Hydrobiologia (2006) 566:109–113
M.T. Furse, D. Hering, K. Brabec, A. Buffagni, L. Sandin & P.F.M. Verdonschot (eds), The Ecological Status of European Rivers: Evaluation and Intercalibration of Assessment Methods
DOI 10.1007/s10750-006-0098-z

Linking organism groups – major results and conclusions from the STAR project

Daniel Hering[1,]*, Richard K. Johnson[2] & Andrea Buffagni[3]
[1]*Department of Hydrobiology, University of Duisburg-Essen, D-45117 Essen, Germany*
[2]*Department of Environmental Assessment, Swedish University of Agricultural Sciences, 7050, SE-750 07 Uppsala, Sweden*
[3]*CNR – IRSA, Water Research Institute, Via della Mornera, 25, 20047, Brugherio (MI), Italy*
*(*Author for correspondence: E-mail: daniel.hering@uni-essen.de)*

Key words: fish, benthic invertebrates, macrophytes, diatoms, assessment, rivers, Europe

Abstract

Here we summarize results of the EU funded research project STAR concerning the suitability of different organism groups (fish, benthic invertebrates, macrophytes, diatoms) for monitoring European rivers. In a general way, the suitability of the organism groups is classified by monitoring type, stress type, river type, temporal scale and taxonomic resolution. For example, although all organism groups are affected by acidification, the relatively low species richness of fish and macrophytes in small mountain streams makes these two groups less suitable, and, hence, we argue that benthic diatoms and/or invertebrates may be considered as more robust indicators. Similar, lines of reasoning are given for a number of stressor and stream types.

Introduction

Biological response variables are often selected over physical–chemical variables because they represent valued ecosystem attributes such as diversity or productivity. The use of complementary indicators, as stipulated by the European Water Framework Directive, is based on the premise that using multiple organism groups/assemblages can help to distinguish the effects of human-induced stress more efficiently (with less uncertainty) and more effectively (by detecting the effects of multiple stressors). A number of factors lend support to this conjecture. For example, different organism groups (or assemblages) supposedly respond differently to stress depending on inherent life history attributes: 1. *Physiological* constraints; e.g., (i) Complex, multicellular, organisms such as fish may be better indicators of changes in ambient temperature than single-celled organisms like algae. (ii) Organisms with short generation times, from weeks to months (e.g., algae and invertebrates), may respond more rapidly to environmental changes than organisms with relatively long generation times, from months to years (e.g., fish and macrophytes). 2. *Behavioural* constraints; e.g., (i) Organisms that are acquire nutrients directly from their surroundings (e.g., algae) may be better indicators of nutrient enrichment, in systems where nutrients are a limiting, than organisms (e.g., fish) that acquire their nutrients 'indirectly' (e.g., through a benthic pathway such as nutrients – diatoms – invertebrates – fish). (ii) Relatively large and mobile organisms that use a wide range of habitats [e.g., fish habitats range from small ($<m^2$) to large ($>km^2$)], may be more influenced by factors acting on large spatial scales (e.g., reach and catchment-level variables), than relatively small and sessile organisms (e.g., benthic algae or invertebrates) that are probably more influenced by their immediate surroundings or microhabitat quality. Hence, in theory differences among organism groups can be used to select complementary indicators.

To tests these conjectures, comparative investigations on the response of different organism groups to stress are needed, which have, for example, been performed in the EU funded project STAR and are described in detail by Johnson et al. (2006a, b), Springe et al. (2006) and in addition by Hering et al. (in press) and Johnson et al. (in press). With this paper, we try to transform these results into a more general guidance, with focus on which organism group/groups can be used in biomonitoring.

Parameters for indicator selection

In designing biomonitoring programs, consideration should be given to the river type being addressed, the type of stress(ors) potentially affecting the integrity of the river ecosystem, and the time frame of the study, including knowledge of interannual variability and potential lag-phase responses of degradation and recovery (e.g., Stevenson et al., 2004). By combining conceptual models (expert opinion) and empirical data, more cost-effective monitoring programs, incorporating knowledge of how different organism groups react to different human-generated stressors, can be designed (e.g., USEPA, 2000). For example, since the response of the four organism groups addressed by the Water Framework Directive for river monitoring (fish, benthic invertebrates, benthic diatoms and macrophytes) are often correlated, Hering et al. (in press) and Johnson et al. (in press) argue that it is not necessary to monitor all groups simultaneously.

Based on the STAR results we suggest which organism group(s) is/are most suited for monitoring different types of human-induced stress (Table 1). This is a general guidance and the response of specific metrics should always be taken into consideration.

