The development of a fish-based assessment method for the ecological status of European rivers – a tool to support the implementation of the European Water Framework Directive

The FAME project group

Abstract

In the EC-funded FAME-project[1], two methodological approaches to develop fish-based methods for assessing the ecological status of European rivers were tested. The site-specific approach yielded the European Fish Index (EFI), which enables ecological status assessment on a European scale. The spatially-based approach aimed at developing type-specific methods on both the ecoregional and the European scale.

Method evaluation based on practical field testing and statistical comparison of the accuracy of the FAME methods and existing regional methods demonstrated that the European Fish Index is as precise as other methods. Moreover, the EFI allows assessment of European rivers with a single, standardized method, thus preventing intercalibration between different river types and/or river basins. The EFI was therefore selected as the final FAME assessment method.

By developing a fish-based assessment method to assess the ecological status of rivers, FAME contributed to implementing the ecological targets of the European Water Framework Directive.

Introduction

In December 2000 the EU launched a new, ambitious water policy by enacting the Water Framework Directive (WFD). According to the WFD, Member States are obliged to protect, enhance and restore all surface waters with the aim of achieving good ecological status by 2015. For rivers, four biological indicators were defined for the assessment: phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna and fish fauna. As outlined in the WFD, the principle of the assessment procedure is to measure the deviation of the ecological situation of any observed site from (type-specific) reference conditions. Thereby, reference conditions represent a status with no or only minor human alterations of all quality elements included in the monitoring.

Fish have been used as indicators for ecological status assessment for about 20 years (Hughes & Oberdorff, 1999). To date, however, many Member States have not yet included fish in their routine monitoring programs. Other countries use assessment methods that differ, for example, in terms of the rationale behind selecting quality targets (reference conditions), basic principles and method development. Some methods were established based on expert judgement, while others use sophisticated statistical models (Roset et al.,

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2005). They all are adapted to the particular characteristics of the region they were developed for and do not include the range of variability of river-types across Europe. Finally, existing methods do not fully comply with the general procedures and requirements as specified in the WFD. As a consequence, these methods are not applicable on a European level.

The provision of scientifically sound methods allowing the assessment of sites across Europe in a coherent and standardized manner is thus a basic requirement for the success of the WFD. The FAME project contributed to the implementation of the WFD by developing, evaluating and implementing a fish-based assessment method for the ecological status of European rivers.

Basic principles

The development of a fish-based ecological status assessment method was founded on the principle of the Index of Biotic Integrity (IBI) established in the USA in the early 1980s (Karr, 1981). In the last 2 decades the IBI was adapted to different regional conditions, although the basic principles are the same for all methods. The fundamental assumption is that the composition and structure of fish assemblages change under human pressures in a traceable manner.

Fish species have different and in many cases well-known ecological requirements. Thus, they also have a specific sensitivity to human alterations. To account for these particularities, “metrics” are introduced as a measurable part or process of the biological system responding to human influence. Within each metric group considered, species with similar ecological requirements are compiled into functional guilds (e.g. for reproduction, habitat, tolerance, migration, feeding).

The original IBI as well as many of the modified fish-based assessment methods were developed based on expert knowledge. In contrast, FAME aimed at establishing a method based on the analysis of a large number of existing sampling data.

Prerequisites and methods

The most important prerequisite for the method development was the large central database FIDES (FIsh Database of European Streams). It holds fish sampling data from 12 European countries (Austria, Belgium, France, Germany, Greece, Lithuania, Poland, Portugal, Spain, Sweden, The Netherlands, United Kingdom). Altogether about 15,000 samples (“fishing occasions”) from some 8000 sites are integrated in FIDES. Fifty-two variables were used to characterise fishing occasions in terms of abiotic criteria and human pressures; each of these was classified according to 5 different levels of impact on the fish fauna. Eight criteria described the sampling procedure and 9 the geographical position. Fish data were integrated as number of individuals, length or length class, number of 0+-individuals and, if available, biomass (Beier et al., 2005).

FIDES datasets comprise different river types, reference sites and different levels of degradation of European rivers. In order to identify reference sites and levels of degradation, each fishing occasion was classified using a joint pressure variable. The latter was computed as the mean of 4 or 5 single pressure variables: morphological and hydrological conditions,

nutrients/organic input, toxic substances/acidification and connectivity. Sites where none of the main pressures was classified higher than two (joint pressure status = 1 or 2) were extracted as reference or “calibration” datasets.

Another important prerequisite was the assignment of fish species to functional guilds, i.e. describing the requirements and behaviour of each species in terms of habitat, reproduction, feeding or tolerance. The fish species classification was the basis for the metrics calculation. In accordance with the WFD, the metrics selected in FAME refer to species composition (including overall composition and functional structure), density and population structure. For the latter, 45 sentinel species which are indicative of particular river zones and provide important information on ecological status were chosen. Altogether about 450 metrics were computed (Noble et al., 2005).

