Standardisation of river classifications:

Framework method for calibrating different biological survey results against ecological quality classifications to be developed for the Water Framework Directive

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Strategy paper for the suitability of the individual organism groups

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Water Quality –
Guidance standard on the use of multiple organism groups in bioassessment

Content

Foreword

This document has been produced by members of the STAR consortium, an EU funded research project aiming amongst others at transferring scientific results in freshwater assessment into CEN standardisation. It describes a general framework for selecting and using multiple organism groups or metrics in freshwater assessment.

1 Introduction

1.1 Scope

The guidance document outlines the theory behind the use of multiple organism groups (or metrics) in bioassessment to more effectively detect ecological change if/when change occurs. The approach is applicable for all types of variables normally used in ecological assessment (i.e. both biotic and abiotic), however focus here is on bioassessment and hence biological quality elements (e.g. fish, invertebrates and aquatic flora) are discussed.

1.2 General introduction

The European Parliament has mandated that all Member states improve the ecological status of their surface and coastal waters by 2015 (European Commission 2000), and to reach this ambitious environmental goal the Directive is innovative in that it requires member states to use a suite of biological and chemical variables to assess ecological status. The use of multiple groups or assemblages to detect human-induced change in ecosystem integrity can be traced back to the development and use of the Saprobien system in the early 1900s to assess the effects of organic pollution on stream systems (e.g. Kolkwitz and. Marsson 1902). Although the idea of using multiple organism groups is not new, few studies have simultaneously evaluated the discriminatory power of different organism groups/metrics to detect ecological change. This is a bit distressing since the use of multiple organism groups, as stipulated by Water Framework Directive, is not without cost, e.g. the selection of highly redundant taxa would drain on resources unnecessarily. On the other hand, there is a widely accepted view in bioassessment that single taxonomic groups might indicate changes in other biotic ecosystem components. If this conjecture is not correct then selection of the “wrong” indicator groups/metric may result in degradation occurring but not being detected (i.e. false negative error).

A principal challenge confronting applied ecologists and environmental managers is the ability to isolate human-induced effects on ecosystem integrity from the natural, inherent variability associated with ecosystem structure and function. Trying to isolate an environmental impact or signal (change in a response variable) from background noise (natural variability) often requires an understanding of how the selected response variable(s) vary naturally in space and time. For example, a number of empirical studies have shown that species generally occur in a limited range of habitats within their geographic range and tend to be most abundant around their particular environmental optimum (e.g. ter Braak 1988) (Fig. 1), and building on this well-established axiom a number of biotic metrics, in particular using benthic invertebrates, have been constructed to evaluate the structural and functional integrity of surface waters (e.g. Metcalfe 1989, Johnson 1995). Ideally, we aim to use complementary organism groups/metrics that increase statistical power or the detection of change with low false negative error. This guidance document hopes to add clarity in the selection and use of multiple organism groups/metrics in assessing ecological change. Determining what group or groups of indicators are best suited for assessing the ecological effects of a known stressor requires knowledge of a number of indicator-inherent properties. Here we evaluate the discriminatory power of four organism assemblages (namely, fish, benthic invertebrates, macrophytes and benthic diatoms) to detect change by comparing their precision (variability associated with a predicted response) and sensitivity (magnitude of effect) along a number of putative stress gradients.

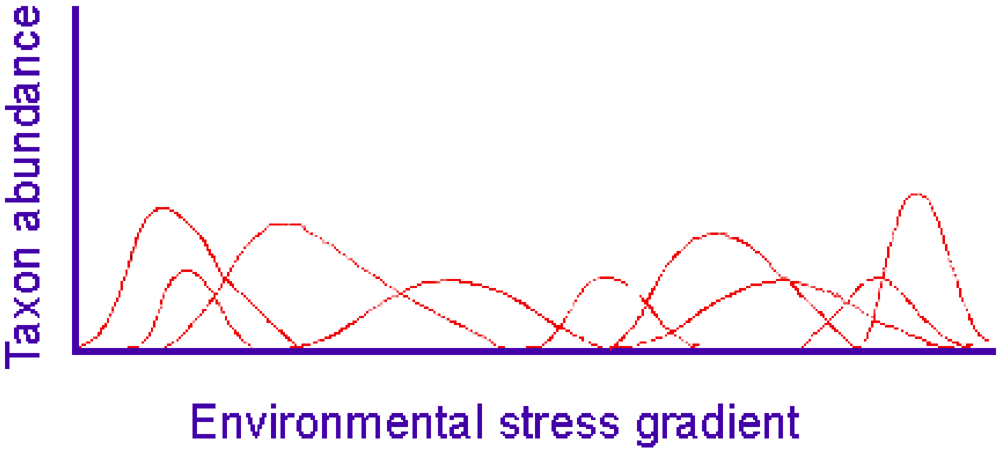

Figure 1. Schematic diagram showing hypothetical species response (taxon abundance) to stress.