Type of monitoring

For monitoring European rivers formal criteria for indicator selection are set by the Water Framework Directive. *Surveillance monitoring for the Water Framework Directive* requires the use of all organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes). However, all four organism groups are not necessarily required for covering different types of stressors and different scales; thus, *surveillance monitoring for purposes other than the Water Framework Directive* should mainly ensure that all relevant stressors potentially affecting the monitored rivers and the relevant spatial and temporal scales are covered. This can either be achieved by monitoring benthic invertebrates, which respond to many stressors, or by the combination of diatoms (mainly reacting on eutrophication and land use pressures) and fish (mainly responding to large scale hydromorphological degradation) (Hering et al., in press; Johnson et al., in press). For *operational monitoring* indicators for assessing the main stressor affecting the integrity of the river being monitored should be selected (see below). For *assessing the success of restoration measures*, an indicator group mainly addressing the stress type which effect is restored should be selected. Early warning indicators should be used with caution, since their signal may be subject to high natural variability.

River type

In *small mountain streams in Central and Northern Europe* benthic diatoms and invertebrates are the most diverse organism groups and, consequently, most suited for monitoring. Fish assemblages are usually species-poor and, with the exception of down-stream weir effects, this organism group is not recommended for monitoring many stressors. Further, macrophytes are often patchily distributed and, thus, less suited for monitoring purposes. In *medium-sized mountain streams in Central and Northern Europe*, in *small and medium-sized lowland streams in Central and Northern Europe* and in *large rivers in Central and Northern Europe* all organism groups are, in principal, suited for monitoring. The selection of indicator(s) depends on the stressor-type being assessed and the monitoring type. Due to poor taxonomical knowledge, benthic invertebrates are less suited for monitoring the effects of hydromorphological degradation in southern European rivers. For the effects of land use, eutrophication and other anthropogenic effects all organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes) can be used.

Table 1. Recommended (combination of) indicator(s) for biomonitoring of European rivers

Monitoring type	River types	Diatoms	Macrophytes	Invertebrates	Fish	Comments
Surveillance monitoring WFD	All	+	+	+	+	
Surveillance monitoring other purposes	All			+		cost-effective option
Surveillance monitoring other purposes	All, except small mountain streams	+			+	
Surveillance monitoring other purposes	Small mountain streams	+		+		
Operational monitoring, eutrophication/pollution	Small mountain streams	+				cost-effective option if no other stressors are present
Operational monitoring, eutrophication/pollution	All, except small mountain streams	+	+	+	+	
Operational monitoring, hydromorphological degradation	Small mountain streams			+		
Operational monitoring, hydromorphological degradation	All, except small mountain streams		+	+	+	
Operational monitoring, catchment land use effects	Small mountain streams	+		+		
Operational monitoring, catchment land use effects	All, except small mountain streams	+		+	+	
Operational monitoring, acidification	Small mountain streams	+		+		
Operational monitoring, different stressors	Small mountain streams	+		+		
Operational monitoring, different stressors	Medium-sized mountain streams, lowland streams	+			+	
Operational monitoring, different stressors	Medium-sized mountain streams, lowland streams		+		+	
Operational monitoring, different stressors	Medium-sized mountain streams, lowland streams	+		+		

Type of anthropogenic stress

Although the effects of *eutrophication* (nutrient enrichment) and *organic pollution* (e.g., increased BOD) are of different origin, they are often correlated and, thus, similar indicators can be used in most cases to detect both types of stressors. All organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes) respond to eutrophication/organic pollution and are thus, in principal, suited as indicators (Hering et al., submitted; Johnson et al., manuscript). However, the rates and trajectories of change may vary among the organism groups. For example, benthic diatoms often show a stronger response (high sensitivity) compared to the other three organism groups (Johnson et al., 2006a). Hence, benthic diatoms may be best suited for situations in which only pollution/eutrophication is assessed. If multiple stressors are being assessed then benthic invertebrates and/or macrophytes should be considered, which also respond to other stress types (Hering et al., submitted; Johnson et al., 2006a). If the focus of the study is on nutrient enrichment, benthic diatoms and/or macrophytes should be considered, since nutrient enrichment may be the main factor directly affecting both groups. If the focus of the study is on organic pollution, benthic invertebrates and/or fish should be considered, since these groups are more directly affected by oxygen condition (Figure 1).

