Development, Evaluation & Implementation of a Standardised Fish-based Assessment Method for the Ecological Status of European Rivers - A Contribution to the Water Framework Directive (FAME)

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Final Report
Scientific achievements
Sections 5 & 6

Reporting Period 01/01/2002 – 31/10/2004

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Contents

Executive Summary (Section 5)

Contract n°: EVK1-CT-00094-2001 **Project Duration**: 01/01/2002-31/10/2004

Title: Development, Evaluation & Implementation of a Standardised **F**ish-based **A**ssessment **M**ethod for the Ecological Status of **E**uropean Rivers - A Contribution to the Water Framework Directive (FAME)

Objectives:

The objective of FAME was to contribute to the implementation of the WFD by developing, evaluating and implementing a fish-based assessment method for the ecological status of European rivers. In accordance with the requirements of the WFD, the assessment method should (1) classify the ecological status within 5 different levels of degradation, (2) enable a distinction between the various types of human pressures, (3) follow a river-type-specific approach to allow consistent assessment under varying environmental conditions, (4) precisely describe river-type-specific reference conditions of undisturbed fish communities, (5) fulfil requirements of end-users, (6) be cost efficient and (7) be validated in field tests for its practicability. The strengths and shortcomings of the newly developed method should be verified by comparison with existing regional/national methods.

Scientific achievements:

The method development was based on statistical analysis of a large central database FIDES (FIsh Database of European Streams) integrating a sufficient number of datasets to identify river types, reference conditions and different levels of degradation. FIDES holds data from 12 European countries (Austria, Belgium, France, Germany, Greece, Lithuania, Poland, Portugal, Spain, Sweden, The Netherlands, United Kingdom), 17 ecoregions, 2700 rivers and some 15000 samples.

Two different approaches were tested: a site-specific approach and a spatially based type-specific approach. The first one enabled the development of the European Fish Index (EFI). The EFI is the first fish-based assessment method which is applicable over Europe as a whole. It accounts for environmental variability of European rivers by integrating environmental variables in the modelling of reference conditions. The latter are described based on 10 metrics that statistical tests identify as being the most suitable ones out of a set of ca. 250 potential metrics. In terms of functional groups the metrics refer to reproduction (phytophilic and lithophilic species), habitat (rheophilic and benthic sp.), overall tolerance (intolerant and tolerant sp.), migration (long-distance migrants, potamodromous sp.) and trophic structure (insectivorous, omnivorous sp.). Metrics are calculated as either absolute and relative number of species or absolute and relative abundance. Except for omnivorous, phytophilic and tolerant species, all show a decrease under increasing human disturbance. The basic principle behind the EFI is to examine the deviation of observed metric values from the reference metrics and to transform this difference into the probability of representing the reference state for any given site. Calculating the mean of the 10 single probability metrics yields the final index and the ecological status class.

The EFI is applicable for all main river basins and river types where a sufficient number of sites was available. For Mediterranean rivers and those of South-Eastern areas, the EFI may be used after tests with additional data and possible modifications. Note, however, that the assessment of large rivers is only based on predicted reference conditions as actual reference sites for large rivers are not available in Europe anymore.

The spatially based type-specific approach enabled the establishment of 60 river types on the ecoregional level. Out of these 60 river types assessment methods were developed for 44 types with sufficient amount of data. The river types identified on ecoregional level were merged into 15 European river types across ecoregions. Due to the aggregated datasets, methods could be generated for 13 types.

A statistical comparison of the FAME methods and existing regional/national methods demonstrated that the accuracy of the European Fish Index is as precise as other methods. Since it avoids complicated intercalibration procedures between river basins and countries by enabling the ecological status to be identified with a single, standardised method, it was chosen by the FAME members to be the final FAME assessment method. To support the type-specific approach as addressed in the WFD, the European Fish Types (EFT) were integrated in the final software for application as part of the ecological status assessment.

Main deliverables:

The most important deliverable of FAME is the EFI. For its application in routine monitoring, a software routine for the automated calculation was prepared. The software is described in a detailed manual, which also provides an introduction to the background and main parts of the EFI. Several further tools support the application of the EFI (data input files, FIDES database for data recording, FIDES manual, test files).

Several further deliverables were produced, including the FIDES database, the type-specific assessment tools, and some prerequisites for the method development (e.g. classification of 239 fish species as the basis for metrics calculation).

Socio-economic relevance and policy implications:

The development of the EFI contributes directly to implementing the WFD by providing a tool for assessing the ecological status of rivers. Since it is applicable on a European scale, it makes intercalibration between river-basins, river types and countries unnecessary. PC-software, a manual and several supporting tools enable the application of the EFI and the EFT in routine assessment. FAME was contacted by CEN to prepare a standard for classifying running waters in Europe based on fish communities.

Conclusions:

The methodological approach demonstrated that it is possible to develop assessment tools for identifying the ecological status over broad geographical areas by integrating local and regional abiotic factors relevant for the distribution of fish species. A large database containing sufficient data on reference conditions and different degradation levels is a basic prerequisite for developing such methods. The applicability of the EFI, however, may be improved by additional data for European areas not yet included in FIDES, integration of further pressure variables and revision of the accuracy of some basic (environmental) data.

Dissemination of results:

The dissemination of the FAME results will focus on two main target groups. For the scientific community, publications and presentations at relevant international conferences will be main activities. Water and fishery management institutions responsible for implementing the WFD in their countries were integrated in the FAME project, at least for those countries represented in the FAME consortium. For all other institutions the application tools are available on the FAME-webpage. Further documents were prepared as a basic introduction to the FAME results and will be distributed among relevant authorities outside the FAME consortium. Publication activities will focus on applied journals.

Keywords:

Ecological status assessment, ecosystem modelling, fish-based assessment tools, European Fish Index

1. Background (description of the problems to be solved)

The European Union has taken a new, ambitious course in water policy towards an ecologically orientated, sustainable management of water bodies by enacting the Water Framework Directive (WFD) in 2000. Member States shall protect, enhance and restore all bodies of surface water with the aim of achieving good surface water status by 2015 (WFD Article 4). The maintenance and restoration of the quality status needs to be evaluated using a comprehensive monitoring programme which assesses the hydro-morphological, chemical and biological characteristics. Compared to previous policies, the WFD gives strong priority to biological quality targets. It does this by introducing measurements of aquatic biota necessary to identify the structural and functional integrity of ecosystems. In terms of biological status, rivers are assessed by 4 quality elements: phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna and fish fauna (WFD Annex V 1.2.1). The status of the fish fauna should be identified according to species composition, abundance, sensitive species, age structure and reproduction (WFD Annex V 1.2.1). The basic principle behind the approach is to assess the deviation from (nearly) undisturbed river-type-specific reference conditions (*high status*). The general assessment procedure as outlined in the WFD is presented in Figure 1.1.

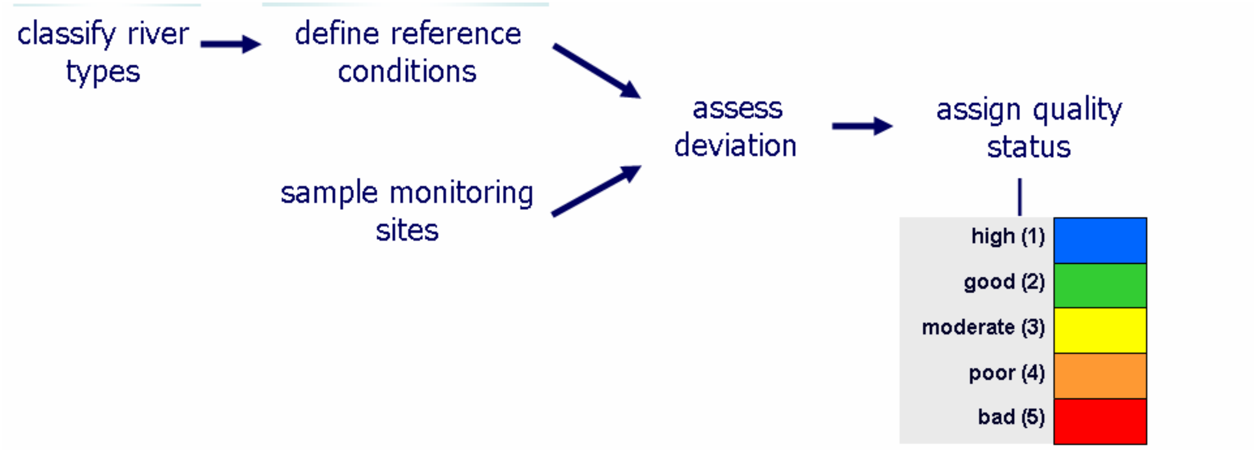

Figure 1.1: General scheme for assessing the ecological status of water bodies according to the WFD

To date, many Member States have not yet included fish in their routine monitoring programmes. Some countries use assessment methods which differ in terms of rationale and background of quality targets (reference conditions), basic principles and method development. Some methods were established based on expert judgement, while others use sophisticated statistical models. All were developed on a regional scale. Thus, they are adapted to these regional conditions and do not include the range of variability of river types over a broad geographical area. Finally, they do not fully comply with the general procedures and requirements as outlined 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 standardised manner is 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.

2. Scientific/technological and socio-economic objectives

Since the establishment of the Index of Biotic Integrity (Karr 1981; Karr et al. 1986) for the assessment of ecological quality, many modified versions were developed because environmental characteristics change by region and by habitat type (Hughes & Oberdorff 1999). All the tools, however, are multimetric indices (Angermeier et al., 2000) reflecting important components of riverine fish communities: taxonomic richness, habitat and trophic guild composition, as well as individual health and abundance. Most of them used the "reference condition approach" (Bailey et al. 1998) by testing an ecosystem exposed to human pressures against a reference condition that is unexposed to such a stress or represents the least impacted situation in a region.

There was general agreement on the need to define assessment criteria and select relevant metrics on a region-specific level (Fausch et al. 1990; Omernik & Bailey 1997; Hughes et al. 1998). Moreover, several criteria for river-type classification, such as river size, were used in addition to the predefined distinction on the regional level (Leonard & Orth 1986; Angermeier & Schlosser 1987; Simon & Emery 1995). Most studies, however, consider only one or rarely two environmental variables, despite the great number of factors likely to control fish communities (Mattews 1998). As a consequence, none of these indices ever encompassed the full range of natural environmental variability of lotic systems. As emphasised by Fausch et al. (1990), a central problem in biological assessment is "the documentation of natural variation in fish communities against which changes due to degradation can be compared".

The implementation of a WFD calls for sensitive biological measures of aquatic ecosystem integrity that can be compared between ecoregions or basins. One way to attain this goal would be to develop standardised assessment methods at the European scale. This requires defining metrics that remain insensitive to natural environmental variability at an unimpaired site. For an impaired site, it requires being able to quantify metric deviation from a predicted value in the presence of any human-induced alteration of that site. Adapting such assessment tools over a broad area necessitates a detailed understanding of the nature of the major environmental gradients that cause, or at least explain, patterns of assemblage composition within and among water bodies under natural conditions (Lyons 1996).