The standardized sampling procedure used in FAME was electric fishing, either by boat or wading, because this turned out to the only common sampling method employed in the FAME partner countries.

Methodologically, two different approaches were tested: a site-specific and a type-specific one. The site-specific approach predicts reference conditions at the site level. The main task was therefore to identify those abiotic criteria that determine the natural variability of fish assemblages of European rivers and to integrate them adequately into the models. In contrast, the spatially based type-specific approach first groups rivers with similar fish species composition into fish-based river types. In a second step, abiotic variables characterising the particular river type are determined. For each river type identified, a specific assessment method, i.e. a multi-metric index, is determined. The type-specific approach was applied on the ecoregional and the European level.

Results

The European Fish Index (EFI)

The principle of the site-specific European Fish Index is to measure, for any observed site, the deviation of observed metrics from predicted reference metrics, and then to compute the probability that the site represents reference conditions. Based on the degree of deviation, the final ecological status class is identified within a 5-tiered assessment scheme.

Reference metrics are predicted as a function of 13 abiotic, location and sampling variables: wetted width, distance from source, flow regime, altitude, slope, mean air temperature, lakes upstream, geology, catchment size, main river region/river group, fished area, sampling method, sampling strategy.

The final metrics list was identified out of a set of nearly 200 metrics. In a first step, all metrics were modelled as a function of the above-mentioned 13 variables, thus accounting for natural variability of fish assemblages of European rivers. Only sites from the calibration dataset were used (i.e. sites having a pressure status of 1 or 2). The validation of the metric-specific models obtained from the first step yielded a list of 29 metrics. In a further step the response of the retained metrics to human pressures was tested by using weakly and strongly disturbed sites from FIDES. Twenty-one metrics demonstrated a clear and

consistent correlation between metric values and level of degradation. After testing the correlation between these candidate metrics, the final list of 10 metrics was obtained.

In terms of functional aspects, the 10 metrics finally retained cover trophic structure of fish assemblages (density of insectivorous and omnivorous species), reproductive guilds (density of phytophilic species, relative abundance of lithophilic species), physical habitat (number of benthic and rheophilic species), tolerance (relative number of intolerant and tolerant species) and, in the case of migratory fish, migration type/behaviour (long-distance migrants, potamodromous species).

Some of these metrics increase (omnivorous, phytophilic, tolerant species) under human pressure, while the others decrease. A transformation into probability values ensures that all metrics show the same trend of reaction (i.e. a decrease). The final index is computed as the sum of the 10 single metrics and was standardised to values ranging from 0 to 1. Thresholds for the 5 status classes are: high status (class 1) = 0.669 – 1.000, good status (class 2) = 0.449 – 0.669, moderate status (class 3) = 0.279 – 0.449, poor status (class 4) = 0.187 – 0.279 and bad status (class 5) = 0.000 – 0.187.

The European Fish Index is independent from the environmental conditions of any independent site. Also, the EFI shows a strong response to chemical (nutrients/organic input, toxic substances/acidification) pressures and a weaker but significant response for sites only exposed to physical pressures (hydrology, morphology).

The EFI is the first fish-based assessment method applicable on a large geographical scale. Currently, however, the application is limited to those river groups integrated in FIDES. It has therefore not been tested for Mediterranean or many East European rivers (for Mediterranean rivers see Ferreira et al. 2005a). Extending the geographic range of the EFI will require future improvements, including additional sampling sites. Moreover, the applicability for large rivers has to be tested because FIDES contained only few reference sites for such rivers. Only fish data obtained by electric fishing (one passage) may be used to calculate the EFI; this might represent another limit for the application to large rivers.

The EFI provides a continuous score value. Ecological status classes were identified afterwards. Some of the attributed status classes should be used with caution because the distinction of classes 1 and 2 (high, good status) and 4 and 5 (poor, bad status) was set arbitrarily (see also Pont et al., 2005).

The spatially based type-specific methods

The European Fish Index is a site-specific method, thus predicting reference conditions as a benchmark against which the impacts of human alterations on fish are analysed on the site level. In contrast, the spatially based methods use reference conditions defined on the level of river-types. Based on the data availability (sufficient number of reference sites for the analyses of fish types and sufficient number of data for different human pressure levels for each type), the spatially based approach was applied to 11 ecoregions (Iberian Peninsula, Pyrenees, Alps, Western Highland, Central Highlands, Western Plains, Central Plains, Baltic Province, Great Britain, Borealic Uplands, Fenno-Scandian Shield; see e.g. Ferreira et al. 2005b, Grenouillet et al., 2005, Virbickas et al. 2005). For other ecoregions the number of

data in FIDES was too low for statistical analyses (Italy, Dinarian Western Balkan, Hellenic Western Balkan, Hungarian Lowlands, The Carpathians, Eastern Plains). Within the 11 analysed ecoregions, 60 river types were identified. For 44 of these types, type-specific metric sets demonstrating a statistically proved correlation between the fish fauna and human pressures were identified. For 16 river types the number of datasets for different degradation levels was too low to develop type-specific assessment methods (Schmutz et al., 2005).