Fish, benthic invertebrates and macrophytes respond to a varying degree to *hydromorphological degradation* (Hering et al., submitted; Johnson et al., manuscript; Johnson et al., 2006a). The selection of the most appropriate organism group for monitoring this stressor is dependent on stream type: In lowland streams and in medium-sized to large rivers all three groups can be considered. The relatively species-poor fish and macrophyte assemblages in small streams may limit the use of these two organism groups, and hence benthic invertebrates should be considered for monitoring the effects of hydromorphological degradation on the reach scale. For hydromorphological effects on smaller spatial scales (microhabitat scales) benthic invertebrates should be considered.

Land-use affects river communities by altering, for example, nutrient levels (eutrophication), habitat quality (sedimentation) and toxicity (e.g., pesticides). These effects are most strongly reflected by fish, benthic invertebrates and benthic diatoms (Hering et al., submitted). This contradicts to some degree with the results of Springe et al. (2006), who found macrophytes and fish being more suitable for assessing ecological quality at the river basin scale, whereas metrics of macroinvertebrates and benthic diatoms were more appropriate at smaller scales.

All organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes) are affected by *acidification* (Stokes et al., 1989; Brodin, 1995).

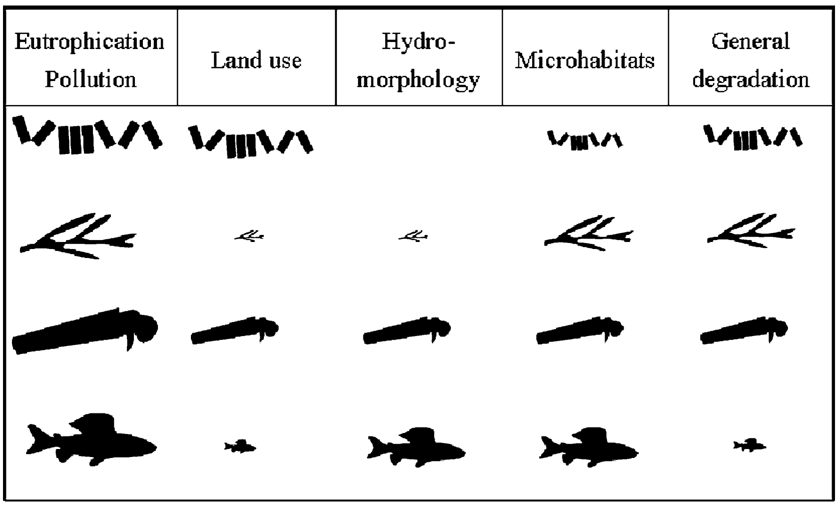

Figure 1. Response of diatoms (first line), macrophytes (second line), benthic invertebrates (third line) and fish (fourth line) to different stress types. The size of the symbols reflects the strength of the response (based on unpublished data and Johnson et al. (manuscript)).

The most profound effects are found, however, in small mountain streams with low buffering capacity. The relatively species-poor fish and macrophyte assemblages in small streams may limit the use of these two organism groups, and hence benthic diatoms and/or benthic invertebrates should be considered for monitoring the effects of acidification stress.

In cases of *different stressors* affecting a river or of *unknown stress type(s)* no general guidance is possible. If only one organism group can be investigated, then benthic invertebrates should be considered since they respond to most stressor types in all river types. If multiple organism groups can be monitored, the following alternatives may be useful: (1) benthic diatoms (for eutrophication and acidification effects) and benthic invertebrates (for various stressors) in small mountain streams; (2) benthic diatoms or macrophytes (for eutrophication and land use effects) and benthic invertebrates or fish (for hydromorphological and land use effects) in medium-sized mountain streams and lowland streams.

Temporal scale

Diatoms, with relatively short generation times, are often considered as early warning indicators, detecting short-term pollution events. Fish, with their relatively long generation times, might be considered for monitoring long-term changes (late-warning indicators). Benthic invertebrates, a taxonomically diverse organism group, have generation times ranging from weeks to years and hence may be considered as both early- and late-warning indicators. In contrast to these considerations, Johnson et al. (2006b) found macrophytes and fish to be superior to diatoms as early warning indicators in European mountain streams.

Taxonomic resolution

At present, most fish-, diatom-, and macrophyte-metrics commonly used in biomonitoring require species-level data. Similarly, for assessing the effects of hydromorphological degradation and land use using benthic invertebrates most metrics require species-level taxonomic resolution. If only family-data are available, invertebrates can only be used for assessing the effects of general degradation.

Acknowledgements

STAR was funded by the European Commission, 5th Framework Program, Energy, Environment and Sustainable Development, Key Action Water, Contract no. EVK1-CT-2001-00089.

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