The scientific objectives of FAME are based on the state of the art of fish-based IBI-development on the one hand and on the principle schemes for assessment and monitoring as described in the WFD on the other hand. Thus, the objectives of FAME were to develop a standardised fish-based assessment method which allows one to

- classify the ecological status of European rivers within 5 different levels of degradation with standardised and coherent methods,
- test the new method in ecoregions represented in the FAME consortium,

- follow the river-type-specific approach according the WFD to allow consistent assessment under varying environmental conditions,
- precisely describe river-type-specific reference conditions of undisturbed fish communities,
- quantify the level of degradation based on a multi-metric index,
- enable a distinction between the various types of human impacts,
- identify the method’s strengths and shortcomings by comparing it with existing regional methods,
- fulfil requirements of end-users,
- be cost efficient,
- be validated in field tests for its practicability.

Another objective of FAME was to provide integrated application tools enabling end-users to follow a standardised procedure (standardised field sampling protocols, PC-software, manual).

3. Applied methodology, scientific achievements and main deliverables

3.1. Applied methodology

The method development was based 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, but the basic principles remained the same for all tools. The fundamental assumption is that the composition and structure of fish assemblages change under human pressures in a traceable manner.

Fish species have different requirements of their habitat – 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 most of the modified fish-based assessment methods were developed based on expert knowledge. In contrast, FAME aimed at establishing a method based on analyses of a large number of existing sampling data. The general methodological procedure of FAME is sketched in Figure 3.1.

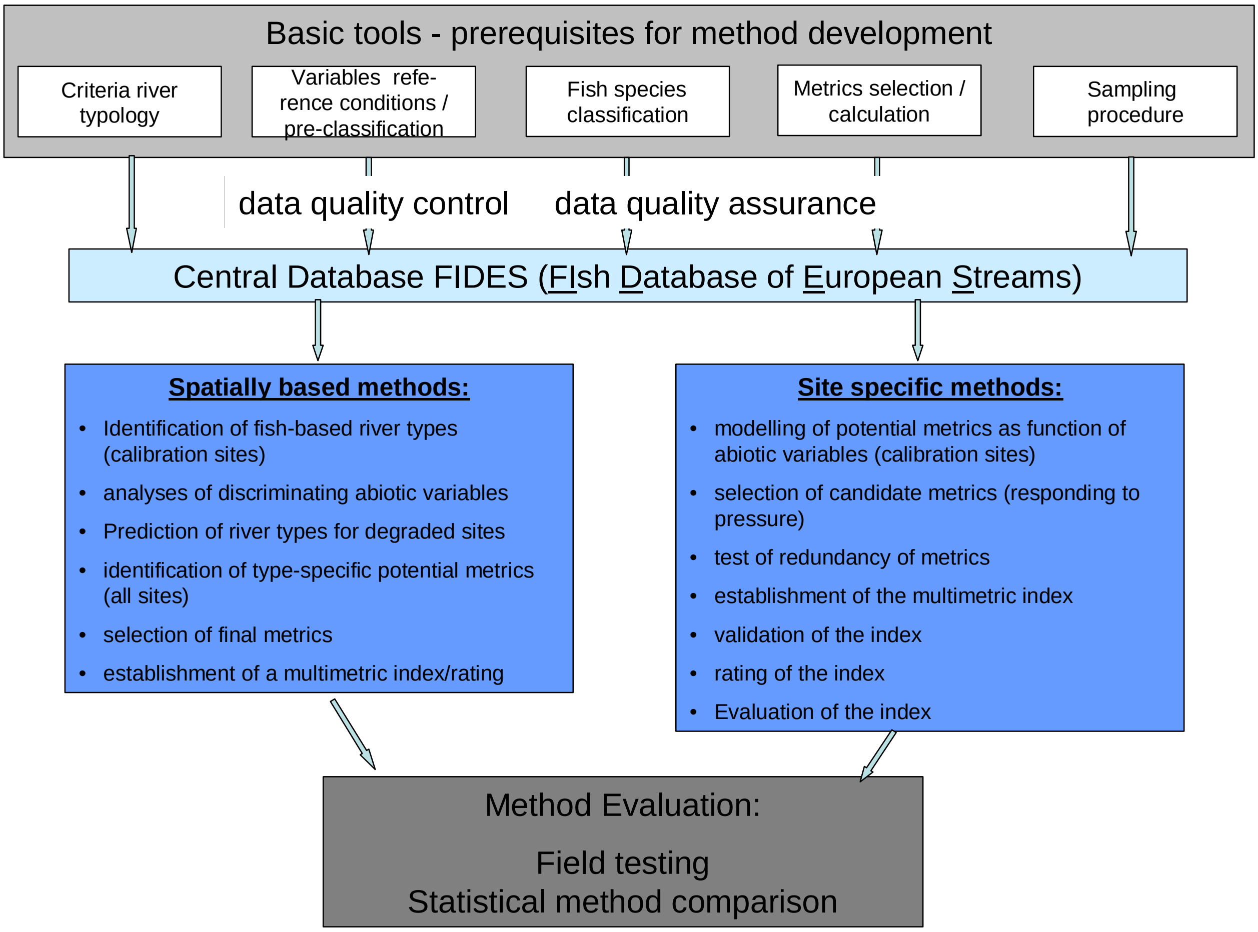

Figure 3.1: Project scheme of FAME

3.1.1. Basic tools – prerequisites for the method development

During the first project phase, existing information on key issues for the method development was compiled and procedures for the FAME method development were agreed upon. This incorporated the status of discussion in the FAME member countries in terms of WFD implementation. In early 2002, however, when the FAME project started, the integration and establishment of issues such as river typologies, the definition of reference conditions or monitoring was an ongoing process in most of the countries.

Criteria and procedure for a fish-based river typology

According to the WFD, river types must be defined based on abiotic criteria. Member States can choose between two different systems (system A and B) which include different abiotic criteria and type-specific thresholds. Within the FAME project, the first step involved developing a fish-based typology. Only in a subsequent step were abiotic factors and thresholds relevant for discriminating fish-assemblages across Europe identified. The identification of fish-based river types relied on existing sampling data from river sites with no or only minor degradation ("calibration dataset", see pre-classification of sites). Sites were grouped by a hierarchical cluster analysis (WARD, Euclidean distance) of total or relative abundance of fish species in the 1st run. Then, in order to allow the assignment of degraded sites or any new monitoring site to the relevant fish-based type, abiotic variables that discriminate fish assemblages into distinct types were identified. This was done by discriminant analysis (prediction of fish type based on abiotic criteria). As Member States are obliged to use either system A or B of the WFD, the relation between the fish-based typology and system A or B was analysed.

In a first step the river typology was developed on an ecoregional scale (i.e. within each ecoregion separately); in a further step, ecoregional types were clustered into "European types" to enlarge the datasets for the development of spatially based methods.

Variables to describe reference conditions and to pre-classify sites based on human pressures:

Reference conditions have to be described for each river type. They represent a situation with no or only minor human disturbances of hydro-morphological and physico-chemical conditions. The selection of the variables to indicate potentially existing human pressures was based on the criteria used in the EU-funded AQEM project[1] as well as on the CIS Guidance paper on the analysis of Pressures and Impacts (CIS working group 2.1., 2002) and extended to include pressures relevant in particular for the fish fauna.

All in all, 23 (24 including multi-scale connectivity) variables, 15 of them obligatory, were selected on three different spatial levels: site, segment and river basin level. The length of a segment depends on the river catchment size: 1 km for streams up to 100 km^2, 5 km for medium-sized rivers from 100-1000 km^2 and 10 km for rivers larger than 1000 km^2. Selected variables refer to pressures such as land use and urbanisation (both river basin and segment level) relevant on a large scale. Among obligatory criteria, connectivity (river basin and segment level), morphological and hydrological conditions (site level), sediment load, upstream dams and lateral movement (segment level) indicate hydro-morphological alterations, whereas nutrients/organic input, toxic substances/acidification and salinity refer to chemical alterations of river sites. Furthermore, the variable "riparian zone, segment level" was included, describing degradations of the vegetation zone adjacent to the stream. Data were obtained from GIS, national data records (e.g. discharge, temperature data) and expert judgement, the latter based on available information (local authorities, extrapolation from nearby sites and maps). For the classification of each variable, the affect of the pressure on the fish fauna was estimated according to 5 status classes ranging from bad status (= 5, severe impact on fish fauna) to 1 (= high, reference conditions: only minor, negligible alterations).

Pre-classification of sites, calibration dataset

For only 16 % of the sites in FIDES were all environmental pressure variables reported (see also chapters referring to the central database FIDES). For 80 % of the sites, 7 variables were reported. Data availability was highest for the 5 main pressure variables (i.e. those that are obligatory in the WFD). Thus, the final pressure status classification of sites was restricted to 5 variables: morphological conditions, hydrological conditions,

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[1] The Development and Testing of an Integrated Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates

nutrients/organic input, toxic substances/acidification (site level) and connectivity (segment level; for further analyses in terms of connectivity see chap. 3.2.4).

In order to identify the joint pressure variable, the average of the four and five, respectively main variables was calculated. Sites where none of the 5 variables had a score higher than 2 were considered as reference conditions, i.e. sites with no or only slight human alterations. They were extracted as the “calibration dataset” for identifying fish-based river types and for modelling reference conditions.

Fish species classification

As a prerequisite for calculating metrics, fish species were classified in terms of their ecological requirements and residency status in river basins. A species list containing species occurring in European rivers (even if only rarely) was compiled. Information was gained from publications, national reports and grey literature, initially on a national level and, in a subsequent step, harmonised in the FAME consortium.

The functional guilds that were considered, along with the classification criteria, are presented in Table 3.1. The residency status (native, introduced) was classified for the spatial/hydrological units of “Main river regions”, representing large catchments down to their confluence to the sea. Smaller catchments (< 10,000 km^2) flowing to the same sea coast were grouped according to the IHBS sea codes (see www.ices.dk).

A number of species was identified as “sentinel”: they represent species that are indicative of particular river zones and are supposed to provide information on ecological status. These species were defined as relevant for recruitment and population structure analyses. Consequently, they are relatively common and easily caught, and electric fishing is not considered to be significantly size selective. In Western Europe, the species identified were generally those dominant and associated with the Huet zonation scheme (Huet 1949, 1954).

