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FISH COMMUNITIES AS INDICATORS OF BIOLOGICAL CONDITIONS OF RIVERS: METHODS FOR REFERENCE CONDITIONS

Carlos Alonso, Diego García de Jalón and Miguel Marchamalo

Universidad Politécnica de Madrid

Abstract

Fish communities are a key element in fluvial ecosystems Their position in the top of the food chain and their sensitivity to a whole range of impacts make them a clear objective for ecosystem conservation and a sound indicator of biological integrity. The UE Water Framework Directive includes fish community composition, abundance and structure as relevant elements for the evaluation os biological condition. Several approaches have been proposed for the evaluation of the condition of fish communities, from the bio-indicator concept to the IBI (Index of biotic integrity) proposals. However, the complexity of fish communities and their ecological responses make this evaluation difficult, and we must avoid both oversimplified and extreme analytical procedures.

In this work we present a new proposal to define reference conditions in fish communities, discussing them from an ecological viewpoint. This method is a synthetic approach called SYNTHETIC OPEN METHODOLOGICAL FRAMEWORK (SOMF) that has been applied to the rivers of Navarra.

As a result, it is recommended the integration of all the available information from spatial, modelling, historical and expert sources, providing the better approach to fish reference conditions, keeping the highest level of information and meeting the legal requirements of the WFD.

Keywords: fish, WFD, biological integrity, reference conditions, Spain

1. INTRODUCTION

Fish communities are a sensitive part of fluvial ecosystems, since they are located in the upper part of the trophic chain and require different habitats and, sometimes, large connected areas for the completion of their life cycle. Thus they also integrate adverse effects of complex and varied stresses on other components of the aquatic ecosystem. Furthermore, they are relatively long-lived so they can reflect disturbances happened in a longer period than other taxa can. These mentioned characteristics and their major societal visibility make fish a useful element or river ecosystem to measure environmental degradation (Fausch et al. 1990).

The WFD includes composition, abundance and age structure of fish fauna as quality elements to be evaluated in rivers and lakes. This evaluation requires an effort in monitoring, as age structure requires dating individuals and sampling reaches must be large enough to include potential habitat and reflect the local and large migrations through fluvial systems.

The WFD promotes the original, pristine communities prior to human disturbance as a template in order to evaluate the ecological status of rivers and lakes. Thus, their biological assessment has to be emphasized on knowing whether all the elements that should be in the river are in fact there, and how much the present community differs from the original one or the one defined as the reference. In this context, ecological status should be assessed by means of the measurement of the deviation of actual conditions from reference conditions.

Reference conditions are usually defined as the ones corresponding to a high ecological status of the fluvial system (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy). A water body is in high ecological status when there are no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions. The values of the biological quality elements for the surface water body reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion. Nevertheless, in a widely used sense they can be considered "reference conditions for biological integrity'' or RC(BI) (Stoddard et al. 2006), and set the reference for the preservation or restoration of the ecological condition to a natural objective (U.S. Clean Water Act, E.U. Water Framework Directive , Water Reform Framework in Australia). Moreover, biological reference conditions are, to some extent, the expression of the integrity of ecological processes on the elements of the ecosystem, so we should talk about reference processes to use a more meaningful term. Nevertheless, as elements can be at the same time, affected by, and drivers of processes, the structure of an ecosystem can be considered as a valuable indicator of its processes.

Reference conditions are "type-specific" and must be set for each water body type in a given classification system. Type-specific biological, hydromorphological and physicochemical conditions shall be established representing the values of the biological, hydromorphological and physicochemical quality elements for that surface water body type at high ecological status as defined in each regulation (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy). Anyway, reference conditions may vary in different approaches, depending on the objective or purpose of the biological integrity assessment, from best remaining ecological conditions to best past conditions, for example. But, as they should strictly reflect the integrity of ecological processes, reference conditions shall be those that can be attained in the presence of the actual natural stressors.

In this work we present the main approaches to fix reference conditions for each Navarra's river types using fish community's traits, discussing them. This method is a synthetic approach called SYNTHETIC OPEN METHODOLOGICAL FRAMEWORK (SOMF) that has been applied to the rivers of Navarra.

