). These evaluation have been performed on the basis of easily observed morphological and behavioral attributes, which are associated with feeding and modes of attachment, concealment, and locomotion, together with life-history patterns (voltinism) and drift propensity [164].

3.5.2 Multiple Biological Traits

Biological traits are related to habitat characteristics and the biological and ecological functions of species, thus permit a view into the function structure of bioconosis [165]. Multiple biological traits of aquatic and terrestrial organisms (e.g., size, body form, life cycle, food and feeding habits, reproductive and other traits) in the context of environmental constraints [25] have been recently developed for freshwater biomonitoring. The utilization of multiple traits generally has been combined with *Multivariate Approaches* (see *3.4* above). Currently, multiple biological traits are mainly used for aquatic invertebrates in the running waters of Europe, and relevant researches proposed a multitude of traits that are weighted by the abundance or occurrence of the taxa [165]. Similar attempts also have been performed on fish assemblages [166]. Several applications of trait based methods (e.g., in relation to river pollution [167-168], anthropogenic influences in general [111, 16?] or ecological assessment theories [25]) demonstrate the potentialities of investigating trait structures.

4. Trends in Biomonitoring of River Ecosystems

4.1. Increasing Application of Functional Measures

By now, diverse biomonitoring techniques have already been developed to quantify the human impact on the environment of streams and rivers. However, because of the new trends in environmental policies, ecologists are currently facing new demands of effective tools to correlate the current status of ecosystems and the management for conservation and restoration [169-171]. Therefore, there are increasing applications of functional measures in river biomonitoring, including microbial enzyme activity [50, 61], bacterial luminescence [172], photosynthesis [173], respiration [174-175], locomotory activity [176], fluctuating asymmetry [177], community metabolism (primary productivity and respiration) [173], nutrient uptake and spiraling [178], and secondary production [179-181], except for FFGs and multiple biological traits mentioned above.

4.2. Molecular Techniques

In recent years, some efforts have been attempted to apply molecular techniques as biomonitoring tools. Molecular approaches used in biomonitoring mainly focus on the species identification and genetic diversity.

It is no doubt that finer taxonomic resolutions are ideal to obtain the most complete analysis of ecosystem health. Unfortunately, the acquisition of genus or species-level information for macroinvertebrates and periphytons is time consuming; and even with high levels of taxonomic skill, misidentifications of species may still result. However, genera or species can be rapidly identified at any life stage by molecular markers. Recent researches demonstrate the accuracy and effectiveness of DNA-based methods as biomonitoring tools, such as PCR-RFLP, T-RFLP and COI sequence, which have been used for Chironomids and periphytons in aquatic systems [182-184].

Genetic diversity is fundamentally a trait of biological populations, and significant changes in genetic diversity reflect important population-level changes. Since data of genetic diversity offer powerful tools for examining the current status of populations, inferring the history of population changes, and anticipating future population directions, molecular approaches provide a logical extension of previously described approaches to measure the variation of environmental status. Such attempts to relate the variability of molecular genetic markers to specific aquatic stressors date back more than 30 years. These studies include both field surveys and controlled laboratory experiments of fish populations, and have evaluated the effects of metals, acidity, pesticides, radionuclides, and complex effluents (see review [185]). Moreover, USEPA has carried out a series of researches to assess the utility of incorporating a genetic diversity indicator into large-scale assessment and monitoring efforts [186]. Although the application of molecular genetic diversity in river monitoring are still in their infancy, there are a number of compelling reasons to believe that molecular genetic measures will ultimately provide highly useful bioindicators.

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