Table 3.1: Functional guilds and criteria for the fish species classification

Guild	Classification criteria
Adult trophic guild	Insectivores, planktivores, omnivores, piscivores, herbivores, detrivores, benthivores, parasite
Reproductive guild	Lithophils, phytophils, phyto-lithophils, psammophils, ostracophils, pelagophils, lithopelagophils, ariadnophils, speleophils, viviparous, polyphils
Reproductive timing	Season or month range indicated
Reproductive behaviour	Single, fractional, protracted, multiple
Degree of rheophily	Rheophilic, eurytopic, limnophilic
Feeding habitat	Water-column, benthic
Migration guild	Short-distance migrants, intermediate migrants, long-distance migrators – anadromous, long-distance migrants – catadromous
Water quality tolerance	Tolerant, intolerant, intermediate
Habitat degradation tolerance	
Temperature tolerance	

Acid tolerance	
Overall Tolerance	Tolerant, intolerant, intermediate
Life history	Short-lived, long-lived, intermediate; long-lived - early spawning, long-lived - late spawning

Metric selection and calculation

The principle of the FAME method development was to test the response of metrics to human pressures. According to the WFD the assessment of the ecological quality status must integrate information on species composition, density and population structure.

In order to select the metrics for the FAME project, existing methods were initially analysed in terms of metrics used. The final metric choice was based on the requirements of the WFD (structure of fish assemblages, capacity to indicate different types of pressures), ecological knowledge, statistical possibilities for measurement (ability to categorise and score the range of values observed against a valid reference condition) and limitations of the sampling procedure. A further simplification of the original guild classification as shown in table 3.1. was necessary to guarantee a sufficient number of species assigned to each guild category. Functional metrics and metric variants are listed in Table 3.2 to Table 3.4. The trend of metric reaction was also defined to model reference conditions of metrics (see chapt. 3.2.4).

Table 3.2: Metrics selected to test response of overall species composition to different intensity of human pressure

Guild/Metric type	Criteria	Calculated metrics
Overall composition	All species	N all species
	Native species	N native species, % native species
Abundance	All species Native species Alien species	Density (n/ha), Biomass (kg/ha), Biomass 1st run (kg/ha)

Table 3.3: Metrics selected to test response in accordance with functional requirements of fish species; all metrics were calculated separately for native and all species

Functional guild	Criteria	Calculated metric variants
Tolerance	Intolerant, tolerant	Number of species, % number of species, individuals (n/ha), % individuals, biomass (kg/ha), % biomass
Habitat - degree of rheophily	Rheophilic, limnophilic, eurytopic	
Habitat - feeding	Water column, benthic,	
Reproduction	Lithophilic, phytophilic	
Longevity	Long-lived, short-lived	
Feeding	Piscivorous, insectivorous/ invertivorous, omnivorous	
Migration	Long-distance, potamodromous	

Table 3.4: Historical metrics selected to test respond in accordance with functional requirements of fish species;

Functional guild/metric type	Criteria	Calculated metrics
Overall composition	Native species	N historical Species, % native of historical Sp
Tolerance	Intolerant, tolerant	% historical species of native species
Habitat – degree rheophily	Rheophilic, limnophilic, eurytopic	
Habitat – feeding	Water column, benthic,	
Reproduction	Lithophilic, phytophilic	
Longevity	Long-lived, short-lived	
Feeding	Piscivorous, insectivorous, omnivorous	
Migration	Long-distance, potamodromous	

For each of the 45 sentinel species, two abundance metrics (density in n/ha, biomass in kg/ha) as well as population structure metrics (presence 0+ (0,1), Density 0+ (n/ha), % of 0+) were calculated.

Fish sampling procedure, field testing

Electric fishing was the most often used method in the FAME group. Therefore, the collection of existing sampling data was restricted to this sampling method. The agreement on a standardised sampling procedure was based on the CEN directive “Water Analysis – Fishing with Electricity (EN 14011).

Depending on the river size and river section to be sampled, electric fishing is carried out by wading or boat. The selection of waveform DC (Direct Current) or PDC (Pulsed Direct Current) depends on the conductivity of the water, the dimensions of the water body and the fish species to be expected. For both wadable and non-wadable rivers (river depth < 0.7 m), fishing equipment must be adapted to sample small individuals (young-of-the-year). According to the CEN-standard, the main purpose of the standardised sampling procedure is to record information concerning fish composition and abundance; therefore, no sampling period is defined (according to CEN). In contrast, FAME agreed on a sampling period in late summer/early autumn except for non-permanent Mediterranean rivers. Table 3.5 andTable 3.6 provide an overview of the electric fishing procedure as agreed for FAME. Furthermore, a standardised sampling protocol was prepared for recording all necessary abiotic and biotic data.

Table 3.5: Standardised sampling procedure as agreed upon in FAME for wadable rivers

Criteria	Wadable rivers
Waveform selection	DC or PDC
Number of anodes	One anode per 5 m river width
Number of hand-netters	Each anode followed by 1 or 2 hand-netters (max. mesh size: 6 mm) and 1 suitable vessel for transporting fish.
Number of runs	One run
Time of the day	Daylight hours
Fishing length	10- 20 times the wetted width; minimum area is 100 m^2

Fished area	The whole site surface
Fishing direction	Upstream
Movement	Slow, covering the habitat with a sweeping movement of the anodes and attempting to draw fish out of hiding.
Stop net	Used if feasible

Table 3.6: Standardised sampling procedure as agreed upon in FAME for non-wadable rivers

Criteria	Wadable rivers
Waveform selection	DC or PDC
Number of anodes	Minimum 2 anodes or boom
Number of runs	One run
Time of the day	Daylight hours
Fishing length	10- 20 times the wetted width; minimum area is 1000 m^2
Fished area	Two banks of the river or a number of sub-samples proportional to the diversity of the habitats present
Fishing direction	Preferably downstream in such a manner as to facilitate good coverage of the habitat
Movement	Slow, covering the habitat with a sweeping movement of the anodes (boom) and attempting to draw fish out of hiding
Stop net	Used if feasible

The field sampling procedure as agreed upon for FAME was tested in 12 ecoregions. In each ecoregion, 2 different river types were considered: one upstream and one lowland river section. In each river section, three different ecological status levels had to be sampled, whereas the pre-classification of sites was done as described above. Two replicates were taken for each sample.

3.1.2. Central database FIDES

The main basis for the method development was a central database, enabling identification of river types, description of reference conditions and testing of metrics response based on a large number of existing sampling data covering different levels of degradation.

The central database FIDES (FIsh Database of European Streams) was established on MS Access 2000. The structure, main tables and help tables as well as the variables creating the relations between the various tables are indicated in Figure 3.2. Variables and criteria integrated in main and help tables were agreed upon in the basic tools-section. Variables were defined as either obligatory or optional. In total, 209 variables were included. Data was initially compiled on the national level. After data quality and data assurance checks, they were integrated into the central database.

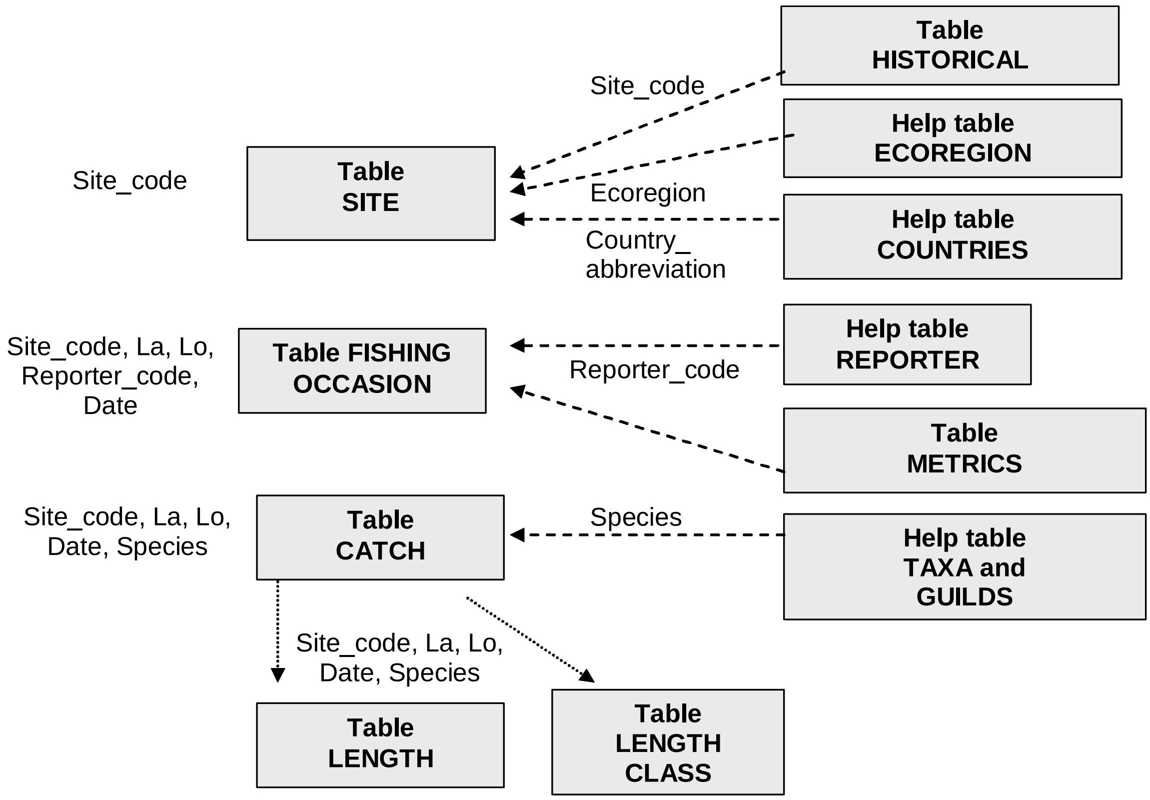

Figure 3.2: Structure of the central database FIDES (Fish Database of European Streams) and variables establishing relations between tables (La, Lo = latitude and longitude)

The most important tables in terms of data evaluation are: “Site-table” containing geographical as well as abiotic data not varying noticeably in time; “Fishing occasion-table” with information about the particular electric fishing occasion, with environmental and pressure data connected to the time of sampling; “Catch-table” including information about the fish catch per species and about methods used to estimate catch biomass and abundance; “Length-table” containing individual fish length data, whereas the “Length class-table” contained data on the number of individuals in length classes. Table “Historical data” contained available historical information on fish species. Variables are listed in detail in Figure 3.3.