After the assessment of these approaches from an ecological viewpoint, it is recommended the integration of all the available information from spatial, modelling, historical and expert sources, providing the better approach to fish reference conditions, keeping the highest level of information and meeting the legal requirements of the WFD. These ideas are the basis for the establishing the new synthetical approach for identifying fish reference conditions: Open Methodological Framework.

2. ASSESSING FISH FAUNA STATUS

Biological dimension of fluvial ecosystems integrates all its biological components from microorganisms (bacteria, fungi, microalgae, protozoa, rotifer, cladocer, copepodae,) to macroorganisms: invertebrates, macrophytes, fish, amphibians, molluscs, birds, riparian vegetation... Several biological assessment indexes have been proposed for specific elements, following three main approaches: a) bioindicator-based indexes; b) Indexes of Biotic Integrity (IBI) and Similarity Indexes (CHE 2005). Fausch et al. (1990) adds species richness, diversity, and evenness as other main approach to evaluate fish communities as indicators of environmental degradation, and includes similarity indexes as a type of multivariate methods.

2.1. Bioindicator approach

Bioindicator based indexes are based on taxa whose ecological requirements and responses to alterations are enough known as to be employed as indicators of such alterations. (De Pauw & Hawkes, 1993). Several scientific groups have pointed out the potential of aquatic macroinvertebrates as bioindicators (Hellawell, 1986; Rosenberg and Resh, 1993; Merrit y Cummins, 1996). This has triggered in the last decades the production of macroinvetebrate-based indexes, such as BMWP, Biological Monitoring Working Party (U.K., Armitage et al., 1983), BBI (Belgium, De Pauw y Vanhooren, 1983), IBGN (France, AFNOR, 1992), usually based in a score system, assigning the highest scores to intolerant taxa and lowest scores con tolerant taxa.

The bioindicator approach is conceptually simple and requires no complicated theory. Thus, it has been easily understood by civil engineers and technical staff in charge of river management without any ecological or biological knowledge. It can also be easily applied with semi-quantitative (relative abundance) or qualitative (presence-absence) sampling of fish communities. A finer resolution of stresses can be attained when habitat, trophic or reproductive guilds are used.

In the other hand, there are few guidelines for choosing appropriate indicator taxa or guilds. Besides, reasons other than degradation (eg. zoogeographic barriers, overharvesting, or biological interactions) can be the cause of a species to be absent. There can be also a regional, seasonal or age-stage related variation in the sensitivity of indicator taxa. Moreover, a certain species can express different sensitivities to different stressors and besides its presence or absence cannot distinguish degrees of degradation. Fausch et al. (1990) suggest developing an index based on changes expected in fish communities when degradation occurs.

In addition, indices based on indicator taxa oversimplify the survey results, as they are generally obtained by adding the ‘weight factor’ associated to each species present in the community, which is given on subjective assessments about the species tolerance or sensitivity to organic pollution. In this situation, a more precise taxonomic identification of river fauna and flora than that required by these indexes (genus or family level) is necessary, and a comparative study of the present situation in relation to the reference condition seems to be demanded, without any previous consideration of the species as indicators of water quality, neither of the scoring system of prescribed values of good and bad conditions, like those reflected in the traditional biological indicator based indexes (García de Jalón, D. & M. Gonzalez Tánago, 2005).

2.2. Biotic Integrity approach

Karr et al. (1986) notice that the term biotic integrity is to some extent abstract and elusive. Nonetheless the concept can be defined as the ability of a system to support and maintain "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr and Dudley 1981), thus providing the system with the ability to withstand or recover from most natural and anthropogenic perturbations. According to these authors, the biotic integrity of a system is thus the best indicator of its potential.

Indexes of Biotic Integrity (IBI) assume that reference conditions can be estimated through various interpretations of the range of metric values currently observed in a region and that usually for any specific stream type or stream size, reference condition is represented by the highest species richness (Stoddard et al., 2006). This kind of indices is based on the fact that fish communities respond to human alterations of aquatic ecosystems in a predictable and quantifiable manner There has been several proposals of IBI indexes focused on macroinvertebrates (AQEM CONSORTIUM 2002), aquatic and riparian vegetation (Bunn et al., 1999) and mainly on fish communities (Karr, 1981; Fausch et al., 1984; Karr et al., 1986; Schmutz 2004).