In a subsequent step the spatially based approach was applied on the European scale. Altogether 15 European fish-based river types were identified based on the 60 ecoregional types. Abiotic variables discriminating these European river types are altitude, slope, mean air temperature, distance from source, wetted width, main river region, conductivity, ecoregion, and geographical position (longitude and latitude). These variables are also used to predict the fish type for any newly sampled site.

Due to the aggregated datasets, a sufficient number of sites covering different degradation levels was available for 13 river types. Thus, type-specific methods were developed for 13 European Fish Types (Melcher et al., 2005).

Method evaluation

The capacity of FAME methods to detect impacted sites correctly was statistically analysed. The basis for the correct classification was the pre-classification of sites based on human pressures. Moreover, the accuracy of FAME was compared with 9 existing national/regional methods.

It was demonstrated that the European Fish Index is as precise as most other FAME methods as well as existing regional methods. EFI, spatially based methods on the eco-regional scale and the above national/regional methods correctly classified about 80 % of the sites when separating only two classes (non-impacted classes - comprising status class 1 and 2, and impacted sites - comprising status classes 3-5). Only the spatially based methods on the European level had a higher precision, with a correct classification of ca. 87 % of FIDES sites (Quataert et al. 2005).

The applicability of the sampling procedure, the European Fish Index and the spatially based methods (ecoregional scale) was also tested by sampling 218 new sites. Again, the capacity of each index to classify impacted and non-impacted sites as derived from the pre-classification correctly was evaluated. In addition, applied partners and field sampling teams commented on the plausibility of the metric lists of the indices.

As a result of the method evaluation process, the European Fish Index was selected as the final FAME assessment method because it allows the ecological status assessment of European rivers with a single, standardized method. In order to support the type-specific approach of the Water Framework Directive, the European Fish Types were integrated.

Final output and tools for application

A user-friendly PC-software was developed to implement the European Fish Index and the European Fish Types in routine monitoring. It performs all calculations necessary for the

European Fish Index, such as (1) observed metrics, (2) theoretical (reference) metrics, (3) probability metrics, (4) the final index, and (5) the ecological status class. Input data are the 13 abiotic, location and sampling variables as the basis for calculating the reference metrics, and the number of fish caught. The corresponding European Fish Type is also identified in an automated routine.

During the import procedure, data are automatically verified with respect to plausibility. is The procedure also checks whether the data meet the requirements for the application of the European Fish Index (e.g. minimum number of individuals caught, limit of sampling area, etc.).

The application manual for the European Fish Index provides a general introduction into the ecological assessment according to the Water Framework Directive, into basic concepts of the European Fish Index (Index of Biotic Integrity) and explains the use of fish as indicators for ecological status. The manual then describes the FAME assessment procedure, starting from field sampling to the calculation of the European Fish Types as well as the European Fish Index. The final part of the manual describes in detail the application of the PC-software. It explains each step from the installation of the software to the interpretation of the results. Several annexes comprise a glossary, the field sampling protocol as well as the taxa and guilds table.

Conclusions

The FAME project enabled the development of the European Fish Index, a fish-based assessment method for the ecological status of rivers which adequately incorporates the natural variability of European rivers. Such a method is an important prerequisite for successfully implementing the Water Framework Directive because no adequate assessment methods were previously available.

The development of the European Fish Index was based on a large number of existing sampling data; this data enabled reference conditions to be defined in accordance with the WFD as well as detailed analyses of fish assemblage responses to different levels of human degradation. The central database FIDES demonstrated that it is possible to standardise fish and environmental data across Europe. Regional differences in fish assemblages were overcome by selecting functional metrics. The final list of metrics of the EFI includes several new metrics, such as migratory behaviour. A statistical method comparison demonstrated that the EFI is as precise as regional and type-specific FAME methods. The EFI is able to detect both physical and chemical pressures. It does not, however, distinguish between different types of pressure. For the latter, more precise data on pressures are required.

End-users participating in the FAME project preferred the EFI as the standardised assessment method. Several countries expressed their interest to include the EFI into routine assessment of the ecological status as required by the WFD. FAME was also invited to start the preparation of a CEN standard for classifying running waters in Europe based on fish communities.

All tools for the application of the European Fish Index are available for downloading at the FAME webpage at http://fame.boku.ac.at.

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