Table Site	
Site_code	
Latitude	
Longitude	
Country_abbreviation	***Geological_typology***
Eco_region_no	*Geological_formation*
Subecoregion	**Mean_air_temperature**
River_type	Mean_Jan_temperature
Main_river_region	Mean_Jul_temperature
River_name	**Gradient_slope**
Site_name	*Huet_zonation*
National_map_code1	*Other_zonation*
National_map_code2	Stream_order
Size_of_catchment_class	***Lakes_upstream***
Size_of_catchment	Distance_to_lake
Width_flooded_area	**Distance_from_source**
Mean_discharge_class	***Distance_to_mouth_class***
Flow_regime	Distance_to_mouth
Altitude	***Water_source_type***

Table Fishing_occasion	
Site_code	
Latitude	
Longitude	
Date	
Reporter_code	
Numdate	***(1) Land_use_river***
Sampling_strategy	***Urbanisation_river***
Method	***Connectivity_river***
Day_Night	***Land_use_segment***
Number_of_runs	***Urbanisation_segment***
Runs_separated	***Riparian_zone_segment***
Water_temperature	***Connectivity_segment***
Conductivity_class	***Connectivity_multiscale***
Conductivity	***Floodplain_lateral_movements_segment***
Locality_length	***Sediment_load_segment***
Locality_width	***Hydrological_regime_site***
Fished_area	*Natural_flow_pattern_site*
Wetted_width	*Natural_flow_quantity_site*
Average_depth	***Upstream_dam_site***
Maximum_depth_class	***Morphological_condition_site***
Dominating_substrate	***Salinity_site***
Stop_nets_used	***Toxic_acidification_site***
No_of_anodes	***Nutrients_organic_input_site***
Type_of_anode	*Introduction_of_fish_site*
Size_of_anode	*Impact_of_stocking_site*
Type_of_current	*Exploitation_site*
Voltage_used	*Fauna_impact_site*
Wattage_used	*Flora_impact_site*
Mesh_size	*Weed_cutting_site*
(2) Reference_site	***Status_ecoregional***
Calibration_dataset	***Status_European_spatial***
Modelling_dataset	***Status_modelling***
Fish_type_ecoregional	**Local_IBI_method**
	Local_IBI_score
	Local_status_classification

Table Catch
Site_code
Latitude
Longitude
Date
Species
Run1_number_all
Run1_number_0_plus
Run2_number_all
Run2_number_0_plus
Run3_number_all
Run3_number_0_plus
Run4_number_all
Run4_number_0_plus
Total_number_all
Total_number_0_plus
Total_biomass
Biomass_estimate
Total_abundance
Abundance_estimate
Estimated_efficiency

Table Length
Site_code
Latitude
Longitude
Date
Species
Type_of_data
Length_type
Length

Table Length_class
Site_code
Latitude
Longitude
Date
Species
Type_of_data
Length_type
Length_class_min
Length_class_max
Number

Historical_data
Site_code
Period_start
Period_end
Period_string
Species
Status_scale_class
Abundance_class

Table Reporter
Reporter_code
Responsible_person
Company_University
Institute_Agency
Street_POB
City
State_Province
Postal_code
Country
Email

Table Taxa_and_guilds	
Species	
Fides_occure	**(Guild classification**
Tolerance	**16 variables)**
Habitat_feeding	**(Sentinel species**
Habitat_rheo	**14 variables)**
Reproduction	**(Native or alien per**
Feeding	**Main River Regions**
Migration	**40 variables)**
Longevity	

Figure 3.3: Main tables and variables included in the central database FIDES

3.1.3. Method development

Two different methodological approaches were tested: a site-specific modelling approach and the spatially based type-specific approach. The first one aims at predicting reference conditions at the site level by establishing models for reference metrics, whereby the models account for natural variability of rivers over Europe. In contrast, the second one accounts for environmental variability by splitting the whole variety of European rivers into distinct groups (river types) and developing assessment methods for each river type.

Site-specific approach – the European Fish Index

For the development of the European Fish Index, 5252 sites fulfilling obligatory environmental variables were used (one fishing occasion per site selected randomly). The pre-classification of the pressure status was done based on four variables: alterations of morphology (1) and hydrology (2), presence of toxic substances or acidification (3), and presence of nutrients (4). Several tests in which the interruption of connectivity was included as a human pressure variable failed (see chap. 3.2.4). The reference dataset[2] was obtained by selecting sites with a mean pressure status between 1 and 2, and none of the single pressure variables rated higher than 2 (1602 sites). Degraded sites were split into a weakly disturbed dataset (1598 sites, sum of pressure status 8–12) and heavily disturbed sites (1262 sites, sum of pressure status >12). All datasets were divided into subsets for method development and validation.

For the modelling of reference metrics, 13 environmental, sampling technic and local variables were used: 9 local abiotic criteria (altitude, distance from source, size of catchment, slope, wetted width, mean annual air temperature, presence/absence of a lake upstream, geological type, flow regime), and 3 variables describing sampling methods and effort (sampling strategy and method, fished area). Five of these explanatory variables were transformed into logarithm (ln(x+1)) to reduce the skewness of their distribution.

The 13th variable integrated the zoogeographical distribution of (native) fish species. According to the WFD, ecoregions as defined by Illies (1978) are the basic geographical unit. Among other factors, such as biogeography or climate, these ecoregions are based on altitudinal thresholds, thus dividing river basins into upper and lower parts. In terms of fish assemblages, however, drainage basins seem to be more appropriate as ecologically relevant regions. Thus, for the development of the European Fish Index, 41 hydrological units representing either large river basins (> 25,000 km^2) or smaller catchments flowing to the same sea coast (ICES/IHBS sea areas; see www.ices.dk) were used as main geographical areas. In all, 154 native species were listed for the 41 catchment (groups). The corresponding (native) fish fauna lists were compared and classified into 16 river groups (Jaccard Index, hierarchical cluster analysis UGPMA type).

The 16 types of functional metrics (see Table 3.3) were tested, considering native and alien species. Furthermore, metrics accounting for total species richness and total

[2] i.e. corresponds to "calibration dataset"; due to the splitting of the FIDES calibration dataset (= sites with a joint pressure status of 1 or 2) into "dataset for model calibration", metrics validation, the index validation is described here as reference dataset

abundance were examined. For each metric, the expected response to degradation was hypothesised prior to modelling (increase for eurytopic, tolerant, omnivorous, water column, phytophilous increase or a decrease for total richness and density, for all others a decrease was expected). The metric variants calculated for each metric types are given in Table 3.3.

The steps involved in the development of the European Fish Index as described below are shown in Figure 3.4.

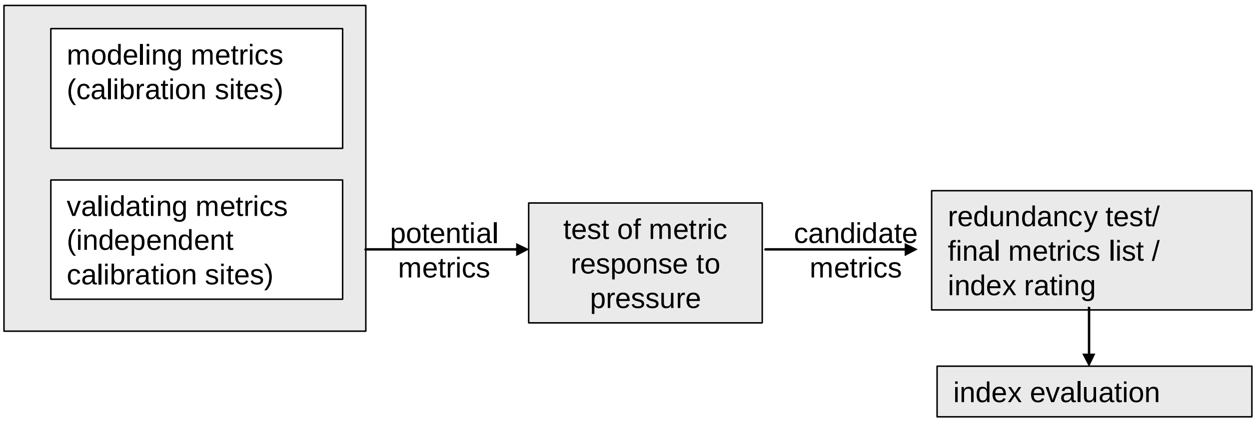

Figure 3.4: Development of the European Fish Index

Metric selection – Modelling and validation: The first step of the metric selection was to model reference metrics as obtained in reference sites as a function of the 13 variables. Due to incomplete data availability, only 11 of the 16 river groups were included (number of sites per river group in reference dataset = 39 to 413). Metrics based on abundance data (n=15) were modelled using stepwise multilinear regression analysis. Squares of quantitative variables were also included to allow for non-linear relationships. For metrics based on the number of species (n=15), the same procedure was applied, but a further explanatory variable, fished area, was added because the sampling effort is known to influence species richness. For metrics based on relative number of species or relative abundance (n=28), stepwise logistic regression analysis on the same set of explanatory variables was used. Variable selection during the stepwise procedure was based on the Aquaike Information Criteria (Hastie & Pregibon 1993).

Metrics obtained in the first step were validated with a separate dataset by comparing observed values of the metric with predicted values. For models to be valid, it was expected: (1) that the intercept and the slope of the regression line of observed versus predicted values will not be significantly different from zero (t-test, p>0.05) and one (t-test, p>0.05), respectively; and (2) that the part of the variance explained by the model (R^2, determination coefficient) for the validation dataset will be higher than 0.30 (arbitrary threshold). Residuals of each of the remaining metric-specific models (i.e. the deviation between the observed and the predicted value of a metric) were used as metric values, independent of natural environmental variability. The residuals were standardised through subtraction and division by the mean and the standard deviation, respectively, of the residuals of the reference data set.

Metrics response to human pressures. The second step of the metric selection was to test their sensitivity to human pressures. For each subset of weakly and heavily impacted sites, the “reference” values for the metrics retained after the sensitivity test were predicted by the models. Residual values were standardised using the mean and standard deviation of the residuals of the reference data set. Afterwards, the assumption was tested (t-test) for each metric that the mean values of the model reference calibration dataset did not differ from the reference validation dataset on the one hand, while on the other hand mean values differed for all other datasets (reference from weakly degraded, weakly from heavily, reference from heavily degraded sites). Furthermore, it was tested whether the absolute mean value of weakly disturbed sites (validation dataset) was lower than the absolute value of heavily disturbed sites (i.e. the metric response must increase with the intensity of disturbance). A total of 21 metrics fulfilled these criteria (candidate metrics, see also chap. 3.2.4 for results). All candidate metrics decreased with disturbance, except for densities of omnivorous species and phytophilous species as well as the relative occurrence of tolerant species. Some metrics exhibited a stronger response than others: for example, densities of lithophilic species compared with densities of omnivorous species.

Transforming metrics into probabilities and final selection: As some standardised residual values tend to increase with disturbance, whereas others decrease, residual values were transformed into probabilities, assuming that the distribution of standardised residuals of the reference calibration sites was normalised (see Oberdorff et al. 2002 and Pont et al. 2005 for details). As a consequence, all metrics will vary between 0 and 1, whereas standardised residuals have no finite values. Moreover, all metrics will have the same response to disturbance (a decrease). After transformation, the metric value observed at any independent site reflects the probability of this site being a reference site, according to the considered metric. An independent site that fits perfectly with the prediction will have a final metric value of 0.5, whereas the value for an impaired site would have to decrease when disturbance intensity increases.

A correlation test was performed for the final selection of metrics (i.e. Pearson’s r <0.80 or >-0.80). When two metrics were highly correlated, the functional metric type (total richness and abundance, tolerance, trophic status, reproduction, habitat, migration) which was not yet represented in the list of selected metrics was selected. When two or more of the same metric type remained present, we selected the metric which demonstrated the strongest response to a high level of disturbance (for results see chap. 3.2.4).