2 Terms and definitions

Aquatic macrophytes – submerged and emergent aquatic plants both rooted as well as non-rooted

Benthic invertebrates – invertebrate animals living in or on sediments or other substratum (macroinvertebrates are usually defined as those retained with a 0.5 mm mesh)

Benthic diatoms – diatom algae living in or on sediments or other substratum

Complementary indicators – the combined use of two or more different organism groups/assemblages to detect ecological change

Fish – a cold-blooded aquatic vertebrate typically with gills

Metric – a measurable characteristic of the biota (e.g. diversity)

Organism assemblage – an association of interacting populations with a habitat (e.g. river)

Organism group – Organism group = Biological quality elements as defined by the WFD (i.e. fish, benthic invertebrates, benthic diatoms, macrophytes)

Precision – the error associated with a stress – response relationship (e.g. coefficient of variation, root mean square error)

Sensitivity – the effect size or magnitude of response (e.g. slope) of a stress – response relationship

3 Principle

3.1 The conceptual model

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 the use of 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, differences among organism groups/assemblages can be used to select complementary indicators resulting in more cost-effective assessments of ecological change.

3.2 Hypothetical models

Figure 2 shows examples of three hypothetical stressor - response relationships to illustrate how an understanding of organism response (measured as sensitivity and precision) can be used to select robust, complementary indicators. *Sensitivity* can be regarded as the magnitude of effect or change (e.g. regression slope) and *precision* as the error (e.g. the coefficient of variation or root mean square error of a predicted response) associated with a predicted stress – response relationship. In figure 2a, both indicators have a similar error associated with the predicted response, but indicator 1 is more strongly correlated (higher slope) with the stress gradient. In the second example (Fig. 2b), the slope of the predicted response is similar between the two indicators, but the error associated with the predicted response differs; with indicator 2 having higher residual variability than indicator 1. In these two examples indicator 1 would be the best choice of the two to assess the effects of this stress. In the third example, indicator 1 shows a linear response to the stress gradient and indicator two shows a non-linear response, with an apparent threshold effect. This latter example, exemplifies the concept of early- versus late-warning indicators (i.e. indicator 2 responds more than indicator 1 to environmental changes).

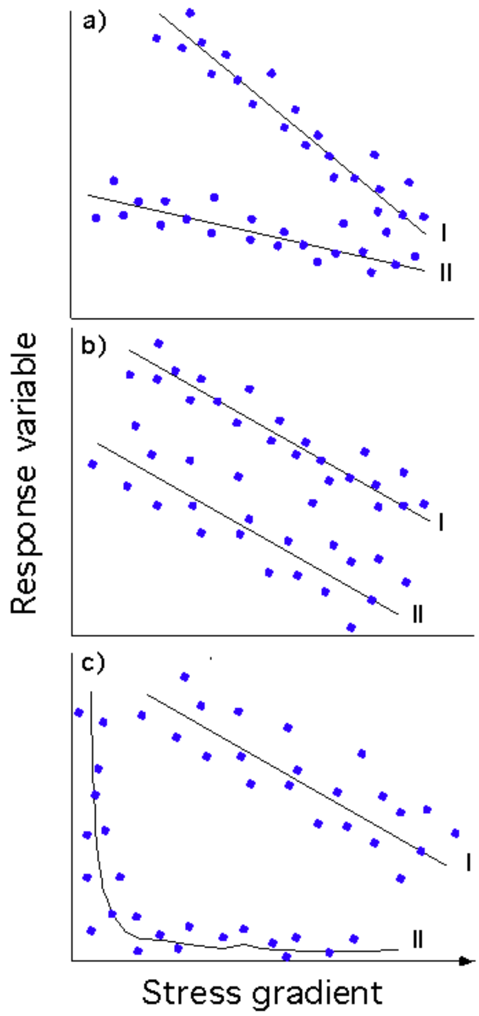

Figure 2. Schematic diagram showing hypothetical species-response to stress.