The use of this kind of indices is more widely extended in USA that in the EU (CHE 2005), but there are some experiences in using this concept to assess the ecological status in the terms of WFD. IBICAT (Sostoa et al. 2004)) represents an adaptation of IBI (Index of Biotic Integrity) Karr (1981) to Catalonian rivers (NE Spain), and it is based on a five-type river classification for which five corresponding indices were proposed, thus classifying the ecological status of rivers into 3 categories. The European Fish Index (EFI) (FAME CONSORTIUM 2004) is based on a predictive model that derives reference conditions for individual sites and quantifies the deviation between predicted and observed conditions of the fish fauna. This index employs 10 metrics describing 5 ecological function groups: trophic structure, reproduction guilds, physical habitat, migratory behaviour and general tolerance to disturbance. The EFI was developed for Western and Northern Europe and calibrated against a rough estimate of human pressure status. This index has recently been extended by EFI+ CONSORTIUM, whose overall objective is to overcome existing limitations of the EFI by developing a new, more accurate and pan-European fish index. Among the limitations of EFI was its applicability to Mediterranean rivers, since fish assemblage's metric responses to perturbation across Mediterranean areas were consistently weaker than those found for Central and Temperate Europe (Pont et al. 2006; Schmutz et al. 2007). Major bottlenecks for the development of a multimetric index in Mediterranean regions included i) a typical low species richness per site, ii) a high degree of endemicity and basin-specific taxa assemblages; iii) the naturally harsh and fluctuating, warm climate-dependent, aquatic environment, and iv) a complex and hardly-predictable combination of hydrological variability with human pressures, either present or inherited throughout centuries of fluvial and landscape uses. As a result Segurado et al. (2008) extended the EFI to be used in Mediterranean rivers assessment studies, although human pressures are different that those in Central Europe and have impacts in the EFI with peculiar patterns (Ferreira et al., 2007).

The advantages of IBIs are that it is a broadly based ecological index that assesses both community structure and function at several trophic levels, providing biologically meaningful IBI classes. It is also flexible and has been applied to various ecological regions where stream fish communities are at least moderately diverse. The metrics in which IBI is based are sensitive to many types of degradation. Its scores are reproducible, and show consistently ranked sites along known gradients of degradation (Fausch et al. 1990).

The main disadvantages of these indices are their methodological requirements (i.e. complete and careful sampling, at least moderate species richness, background information on fish communities from a variety of streams). Besides, subjectiveness is still not avoided when establishing metric criteria (Fausch et al. 1990).

Most IBIs are multimetric indices based on the "reference condition approach" (Bailey et al. 1998), that reflect important component of the fish community such as taxonomic richness, habitat and trophic, guild composition, or individual health and abundance (Schmutz 2004).

2.2. Similarity to reference conditions approach

Similarity indexes were proposed by Hellawell (1986) to be used on stream bio-monitoring, especially for aquatic organisms, and more recently Winward (2000) has suggested their use for monitoring vegetation resources in riparian areas. Similarity indexes can be very useful for quantitative comparison of present vs. reference conditions, by means of identifying key species and comparing their abundance and space and time distribution in present conditions with those considered as "natural". Similarity indexes that mathematically fluctuate between zero and one are interesting and suitable for WFD evaluation. They can use qualitative data (presence/absence of species like those used by Jaccard, Sorensen [1948], etc.), or quantitative data (relative abundance of species as proposed by Raabe, or absolute abundance as proposed in Czekanowski index). Therefore, in order to assess the status of the community composition, qualitative similarity index for comparing to reference composition can be much appropriated, while assessing abundance status quantitative similarity index can be used. Also, these similarity indexes may be used directly as the EQR 'ecological quality ratio' for each metric, as the index value for the reference conditions is always one (identity), and the value of the index would be directly the EQR. Furthermore, if there are different reference sites for the same river type, the issue of determining thresholds between "very good" and "good" ecological status may be undertaken using the minimum value of similarity between two communities from these reference sites (García de Jalón, D. & M. Gonzalez Tánago, 2005).

3. APPROACHES TO REFERENCE CONDITIONS IN FISH COMMUNITIES

REFCOND Guidance Document (Working Group 2.3 – REFCOND), (Wallin et al. 2003) defines the method to be used in determination and validation of reference conditions for every river type depending on the information available, and prescribes that in case of not having enough environmental data from free of impacts and pressures sampling stations, then the following methods should be used:

Method I. Spatially based reference conditions using data from non disturbed monitoring sites;

Method II. Reference conditions based on predictive modelling;

Method III. Temporally based reference conditions using either historical data or palaeoreconstruction or a combination of both;

Method IV. Expert judgement.