Index validation and rating: The final index is obtained by summing up the ten metrics and rescaling the score from 0 to 1. The metric values and the final index scores were computed for the reference calibration dataset and three independent datasets for index validation (reference, weakly, heavily disturbed sites).

Validating the index required verifying that the mean value of the index in the calibration reference data set does not differ from 0.50, that the mean values of the calibration dataset do not differ from the reference validation dataset, and that the mean index value for weakly disturbed sites is significantly lower than for reference sites, yet significantly higher than for heavily disturbed sites.

The efficiency of the index in discriminating between independent reference and disturbed sites was evaluated by examining the percentages of well-classified references as well as weakly and heavily disturbed sites as a function of each index score value. This yielded the best threshold value – i.e. the value for which the number of well-classified reference and disturbed sites were equal and in which the risk of the two types of error (type I and type II) was balanced. A similar approach was used for *rating the index* for classes 2, 3 and 4. For classes 1 and 5 (i.e. threshold between 1 and 2, 4 and 5), thresholds had to be set arbitrarily due to lack of data.

Index evaluation

The independence of the European Fish Index from natural environmental variability was tested by stepwise linear regression of the index values on the 13 environmental descriptors considered during modelling, using the independent reference data set. A multiple comparison Tukey's test was performed for each of the 13 environmental descriptors to test the invariance of the index. In addition, the Index response to the Illies ecoregional classification was tested.

Finally, the index response to different types of human pressure was tested. This was done by independently evaluating subsets of sites affected by only one of these two kinds of human disturbances (physical and chemical). For chemical pressures, sites for which levels of morphological and hydrological pressures were one or two were selected. For physical pressure effects, selected sites had scores for nutrients and toxic/acidification pressures of one or two. For each type of pressure, the impact values varied from 2 to 10 and were then transformed into 5 classes (class 1: 2, class 2: 3-4, class 3: 5-6, class 4: 7-8, class 5: 9-10).

The spatially based type-specific approach

In contrast to the European Fish Index, which accounts for natural variability by including environmental variables on a site scale, the spatially based approach integrates the variability of European rivers and fish assemblages by allocating rivers to specific types. River types can be identified based on abiotic as well as on biological factors. According to the WFD, river typologies must be established by abiotic variables, whereas Member States can choose between two different options (systems A and B). For the FAME project, the river typology was initially based on fish species composition; afterwards, the relevant abiotic factors and thresholds were identified.

For river-type-specific methods, the reference conditions and assessment methods are also type specific. A standardised procedure for the method development was defined. It aimed at achieving comparability of the type-specific methods. The procedure of the development of spatially based methods as described below is shown in Figure 3.6. It was applied on an ecoregional as well as on a European scale.

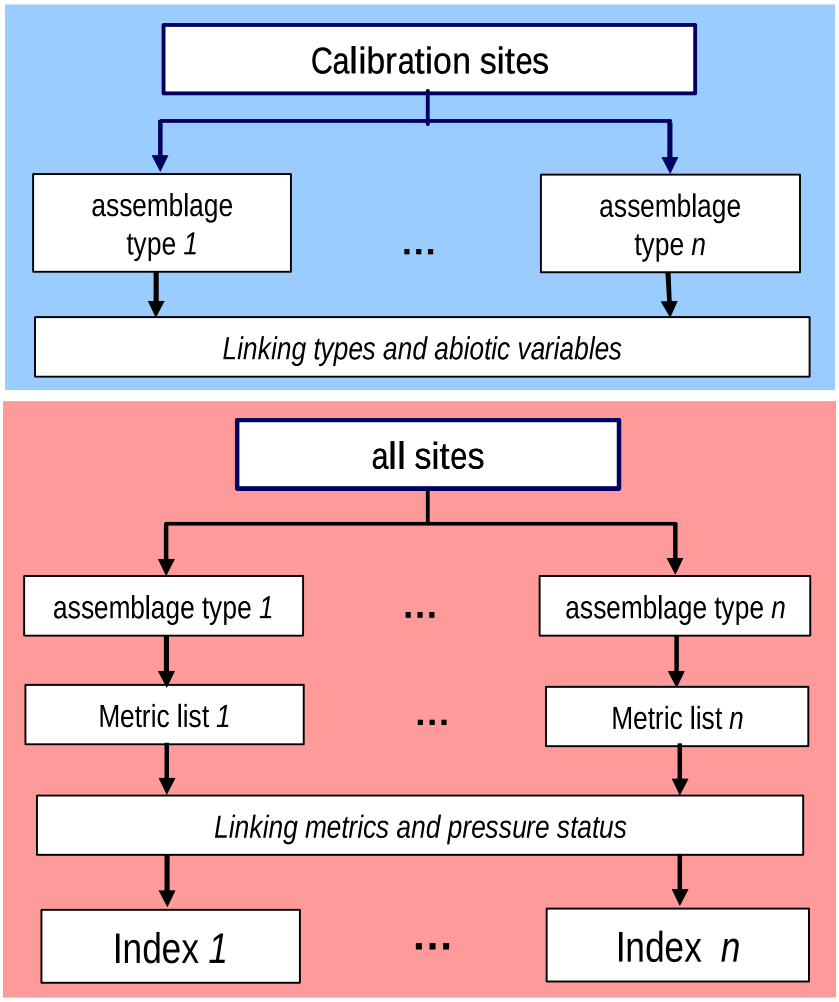

Figure 3.5: General scheme for the development of spatially based methods

Extraction of calibration datasets, pressure variables:

Ecoregional fish-based river types were classified using ecoregional calibration datasets fulfilling the minimum number of sampling sites (30 sites). For the analysis on the ecoregional scale, the calculation of the pressure status was based on the 5 environmental variables morphological (1) and hydrological conditions (2), nutrients/organic input (3) and toxic substances/acidification (4) on the site level and connectivity on the segment level (5). Again, only sites where none of the variables was rated higher than 2 were used. Exceptions, however, were possible to increase the calibration datasets. In the case of the spatially based approach on the European level, the same four variables were used as for the site-specific European Fish Index (connectivity excluded).

Definition of fish-based river types (biological types):

The ecoregion-specific calibration datasets were used to identify fish-based river types as described also in chap. 3.1.1. A hierarchical cluster analysis (WARD method, Euclidean distance measure) was performed using either total or relative abundance of fish species in the 1st run (n/ha).

Linking biotic and abiotic typology:

Degraded sites were assigned to the corresponding type after identifying abiotic factors and thresholds relevant for structuring fish assemblages. This was done by multivariate statistics (discriminant analyses to predict the correct type). Furthermore, it was examined whether the abiotic factors and threshold are in line with either system A or B of the WFD.

Analysis of type-specific metric sets:

(1) Screening of potential metrics and selection of candidate metrics for each river type: Potential metrics are those that are assumed to respond to human pressures. The list of potential metrics included nearly 450. In order to avoid tests of normal distribution for each of these metrics and tests of a linear relation between metrics and impacts, the first screening was done using Spearman´s rank correlation coefficient. The metrics with the highest positive and negative correlation to the joint pressure variable were selected as candidate metrics. They should have correlation coefficients > 0.4 or < -0.4 (candidate metrics being those metrics where the response to human pressures was proved).

(2) Selection of final metrics: Several statistical tools were used for this step: (1) Correlation test to identify e.g. redundant metrics, (2) descriptive statistics to compare metric reactions in different types, to indicate particular single pressures or to establish the distribution of metric values for different degradation levels, (3) discriminant analysis. For all analyses the pre-classification of the pressure status was used as an estimate for pressure intensity.

When the final metrics were selected based on statistical tools as mentioned under (1) and (2), then reference conditions and scores for the quality classes had to be established in a separate step. When the selection was done based on discriminant analysis, the quality class was predicted.

Within the FAME project the spatially based approach was first applied on the ecoregional and in a later stage also on the European level. To identify European Fish Types, all ecoregional types were clustered based on the relative abundance of fish species.

Standardised European Model

Besides the site-specific European Fish Index and the spatially based methods on the ecoregional and European scale, another modification of the spatially based methods was tested to develop an additional standardised method on the European level. For this approach, type-specific metrics were normalised to a range between 0 and 1, whereby the highest metric value for each type was set to 1 and the lowest to 0.

3.1.4. Method comparison

From the two different approaches to develop assessment methods, four different indices types were available: (1) the European Fish Index (EFI), (2) the spatially based models on the ecoregional scale (SBM-ER), (3) the spatially based models on the European scale (SBM-EU) and (4) the standardised European model. Furthermore, a pre-classification of sites based on human degradation was performed, yielding the pressure status (5, PS).

Also, nine existing regional methods as presented in Table 3.7 were included in the method comparison (6^{th} index). In order to identify the strengths and weaknesses of each method, they were compared with each other by statistically testing the performance and differences. In a second step the focus of the analysis was on the EFI, which was finally selected as the FAME assessment method.

Table 3.7: The 9 regional methods integrated to the method comparison, N = number of FIDES sites assessed by the corresponding method

Country	N	Name	Method used to develop the model
Austria	483	Mulfa	Expert judgement
	166	National	Expert judgement
Belgium: Flanders	1043	IBI for upstream rivers & for Barbel and Bream zone	Index of Biotic Integrity (Karr et al., 1986) adapted to the conditions of the Trout and Grayling zone (upstream rivers) and of the Barbel and Bream zone in Flanders. (Breine et al. 2000).
Belgium: Wallonia	65	IBI for the Meuse & the wadable parts of a large river basin	Index of Biotic Integrity (Karr et al., 1986) adapted to the conditions of the Meuse (France, Belgium and the Netherlands) + the wadable parts of a large river basin (Meuse and Scheldt) in Wallonia
France	1584		Reference Condition Approach comparable with EFI (Oberdorff & Hughes, 1992).
Lithuania	355		Index of Biotic Integrity (Karr et al., 1986) adapted to the conditions of Lithuania.
Sweden	3544	FIX (Fish Index)	Index of biological status using fish: Swedish Electro-fishing RegiSter (SERS).
U.K.	203	Salmon Index	Based on the presence of salmon
	203	Trout Index	Based on the presence of trout

Data selection: In order to compare the methods, 3946 sites in which all 6 indices were available were selected. All fishing occasions were retained because selecting only one occasion would reduce the dataset to 1781 sites. Although the number of sites is large, the distribution across Europe is inhomogenous: 36 % of the sites are from Swedish rivers, 36 % from France and 20 % from Flanders/Belgium. In comparing the EFI with other methods, the dataset changed from analysis to analysis to improve data availability (e.g. 9876 sites for the comparison EFI and PS, 5436 for comparing EFI and existing methods).

Data analyses: The performance of the methods was tested by their sensitivity (proportion of impacted sites which will be detected by the method and sites which will be missed) and specificity (proportion of non impacted sites which will be detected and sites which will be missed) of the particulate indices with pressure status classification as benchmark. In contrast to sensitivity the impacted predictive value is calculated based on the number of sites correctly and falsely classified as impacted, while the non-impacted predictive value gives the proportion of correctly and falsely classified as non-impacted sites. Thus for sensitivity and specificity the perspective is the type of the site while for the impacted and non-impacted predictive value it is the result of the test.