3.3 Selection of indicators

The ideal indicator should be stress-specific with high sensitivity and precision (e.g. indicator 1 in figs. 2a,b). Knowledge of the expected response of different organism groups to both human-induced and natural variability can be used to select complementary indicators that more effectively detect change if/when it occurs. Indicators may respond to the same stressor but their rates and trajectories of change may differ and this information can be used to select complementary metrics. In selecting complementary indicators/metrics focus should be, as described above, on evaluating the sensitivity and precision of candidate response indicators to the stressor(s) of interest. Here consideration should be given to the:

(i) *type of response* to stress, e.g. indicators may respond to a single stressor (i.e. stress-specific indicator) or a wide range of stressors (multiple-stress indicator);
(ii) *timing of response* to stress, e.g. indicators may respond more or less rapidly (early- versus late-warning) to stress. Early-warning indicators may, however, also respond rapidly to natural environmental changes resulting in high frequency of false positive error.
(iii) *spatial scale* “monitored” by the indicator (e.g. habitat size).

4 Procedure

4.1 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 combing 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 in this standard (fish, benthic invertebrates, benthic diatoms and macrophytes) are often correlated (i.e. redundant) it is not necessary to monitor all groups simultaneously.

4.2 Type of monitoring

- ***Surveillance monitoring for the Water Framework Directive***
  All organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes) need to be monitored.
- ***Surveillance monitoring for other purposes***
  The selection of indicators should ensure that all relevant stressors potentially affecting the monitored rivers and the relevant spatial and temporal scales are covered. Options:
  - Benthic invertebrates, which respond to many stressors
  - Diatoms (early warning indicators, mainly reacting on eutrophication and land use pressures) and fish (late warning indicators, mainly reacting on large scale hydromorphological degradation)
- ***Operational monitoring***
  Indicators for assessing the main stressor affecting the integrity of the river being monitored should be selected (see below).
- ***Surveying 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.

4.3 River type group

- ***Small mountain streams in Central and Northern Europe***
  Benthic diatoms and invertebrates are the most diverse organism groups and, thus, 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.
- ***Medium-sized mountain streams in Central and Northern Europe***
  All organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes) are, in principal, suited for monitoring medium-sized mountain streams. The selection of indicator(s) depends on the stressor-type being assessed and the monitoring type.
- ***Small and medium-sized lowland streams in Central and Northern Europe***

All organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes) are, in principal, suited for monitoring lowland streams. The selection of indicator(s) depends on the stressor-type being assessed and the monitoring type.

- ***Large rivers in Central and Northern Europe***
  All organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes) are, in principal, suited for monitoring large rivers. Although not considered here, phytoplankton is an additional option for monitoring the effects of nutrient enrichment. The selection of indicator(s) depends on the stressor-type being assessed and the monitoring type.
- ***Southern European rivers***
  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) are, in principal, suited for monitoring southern European rivers.

4.4 Types of anthropogenic stress

- ***Eutrophication and organic pollution***
  Although the effects of eutrophication (nutrient enrichment) and organic pollution (e.g. increased BOD) are of different origin, they are 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. However, the rates and trajectories of change may vary among the organism groups. For example, benthic diatoms often show a stronger response (high sensitivity) and low error (high precision) compared to the other three organism groups. 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. 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.
- ***Hydromorphological degradation (reach scale and microhabitat scale)***
  With the exception of diatoms all organism groups (fish, benthic invertebrates, macrophytes) respond to hydromorphological degradation. The selection of the most appropriate organism group is also 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 (catchment scale)***
  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.
- ***Acidification***
  All organism groups (fish, benthic invertebrates, benthic diatoms, macrophytes) are affected by acidification. 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.

- ***Different stressors or unknown stress type(s)***
  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 are useful:
  - Benthic diatoms (for eutrophication and acidification effects) and benthic invertebrates (for various stressors) in small mountain streams.
  - 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.

4.5 Temporal scale

Individual organism groups/assemblages may respond differently to stress depending on differences in generation times. For example, benthic diatoms may respond more rapidly than macrophytes to changes in nutrient enrichment (e.g. Fig 2c). However, the “early response” (or signal) of diatoms to nutrient enrichment may be confounded by naturally high seasonal variability (i.e. high frequency of false positive error). Macrophytes, although responding less rapidly to nutrient enrichment than diatoms, may exhibit lower natural variability resulting in lower uncertainty (i.e. low frequency of false negative error). Moreover, macrophytes might be responding to both nutrient enrichment and changes in substratum (sedimentation). Hence, these two indicators might be selected as complementary indicators regarding the timing (early vs late-warning) and type (e.g. single vs multiple stressor) of response. Although, in this example the two indicators were both primary producers it should be kept in mind that it is the concept that is important and not the idea of combining similar organisms (here primary producers) as complementary indicators. Diatoms, with relatively short generation times, might be suited as early warning indicators, detecting short-term pollution events. Fish, with their relatively long generation times, might be consider 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.

4.6 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.

4.7 Recommended indicator combinations

monitoring type	river type group	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	+		+		

White cells: all organism groups indicated are recommended as complementary indicators
Grey cells: one or more of the indicated organism groups is recommended

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