For spatially based type-specific biological reference conditions, Member States shall develop a reference network for each surface water body type. The network shall contain a sufficient number of sites of high status to provide a sufficient level of confidence about the values for the reference conditions, given the variability in the values of the quality elements corresponding to high ecological status for that surface water body type and the modelling techniques which are to be applied.

Each of the above cited methods presents advantages and disadvantages as state Bonada et al. (2002) based on Owen et al. (2001), so we consider that misuse or waste of existing information can be committed when opting for one given method instead of the others. This fact may be hard to justify when available data are often scarce and any information may help to obtain more accurate results. Owen et al. (2001) propose that a hierarchical decision process should be established to assist in the selection of approach used to establish reference conditions. The same authors state that where undisturbed or nearly undisturbed conditions prevail then a validated spatial network is preferred. If degraded conditions prevail then minimally disturbed stations and historical data may be used to model a good stress-ecological response relationship. They point out that expert judgement should be used only as a last resort and then accompanied by an acceptable validation process.

The establishment of fish fauna reference conditions requires the exploitation of available data. Owen et al. (2001) found that the methods more often used to establishing Reference conditions in rivers are those based on spatial data (42%) and the rarest is modelling (10%). However, analyzing only the cases were fish was used; spatial data methods were not so important (34%) while modelling (14%) and Historical data (29%) were more frequent. Spatial based methods are best option when unimpacted representative sites of all river types are available, although they are expensive to initiate. Modelling is site specific, but requires data, calibration and validation (Owen et al. 2001; Johnson, 2001). Methods based on Historical data are often inexpensive to obtain, but the data quality may be poor or unknown and their variability restricted. Finally, expert judgement incorporates present day's concepts in a balanced way, but may be affected by bias.

4. THE SYNTHETIC APPROACH: OPEN METHODOLOGICAL FRAMEWORK (SOMF)

Reference conditions for a fish community should reflect their natural variability between regions and within the same region (Fausch et al. 1990). Thus, the benchmark to which the current conditions of the community have to be compared can be known, taking into account its variation through different scales.

One of the conditions that must be met is that the methodology used is consistent and can be applied to different regions at different scales and that results are comparable. One of the problems arising from the application of the concept of reference conditions is the ambiguity shown by the users of the term, as well as the different methodologies used to its estimation (Stoddard et al. 2006).

A synthetic approach that involves the outputs of all the different types of methods into a single set of results has been recently proposed. It has been named Synthetic Open Methodological Framework, SOMF, and it is designed to reflect the natural variability of reference conditions within a river type taking into consideration physiographic or geographic gradients that drive that variability (Fausch et al. 1990) such as altitude or river width, among others, (Alonso et al. 2009).

This methodological framework takes systematically into account the information independently obtained by the application of every known method (namely reference-site approach, predictive modeling, historical conditions and expert judgment). This approach pursues two main objectives:

- to keep the different sensitivities of the methods, keeping all the information obtained from the most sensitive method in each case (e.g. in order to detect whether a species must be present or not in a given water body in reference conditions), and

- To estimate the soundness of the reference conditions thus established, quantified as a function of the number of methods that predict them (e.g. the presence of a given species in a given water body).

This methodology was designed in the form of an open methodological framework in order to keep the ability of being adapted to any circumstances, such as the methods to be considered in order to accomplish different national or supra-national normative (e.g. U.S. Clean Water Act, E.U. Water Framework Directive, Australian Water Reform Framework), the disposal of data or the different concepts of reference conditions to be determined and theoretical criteria to be used (Stoddard et al. 2006). The name Synthetic Open Methodological Framework means that its process of application has not to be understood as a fixed methodology but as a highly adaptive logical framework in which only the fundamentals of the methodology have to be strictly accomplished, and the specific circumstances of the case in which it is to be applied may impose modifications of the details of the methodology. The fundamentals of SOMF are:

(1) to use of a set of a priori defined quality elements to accomplish a previously designed monitoring process (e.g. WFD);

(2) to keep all the available information after the application of all considered methods thus taking into consideration the different sensitiveness of the methods; and