The EFI is a continuous variable. This enables its more detailed analysis by testing the consistency in terms of different criteria such as national methods, river groups, ecoregions, pressure status and the 5 functional guild groups of the EFI metrics list. The interpretation was based on cumulative distribution curves and thresholds obtained for the EFI (0.67, 0.45, 0.28, 0.19).

During the analysis, several levels of detail in terms of status classes were tested: The full level of detail with a separation of all 5 status classes, and a lower level of detail involving several groups of classes (class 1 and 2 vs. classes 3-5 as non-impacted vs. impacted, class 1 and 2 vs. class 3 vs. class 4 and 5 as non-impacted vs. weakly impacted vs. heavily impacted). Furthermore, four binary contrasts were analysed (class 1 vs. classes 2-5, class 1 and 2 vs. 3-5, classes 1-3 vs. 4 and 5 and classes 1-4 vs. 5). The results presented in chap. 3.2.7. focus mainly on the discrimination capacity between the two main levels, i.e. classes 1 and 2 vs. classes 3-5 because this is the most important one for the WFD (for further results see Quataert et al. 2004).

3.2. Scientific achievements

3.2.1. General overview of scientific achievements

In the FAME project, several fish-based methods for assessing the ecological status of European rivers were developed. Two principle approaches were applied: (1) a site-specific approach, predicting reference conditions for each of the 10 finally selected metrics on the site level, and (2) a spatially based type-specific approach which identified reference conditions and assessment methods for fish-based river types. Thus, 4 different types of methods were developed: the site-specific European Fish Index, applicable on the European scale, and spatially based models applicable on the ecoregional as well as on the European scale. The applicability of the methods in practice was tested and their performance was compared by statistical analyses. Based on these tests the final choice of the FAME group was to propose the European Fish Index as the standardised FAME assessment method.

Most results pertaining to basic tools are included in the results of the method development. Only the fish species classification and the description of the FIDES contents are provided here separately.

3.2.2. Species classification

A total of 236 fish species, 44 of them being species introduced into Europe, were identified to inhabit the rivers considered by FAME partners. Of these, 122 species were fully classified into one of the functional guilds described in chap. 3.1.1 based on existing ecological knowledge. A total of 155 species could be classified into the three main ecological groups of trophic, reproductive and habitat functions. This highlights that ecological assessments are still restricted by an insufficient ecological understanding of many species, especially for endemic species of the Southern European ecoregions such as the Balkans and the Aegean. Some ecological functions demonstrated great flexibility within populations as well as between populations across their range, in particular for feeding guilds. A modification of the guild criteria in the current format should be considered (integration of feeding flexibility of fish species and inclusion of secondary food types). Such a modification was not attempted during the FAME project. Furthermore, the assessment of “tolerance” is quite vague for many fish species. Until additional ecological knowledge becomes available, however, the designation of tolerant and intolerant species will reasonably classify those species with a known reaction to human pressure but for which the mechanisms of reaction are not fully understood.

Where naturalised, alien species should be fully integrated into ecological assessment methods to determine the ecological status of rivers. However, separate assessments should be made for the relative status of alien and native species and the conservation status of communities. Such separate assessments may be required for the implementation of conservation directives under the umbrella of the WFD.

3.2.3. Contents of FIDES

National data were delivered from 12 countries (Austria, Belgium, France, Germany, Greece, Lithuania, Poland, Portugal, Spain, Sweden, The Netherlands, United Kingdom).This data covered information about 17 ecoregions and 40 main river regions. All in all, datasets from 2651 rivers, 8228 sites and about 15,000 fishing occasions (including samples taken between 1955 and 2002) are incorporated, although most of data are from 1980 onwards. The contents per country are presented in Table 3.8 (see also Beier et al. 2005). The locations of sites were more concentrated in the central western part of Europe, with less dense representation towards the south, east and north.

Table 3.8: Overview on FIDES datasets; for abiotic and pressure variables used for developing the European Fish Index EFI, see below and chap. 3.1.3.

	Table “Site”		**Table “Fishing occasion”**			**Table “Catch”**	**Table “Length / Length class”**
Country	N cases	Mean % Valid cases variables used for EFI	N cases	Mean % Valid cases variables used for EFI	% Sites with multiple fishing occasions	N Recorded catches (species at fishing occasions)	% Fishing occasions with provided length data
Austria	1 053	100	1 395	100	15	7 595	99
BE - Flanders	1 042	100	1 684	100	41	7 769	39
BE - Wallonia	120	100	158	100	12	1 485	100
Germany	1 854	62	2 300	42	12	12 980	68
Spain	294	100	356	100	21	747	57
France	815	100	1 584	100	48	12 420	0
Greece	56	100	83	100	23	200	73
Lithuania	253	100	355	100	23	2 863	25
Netherlands	662	100	976	88	26	5 619	0
Poland	154	100	154	100	0	967	73
Portugal	232	100	232	95	0	997	0
Sweden	623	97	3 765	100	80	10 888	93
United Kingdom	1 070	100	2 141	99	27	14 030	58
TOTAL	**8 228**	**91**	**15 183**	**90**	**15**	**78 560**	**59**

Pressure status of European rivers:

Out of the 15,183 fishing occasions in FIDES, complete reporting of all 24 impact variables was only available for 4067 occasions. For some ecoregions no complete data sets existed. In consequence it was decided that the joint impact variable should be the average of the summed impact (1-5) of four (EFI, SBM-EU) or five variables (SBM-ER): hydrological regime, morphological condition, toxic and acidic substances, input of nutrients and organic matter, and connectivity (segment level). The classification of the single variables is summarized in Table 3.9. Connectivity at the river basin scale was classified as disturbed (impact class 3 to 5) in ca. 60% of investigated sites, with a better situation in the larger rivers. Also for morphological conditions, about 50 % (small rivers) and 70 % (large rivers) of the sites were degraded. In terms of hydrological regime, 38% of small river and 62 % of larger rivers sites were classified as moderate or worse. Chemical impact in the form of toxic or acidic substances affecting fish communities was considered rare in the larger rivers, while the conditions were regarded as unsatisfactory in 27% of the smaller rivers. At 49% of all sites the load of nutrients or organic matter was shown to be too high (impact class 3-5).

The pressure status in terms of the single variables considered in the method development (both, SBM and EFI) and the overall pressure status is listed in Figure 3.6.

Table 3.9. Proportion (%) of sites classified as high and good status (pressure status 1-2), moderate status (3), and poor and bad status (4-5) for the variables used to calculate the joint pressure status. Rivers divided into small (<1000 km^2) and large (>1000 km^2) Catchments.

Variable	**Catchment size**	**Impact classification 1-2**	**3**	**4-5**	**n**
Connectivity river	*Small*	34,5%	18,2%	47,3%	5357
	Large	63,8%	17,6%	18,6%	1259
Hydrological regime	*Small*	67,9%	17,1%	15%	5256
	Large	38%	38,3%	23,7%	1258
Morphological conditions at site	*Small*	55,1%	24%	20,9%	5708
	Large	28,4%	14,4%	57,2%	1325
Toxic or acid substances	*Small*	73,4%	13,5%	13,1%	5789
	Large	91,5%	5,9%	2,6%	1326
Nutrients and organic input	*Small*	54,6%	19,6%	25,8%	5586
	Large	34,8%	59,8%	5,4%	1320

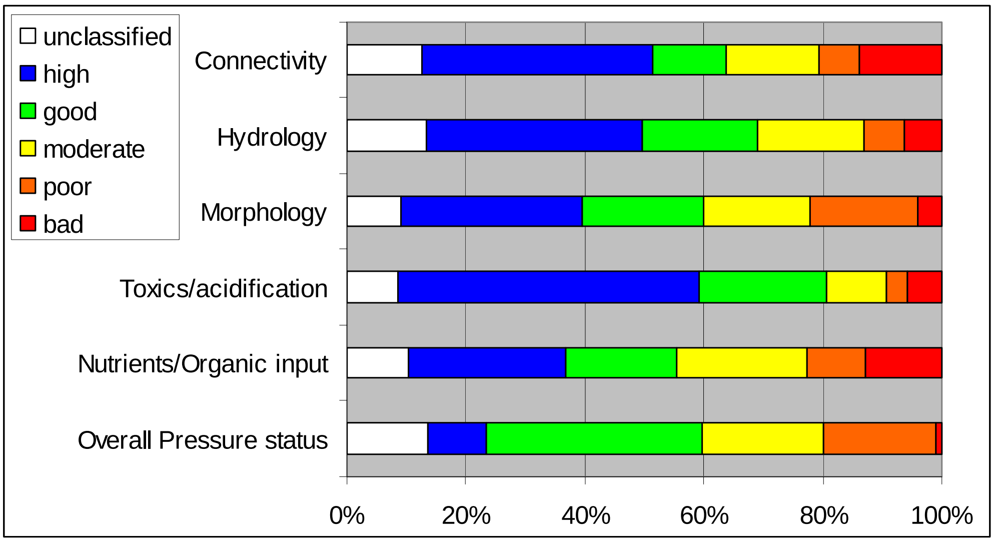

Figure 3.6: The status classification (percentage) of single pressure variables and of the overall pressure status (all fishing occasions; N =15,138).

3.2.4. The European Fish Index (EFI)

The modelling and validation of nearly 200 potential metrics as a function of the 13 variables yielded 29 metrics. After testing the sensitivity of these metrics to human pressures (weakly and heavily disturbed sites), 21 candidate metrics remained. The final list of 10 assessment metrics was obtained after testing the redundancy and extent of response to human pressure. In terms of functional aspects the finally selected metrics 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
- migratory behaviour (long-distance migrants, potamodromous species).

The values of correlation coefficients between the 10 selected metrics vary between 0.08 and 0.76, the highest value being between benthic and rheophilic species richness. Except for the density of omnivorous species and the relative occurrence of tolerant species, river group as variable integrating the regional factor is represented in all models. Slope, altitude and mean air temperature are the most important descriptors. Table 3.10 provides an overview on the variables as included in the reference models.

Table 3.10: The abiotic and location variables included in each of the 10 metric-specific reference models

	Fished area	Sampling method	Sampling strategy	Catchment class	Lake upstream	Geology	Flow regime	Altitude	Distance from source	Wetted width	Mean air temperature	River slope	River group
Insectivorous		+	+					+		+	+	+	+
Omnivorous			+		+			+	+	+	+	+	
Phytophylous			+		+			+		+		+	+
Benthic	+		+					+	+		+	+	+
Rheophilic	+		+					+	+		+	+	+
Diadromous	+					+	+	+		+		+	+
Potamodromous	+			+			+	+			+	+	+
Lithophilous		+	+	+	+	+	+	+	+	+	+	+	+
Intolerant	+	+			+		+				+	+	+
Tolerant		+			+	+		+		+	+	+	
Total number	5	4	6	2	5	3	4	9	4	6	8	10	8

The index validation demonstrated that (1) the mean value of the index in the calibration reference data set did not differ from 0.50 (t = 1.834, p-value = 0.067), (2) the mean index values in the calibration reference dataset did not differ significantly from the validation reference dataset (t = 0.312, p-value = 0.7551), (3) the mean index value in the weakly disturbed sites was significantly lower than that of the reference sites (t = 16.546, P<0.000001) and significantly higher than that of the highly disturbed sites (0.24, t = 10.36, P<0000001).

The test for correctly classified sites as a function of the index value demonstrated – for an index value of 0.425 – an about 80 % correct prediction of degraded and non-impacted sites. At an index value below 0.395, 86.2 % of the sites were correctly classified.

The index rating, which was based on an approach similar to index validation, was done using data from 3205 sites. The threshold between integrity classes 2 and 3 was set at an index value of 0.449, with 75.7% correctly classified sites. The threshold between classes 3 and 4 was 2.79, with 62.8% correct status assignment. Thresholds between classes 1 and 2 as well as between 4 and 5 had to be defined arbitrarily due to lack of data. The final rating of the index for the ecological status classes 1- 5 is presented in Table 3.11.

Table 3.11: Rating of the European Fish Index for the 5 ecological status classes

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
Bad status (class 5): 0.000 – 0.187

Index evaluation - Response to natural environmental variability: The stepwise linear regression of index values on the 13 variables showed that none of the descriptors were retained by the procedure and that the part of the index variability explained by these descriptors was non-significant (R^2 = 0.115, F-test = 1.505, P = 0.064). When considering each of the 13 environmental descriptors separately, the multiple comparison Tukey's test showed that the index values were invariant, whatever the value of the considered descriptor, except for the two highest altitude classes, and the two lowest fishing area classes.

The European Fish Index is insensitive to ecoregion, which for the EFI is an independent regional variable (multiple comparison Tukey's test, p>0.05). This result demonstrates that the river group classification, based on the 41 hydrological units, is able to integrate most of the variability of our 10 functional metrics at the regional scale.

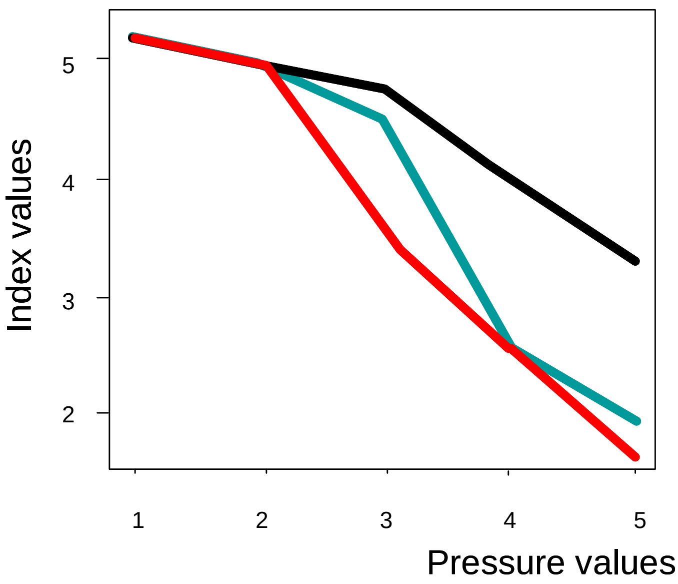

Figure 3.7: Index response for sites affected by 4 pressures (red line), only chemical pressures (blue) and only physical pressures (black).

Index evaluation - Response to human pressure: The test was performed for physical (alterations of hydrology, morphology) and chemical pressures (nutrients/organic input, toxic substances/acidification). The index response to chemical alteration (Table 3.12) is similar to that obtained when considering all four pressure variables (multi-impacted sites), except for class 3, in which the mean value of the index is higher when considering water quality alterations alone. For sites only affected by physical pressures, the index demonstrates a significant but weaker response, with a mean index value close to 0.35 for a pressure class of 5 compared with about 0.20 for other types of pressures. The deviation is particularly small for class 3.

Table 3.12: Mean fish index score (5% confidence interval in brackets; number of sites in italics) per each of the five classes of human pressure (for classes see table 3.11) when considering all types of pressures, only chemical pressures and only physical pressures.

Pressure Classes	All pressures	Chemical pressures	Physical pressures
Class 1	0.52 (0.02) *84*	0.52 (0.01) *172*	0.52 (0.02) *134*
Class 2	0.51 (0.01) *220*	0.50 (0.02) *132*	0.51 (0.02) *170*
Class 3	0.34 (0.01) *304*	0.43 (0.07) *12*	0.42 (0.04) *26*
Class 4	0.24 (0.01) *283*	0.22 (0.06) *11*	0.40 (0.04) *27*
Class 5	0.16 (0.04) *21*	0.23 (0.06) *14*	0.35 (0.13) *3*

Limits of the application of EFI

The EFI is a sound, scientifically based assessment method for the ecological status of rivers. Due to the properties of the database used for the method development, however, it cannot be applied for all rivers without further modifications. In terms of geographical limits, the EFI was developed mainly based on data from central, western, northern and north-eastern parts of Europe. Only few southern river sites were included (some sites from northern Portugal and northern Spain). As such, the EFI can be applied only for the 11 river groups which were integrated (Ebro River, Catalunian-Mediterranean rivers, northern Portugal, Danube group, South-West Sweden, North-East Plains, French-Mediterranean rivers, Western Plains, United Kingdom, Rhone River, Meuse-group rivers; for details see Pont et al. 2004, Pont et al. 2005).

In order to provide methods for the southern part of Europe a new database for Mediterranean rivers was established by Portuguese, Spanish, French and Greek partners parallel to the FAME project. An assessment method based on an approach comparable to the EFI will be developed and available soon.

In terms of abiotic criteria, characteristic values (as minimum, maximum, median) are presented in Table 3.13 for some main variables characteristic for FIDES sites.

Table 3.13: Minimum, median and maximal values of environmental characteristic

Characteristics	Minimum	Median	Maximum
Distance from source	0.0	20.0	990.0
Altitude	0.0	56.0	1950.0
Slope gradient (m/1000m)	0.50	7.0	199.0
Wetted width	0.5	7.0	1600.0
Mean air temperature	-2.0	10.0	16.0

The FIDES dataset contained no reference sites for large rivers. Thus, metrics selection and index development did not focus on the particularities of these rivers. Although the percentage of correct classification of sites with a catchment class > 10,000 km^2 was 94 %, the applicability of the EFI for large rivers is not well proved. Furthermore, only fish data obtained with electric fishing (one passage) may be used to calculate the EFI – which seems to be another limit of applicability for large rivers.

The EFI provides a continuous score value. Some of the attributed integrity classes should be interpreted with caution because the distinction of classes 1 and 2 (high, good status) and 4 and 5 (poor, bad status) was set arbitrarily.

Minimum standards for sites to be valid for the application of the EFI: > 30 sampled individuals at one site; minimum fished area 100 m^2. Only electric fishing data can be used. Furthermore, the EFI is calculated from the catch of the 1st run.

Tests of integrating connectivity as human pressure

Data on alterations of river connectivity (artificial migration barriers) were included in FIDES at two scales: the river basin and the segment. Similarly to other pressure variables, sites were classified into 5 different levels (high status: no artificial barriers, or bypasses and similar devices were present; good status: passage of an artificial obstacle was possible for most species in most years; moderate: migration was possible during certain years only or only for certain species; poor status applies when only single species could pass occasionally, and when no species could pass the status was bad).

Connectivity was initially included as the 5th main pressure variable in calculating the joint pressure status. However, there was no response of the 1st version of the European Fish Index to connectivity. To be able to assess the additive effects of connectivity at the river basin and segment scales, a combined variable, “Connectivity at the multi-scale level”, was calculated and integrated again as the 5th pressure variable. Again, the results remained unsatisfactory. Connectivity was therefore finally excluded from the development of the European Fish Index.

3.2.5. The spatially based type-specific methods

The European Fish Index is a site-specific method, thus predicting reference conditions as 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 a river-type level. 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), the spatially based approach was applied to 11 ecoregions (Iberian Peninsula, Pyrennes, Alps, Western Highland, Central Highlands, Western Plains, Central Plains, Baltic Province, Great Britain, Borealic Uplands, Fenno-Scandian Shield). 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 data for different degradation levels was too low to develop type-specific assessment methods.

The European Fish Types (EFT) and spatially based models on the European scale

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 the fish-based 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.

3.2.6. Practical test of the field sampling strategy and applicability of EFI and SBMs

The practicability of the EFI and the spatially based methods on the ecoregional level were tested by applying them to newly sampled sites. A total of 218 samples in 12 ecoregions and 121 rivers were taken. Both methods, however, were available and applicable for only 123 sites.

For the SBMs-ER scale, 63 % of the sites were classified correctly in terms of pressure status and splitting into impacted and non-impacted sites only. For 25 % of the sites the pressure status was 1 or 2, whereas the corresponding type-specific SBM classified the site as impacted. For 12 % of the sites the SBMs classified better than the pressure status. By applying the EFI, 73 % of the sites were classified correctly, while EFI missed 18 % of the impacted sites in terms of pressure status as the benchmark.

3.2.7. Method comparison

The correspondence of each FAME index with respect to the pressure status decreases with the level of detail. When separating between non-impacted (class 1, 2) and impacted sites (classes 3-5), between 80-90 % of the sites were classified correctly. For all 5 classes ranging from high to bad status, the percentages decrease to values between 35 (existing methods) and 60 (SBM-EU).

The performance of the indices developed within FAME (EFI, SBM and SEM) does not vary much. Differences between classes 1 and 2 as well as 4 and 5 are not very reliable as the number of sites is too low. Regrouping into three classes (1-2, 3 and 4-5) improves the comparability of the indices. In most methods, class 3 takes an intermediate position and the cumulative curves of the reference situation (1-2) and the poor to bad status (4-5) are well separated. This fulfils the requirement of the WFD to have a good distinction between unimpacted and disturbed sites (the contrast between 1-2 and 3-5).

The evaluation in terms of sensitivity and specificity to detect the pressure status (PS) ranks the SMB-EU and SEM at an equal position. Moreover, about 90 % of the classifications are correct, higher than EFI (80 %). However, this difference is probably not very significant because the pre-classification of the pressure status is not without error. Further, the EFI, in contrast to SBM-EU and SEM, does not optimise directly on the distinction between disturbed and undisturbed based on the pressure status, but first models the reference situation without refering to pressure status. Only in the next step are the well-behaving metrics selected based on the contrast between reference and disturbed sites (weakly and heavily impacted sites). Although this indirect optimisation is a handicap in terms of sensitivity and specificity, it protects against over-fitting, i.e. adjusting the parameters too much to the available data at the expense of extrapolation power.

In spite of this handicap in the modelling process, the prediction quality of EFI is comparable to the other approaches. This is remarkable and indicates that the fundaments of the model are biologically sound, practicable and go beyond a purely empirical fitting. For these reasons among others the FAME-project selected the site-specific approach as the final assessment method: the European Fish Index (EFI).