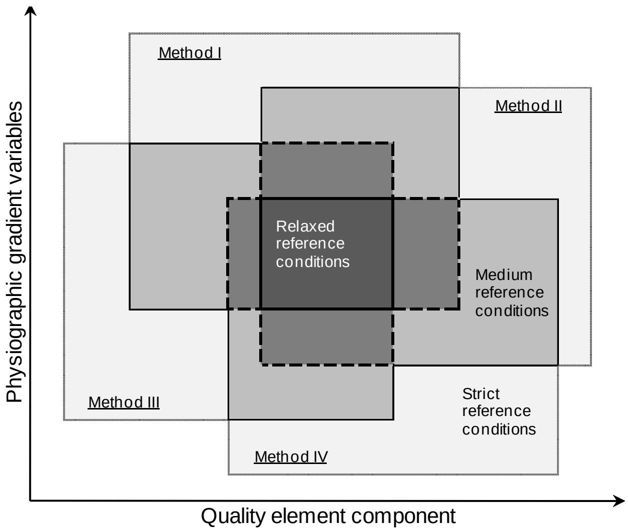
(3) To quantify the soundness of the results as a function (e.g. linear combination) of the number of independent methods that lead to a given reference condition.

For each river type, specific reference conditions can be determined by means of a two-phase process:

Phase 1: River type-specific reference conditions are set for every quality element by independently using as many different methods as can be considered; which in our case study are the four methods given by Guidance Document no. 10 (Working Group 2.3 – REFCOND) (Wallin et al. 2003). Within a given river type, reference conditions can change following a gradient which might be determined by a physiographic or geographic variable such as river width, latitude, altitude,...., or a combination of several of them.

Thus reference conditions should reflect to some extent this observed gradients.

Figure 1.- Synthesis of several (four) reference conditions methods into a single integrated result graph; different shading degrees represent different degrees of soundness of the results.



Phase 2: All the information given by each method is integrated into a synthetic set of reference conditions accounting for the number of methods that estimate a certain reference condition (i.e. the value of every quality element in theoretical minimally disturbed conditions according to every method), in a process that can also hold different weighting coefficients for each method- although in our case study methods were weighted equally. This way, robustness of the estimation can be classified into several strictness classes (Figure 1): from relaxed (e.g. a species is only to be in the fish community when more than 3 methods predict its presence in reference conditions; the abundance of a given species is the average of the 3 lowest results of the 4 methods) to strict reference conditions (e.g. a species is to be in the fish community when as soon as a single method predicts its presence; the abundance of a species is the value of the highest result of the 4 methods).

4.1. Application to Navarra rivers

This synthetic approach was applied within the context of a project (Gobierno Navarra 2006) funded by Navarra Regional Government whose main goals were: (1) to classify the rivers of Navarra, by using preferably "System B" methods; (2) to set reference conditions for every identified river type; and (3) to assess the ecological status of rivers in Navarre according to WFD requirements. In this paper we deal only with the second goal of setting the reference conditions of the fish biological element. These fish reference conditions were defined for each of the eleven river types defined for Navarra previously (Gonzalez Tánago et al, 2006)

Fish communities records from 293 sampling sites among the rivers of Navarra including composition and species abundances were used.

In the mentioned project, due to the geographical characteristics of the river network of Navarra (narrow latitude and river width range), altitude was the main gradient variable with sufficient ecological significance. According to WFD REFCOND Guidance Document (Wallin et al. 2003), four methods were used in Phase 1 of the SOMF application:

- Method I. Spatially based reference conditions. 32 non- or minimally disturbed sites were used in the reference-site approach.

- Method II. Predictive models. For each river type four models were used predicting the variation of the several variables following a physiographic gradient (i.e. altitude) in theoretically undisturbed conditions. Modeled variables were: (1) proportion of every group of species (i.e. species that usually coexist) within the fish community; (2) number of native species in the fish community; (3) probability of every species of being present in the fish community; and (4) relative abundances of every species.

- Method III. Historical or paleo-reconstruction originated information. Municipal recordings of Geographic and Statistic Dictionary of Spain (Madoz 1850) were used as dataset.

- Method IV. Expert judgment.