In terms of comparison with pressure pre-classification, existing methods perform similarly to FAME methods when differentiating between 2 classes only. With increasing detail (3 classes and all 5 classes), however, the correspondence decreases to only ca. 30 %.

Detailed analysis of EFI

Performance with respect to Pressure Status: There is a clear separation between classes 1-2 and 4-5, with class 3 having an intermediate position. For non-impacted and disturbed sites the sensitivity to detect a poor or bad status (4 or 5) is close to 100 %; for the moderate status (3), sensitivity is still 70 %, with a specificity of 80 %. This gives a good balance between sensitivity and specificity and yields a predictive value for impacted sites of about 80 %. At the next threshold (1-3/4-5), the specificity is about 100 % for classes 1 and 2 (nearly no undisturbed sites are classified as poor or bad) and 70 % for class 3. The sensitivity for classes 4 and 5 still remains higher than 80%.

Performance with respect to existing regional methods: The relation between EFI and the existing methods is seldom good. For Austria, EFI cannot reproduce the results of any of the two Austrian methods Flemish sites range from 2 to 4 based on the index of Flanders (in Belgium). EFI classifies them from 3 to 5 and does not discriminate between level 2 or 3. The difference in quality seen from a Flemish perspective vanishes at a European level. In France the correspondence is good with regard to the main contrast; much of the discriminating capacity, however, disappears at the next threshold (1-3/4-5). The differentiation made by the index of disappears when the EFI is applied, and most of the cases classified as 2 receive a worse score. In Sweden, 97 % of the sites have a very good status. About 20 % of them are scored 3 by EFI. Of the 2.6 % in class 2, about 50 % receive a worse score. The differentiation made between classes 1-4 by the salmon index in the UK disappears. Nearly always, EFI gives a score of 2. For class 5, EFI ranges from 2 to 4.

Performance of the metric group of the EFI with respect to PS: The (normalised) continuous EFI_n is the average of 10 different metric scores, which can be grouped two by two into 5 dimensions: trophic structure, reproduction guilds, type of habitat, migration and connectivity, and sensitivity to general disturbance. None of them exhibited deviant behaviour. The metrics related with trophic structure (insectivorous and omnivorous guilds) and disturbance in general (tolerant species and intolerant species) seem to contribute most to the discrimination capacity. The migration/connectivity metrics seem to have the smallest contribution.

3.3. Main deliverables

The FAME assessment methods

The main deliverable of FAME is the European Fish Index. Furthermore, several spatially based assessment methods stem from the type-specific approach applied on the ecoregional as well as on the European level. Detailed descriptions are provided in chapters 3.2.4 and 3.2.5.

The FAME PC Software for EFI and EFT calculation:

For the implementation of the European Fish Index, a user friendly PC-Software was developed as a MS-Excel application. It performs all calculations necessary for the European Fish Index, including: (1) observed metrics, (2) theoretical (reference) metrics, (3) probability metrics, (4) the final score, (5) the index and (6) the ecological status class. With respect to data input, the assumption is that many institutions have their own databases for input and storage of sampling data. If institutions do not yet use such a database, they can use the FAME database FIDES. It is equipped with an automatic routine to prepare data adequately. Also, two MS-Excel files are provided as a supporting tool to prepare data for import (correct order, column headings as required) to the FAME software EFI. During the import procedure, data are automatically verified with respect to plausibility. Data are also checked on whether they meet the requirements for the application of the European Fish Index (e.g. minimum number of individuals caught, limit of sampling area, etc.).

The FAME manual:

Besides a PC-Software, a detailed manual was prepared for the application of the European Fish Index. The manual consists of 3 parts and several annexes: Part 1 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. Part 2 describes the assessment procedure, starting from the field sampling, the calculation of the European Fish Types as well as the European Fish Index. Part 3 is the manual for the application of the PC Software. It explains each step from the installation of the Software up to the interpretation of the results. The annexes comprise a glossary, the field sampling protocol as well as the taxa and guilds table.

The FIDES database and database manual

FIDES is a database established on MS-Access and can be used to record fish samples.

Guilds classification

The ecological requirements of 236 fish species identified to inhabit rivers considered by FAME partners were classified. For 122 species, a full classification into 12 functional guilds was possible; for 155 species the three main ecological traits (trophic, reproductive and habitat functions) are considered. For all other fish species, only some of the ecological guilds were known.

Further deliverables

Additionally, FAME produced, during the process of the method development, several reports on “intermediate” results and method evaluation.

- During the preparation of the basic tools several reports were prepared on the establishment of a fish-based river typology, on the definition of criteria for reference conditions, the selection of metrics, existing national assessment methods and on sampling procedures. All these reports contain information about the corresponding national standards and views.
- Reports were prepared about the results of the method evaluation, describing in detail the field sampling and application of the FAME methods to the newly sampled sites; they also contained the statistical method comparison.
- A report was prepared about the integration of applied partners and the transfer of the FAME project progress and results into water and fishery management.

4. Conclusions including socio-economic relevance, strategic aspects and policy implications

The main output of the FAME project is a single, standardised, fish-based assessment method for the ecological status of European rivers. The project demonstrated that the European Fish Index is as precise as spatially based type-specific methods and existing regional/national tools, which are adapted to environmental conditions of smaller scales. Two important prerequisites enabled the development of a tool to evaluate the biotic integrity over such a broad geographical area. First, it was possible to account for local and regional natural variability by including the most relevant abiotic factors into reference models. Second, a large central database containing sufficient datasets for reference conditions and different levels of degradation from 2700 European rivers was available.

Nevertheless, some limits have to be considered. These limits derive mainly from the lack of data for some catchments and particular river types. The application of the EFI is restricted to those main river basins where datasets for the method development were available. For the Mediterranean region a separate assessment method is in development. A transfer of this approach to many other river basins, especially in Eastern Europe, might be possible after adaptations based on additional data. Furthermore, the usability for large rivers as well as for rivers with few fish species remains to be tested. In contrast to the original objectives of the FAME project, it is not possible to identify different types of pressures with the EFI.

The EFI discriminates clearly between the status classes 2 and 3, which is the most important threshold for the successful implementation of the WFD. The ability to discriminate between classes 1 and 2 as well as 4 and 5, however, is not fully reliable. In terms of the evaluated response of fish assemblages to human pressures, note that the four main pressure variables (hydrology, morphology, nutrients/organic input, toxic substances/acidification) for the development of the EFI were often classified based on expert judgement. Also, an integration of further pressure variables may improve the capacity of the EFI.

In terms of policy implications, the European Fish Index contributes to the implementation of the WFD by providing a standardised tool to assess the ecological status of rivers. Intercalibrations between different assessment methods can be avoided – a great advantage of the EFI. To account for the type-specific approach as addressed in the WFD, the European Fish Types were integrated as an essential part of the EFI. This allows the identification of river types and reference species composition for any site.

Currently, a first testing phase of the EFI will be started. Several countries expressed their interest to include it into the routine assessment of the ecological status as required by the WFD. FAME was invited to start the preparation of a CEN standard for the classification of running waters in Europe based on fish communities.

5. Dissemination and exploitation of the results

5.1. Tools for the application of the European Fish Index in routine assessment

Within the FAME project, several tools were developed to apply the FAME assessment method:

- The FAME Software enables an automatic calculation of the EFI and the EFT in routine assessment.
- The FAME Software manual provides a basic introduction to the EFI and the EFT and gives a detailed description of the software.
- Data input files for the EFI and for the EFT support the correct organisation and structuring of data for import into the FAME software.
- Two tables with existing sampling data are provided for testing and familiarisation with the software; the data were sampled during the FAME project to test the standardised sampling procedure.
- Finally, the FIDES database (Fish Database of European Streams) is provided for data recording. FIDES is equipped with a query to extract data in the correct format for importing it into the FAME software.

5.2. Dissemination

Dissemination and publication activities will focus on two target groups: the scientific community and water and fishery management institutions involved in implementing the WFD. The scientific community will be addressed by publications and presentations at relevant conferences. An edited book with peer-reviewed chapters will be prepared in which all FAME results are summarized. Further publications will be individuals papers in peer-reviewed scientific journals.

For the dissemination of the FAME results within water and fishery management institutions, several documents were prepared, including (1) a printed leaflet and a poster to be distributed by all FAME partners. The leaflet and the poster were produced in English. FAME partners will also prepare translations into national languages. (2) a standard presentation to be used for conferences or workshops and training courses to inform about the overall results of FAME. (3) A short summary focusing on the European Fish Index; it is intended to be published in applied journals. Translations for publication in national journals will be prepared. (4) the final FAME webpage (http://fame.boku.ac.at).

From the FAME partner countries, institutions involved in implementing the WFD were integrated in the project as “Applied partners”. In order to promote the exploitation of the EFI, several applied partners intend to organise special workshops and training courses in which the method is explained and the application of the PC-software is demonstrated.

Representatives from countries outside the FAME consortium will be invited to attend the conference “Assessing the ecological status of rivers, lakes and transitional waters” (organised at the University of Hull, 11-15 July 2005). The results from the FAME project will be presented there in a separate session. It is also intended to organise special workshops on the application of the EFI.

6. Main literature produced

Papers in the **special publication** at Blackwell Science, Fishing News Books (peer reviewed):

Schmutz, S. et al. (2005): Concepts and principles of the development of a fish-based assessment method for the ecological status of European rivers.

Roset, N., G. Grenouillet, D. Goffaux, D. Pont, P. Kestemont (2005): Review of existing fish-based assessment methods and selection of metrics.

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Schmutz, S. et al. (2005): Overview on the spatially based approach - principles and comparison.

Ferreira T., N. Caiola, F. Casals, J. Oliveira, A. de Sostoa (2005): Assessing river perturbation in the Iberian Ecoregion using metric response from spatially based fish types.

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Quataert, P., J. Breine, I. Simoens (2005): Evaluation of the capacity of the European Fish Index to distinguish between (nearly) pristine and disturbed state of a river.

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Further Publications:

Quataert, P., J. Breine, I. Simoens (2004): A comparison of the FAME index of biotic integrity with existing local IBI´s in Europe. Proceedings of the 5th International Symposium on Ecohydraulics, September 12-17 2004, Madrid. Volume 1, p. 192-197.

Ferreira, T. & J. Oliveira (2004): Fish-based quality assessment of Iberian rivers using a spatial approach. Proceedings of the 5th International Symposium on Ecohydraulics, September 12-17 2004, Madrid. Volume 1, p. 198-204.

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Grenouillet, G., Roset, N., Goffaux, D., Breine, J., Simoens, I., de Leeuw, J. and Kestemont, P. Using fish assemblages to assess the ecological condition of European rivers: a type-specific approach in Western Highlands and Western Plains. Freshwater Biology (accepted pending revision)

Goffaux, D., Grenouillet, G. & Kestemont, P. Electrofishing versus gillnet sampling for the assessment of fish assemblages in large rivers. Archiv für Hydrobiologie (in press)

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