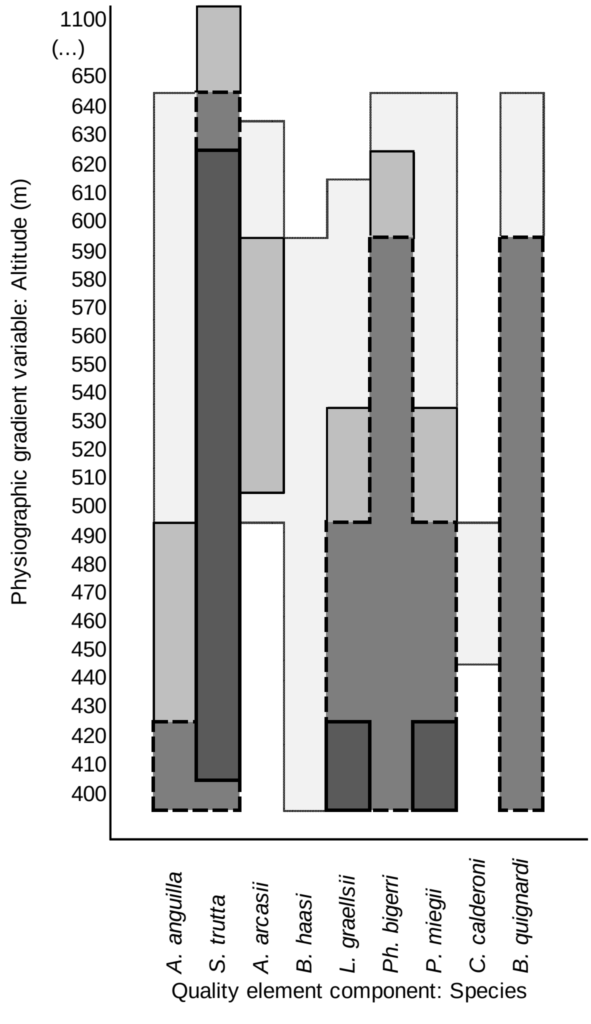
Results of the application of SOMF showed the reference conditions for quality elements composition and relative abundance of fish community. As an example of the results, Figure 2 shows the composition of the fish community in the reference conditions inferred trough SOMF approach. The different strictness classes can be noticed by different gray shadings (the darker shading the stricter reference conditions).

This synthetic approach was also used to estimate reference conditions for macro-invertebrate and microalgae quality elements in the same project.

The main advantages of the SOMF are its simplicity, adaptive approach and that it takes advantage of the different sensitivities of all considered types of methods. Besides, the soundness of the reference conditions thus established can be quantified. It is open, which means that it can be adapted to strictly fulfill any theoretical concept or previously designed methodological process such as national or supra-national normative.

Furthermore, it allows the use of Similarity Index based EQRs when assessing the status of the quality element, quantified in terms of its deviation from reference condition, thus allowing knowing to what extent every quality element is responsible of the observed EQR, and therefore becoming useful guidelines to set the restoration goals to be attained in order to reach the good ecological status.

Figure 2.*- Example of the results: species composition of the fish community in reference conditions obtained from the application of SOMF in type 4 rivers (i.e. calcareous medium and small sized streams of wet mountain climate) of Navarra*



In order to avoid the weaknesses identified in these kinds of multivariate methods (namely result interpretation) (Fausch et al. 1990) more research on causality of identified relations among impacts and quality elements is needed. The shift from reference conditions to reference processes appears to be a major perspective in river ecological assessment (Dufour and Piégay 2009), and this can be achieved by using SOMF synthetic approach but much research has to be done in this direction.

5. CONCLUSIONS

The purpose of this text is to sum up the different techniques that use fish communities as indicators of ecological status of rivers, emphasizing the different methods leading to the determination of the reference conditions. Misuse or waste of existing information can be committed when opting for one given method instead of the others. This fact may be hard to justify when available data are often scarce and any information may help to obtain more accurate results.

SOMF is not expected to be a revision of the method establish by WFD to set reference conditions, but an efficient solution when reference sites are scarce or not representative of the whole population of reaches in a given ecotype

Therefore, SOMF represents a flexible approach to be used in (riverine) ecosystem management plans with a flexible framework designed to envelope a variety of data sets, methods and ecological concepts, providing water-resource managers and biologists a tool to address the question: what should rivers look like?.

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