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Ecological engineering: from concepts to applications

Lake ecological assessment systems and intercalibration for the European Water Framework Directive: aims, achievements and further challenges

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Abstract

The Water Framework Directive (WFD) has been published in 2000 and the process of its implementation has created a new paradigm in the understanding of ecological status of water bodies in Europe. The Directive explicitly requires that ecological status is assessed through the analysis of various characteristics of aquatic flora and fauna. An Intercalibration exercise is foreseen to identify and resolve significant inconsistencies between the ecological quality classifications of EU Member States to ensure that the obligation to reach good status has the same meaning throughout Europe.

The results of the first Lake Intercalibration exercise (2003-2008) are the setting of reference conditions and class boundaries for phytoplankton biomass metrics for all lake intercalibration types and all geographical regions of the EU. Work on macrophyte assessment methods has been carried out in the Alpine, Central/Baltic and Northern region, while only Alpine and Mediterranean countries have succeeded to develop and harmonize phytoplankton composition assessment methods.

The aim of the second phase of intercalibration (2008-2011) is to close these gaps and improve the comparability of the results in time for the second river basin management plans due in 2015.

Keywords: ecological assessment; intercalibration; lake assessment methods; Water Framework Directive

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1. Introduction

During the latest decennia it has become obvious that human activity is causing serious degradation of the aquatic ecosystems from the local to the global scale. General analyses and reviews over the past two decades [1,2,3,4] have identified a range of pressures that cause adverse change in the aquatic ecosystems – physical alteration, pollution, habitat loss and degradation, water withdrawal, overexploitation, introduction of invasive species, and global climate change to be the leading causes. In consequence, many aquatic ecosystems have continued to be heavily degraded, with many completely lost, some irreversibly [5,6].

A global consensus has emerged that the management of water resources requires a comprehensive understanding of ecosystem functions and interactions. The application of such knowledge in an integrated approach is referred to as an "ecosystem approach", and such a holistic response to the challenges facing the world water resources is at the heart of EU water policy. The European Commission Water Framework Directive [WFD; 7] is potentially ground-breaking and a truly ecological approach to the water management in Europe. It seeks to bring about improvement of aquatic habitats to "good ecological status", defined as a slight deviation from reference conditions, with no or minor human impact. Thus the WFD is the first attempt to move from physico-chemical quality standards to ecological quality targets, describing minimum acceptable state of ecosystem and its components.

The Directive explicitly requires that ecological status is based upon different biological quality elements and their metrics. For lakes these are composition, abundance and bloom metrics of phytoplankton; composition and abundance of macrophytes and phytobenthos; composition, abundance and diversity of benthic invertebrate fauna; composition, abundance and age structure of fish fauna. According to the WFD, all member states (MS) should have developed assessment systems before the end of 2006. Nevertheless, the development of indicators and setting of class boundaries has turned out to be one of the most critical and difficult tasks of the WFD implementation and is not completed yet.

One of the key actions identified by the WFD is to carry out a European benchmarking or intercalibration (IC) exercise to ensure that good ecological status represents the same level of ecological quality everywhere in Europe (Annex V of WFD). It is designed to ensure that the values assigned by each Member State (MS) to the good ecological class boundaries are consistent with the Directive's generic description of these boundaries and comparable to the boundaries proposed by other MS. The IC of surface water ecological quality status assessment systems is a legal obligation.

The IC exercise aims to ensure that the good status boundaries in all MS's assessment methods for biological quality elements correspond to comparable levels of ecosystem alteration [8]. IC can be carried out in different ways depending on the availability and similarity of MS assessment methods:

- IC can be carried out as pairwise comparison and harmonisation of different methods;
- Alternatively, in case of the lack of sufficiently large and consistent international database, IC can be implemented as indirect comparison *via* IC common metrics, generating a common assessment procedure and comparing national assessment methods against this common method;
- In case when assessment methods are not developed yet, MS can choose to set boundaries based on common database using the same assessment metrics.

The initial steps of Lake IC were defining of geographically homogenous regions (Geographical Intercalibration Groups; GIGs) and common types of lakes within them [9,10]:

- Five Lake geographical regions were defined for the first phase of IC (Alpine, Atlantic, Mediterranean, Central/Baltic and Northern);
- Common lake typology with fifteen international lake types were selected for IC (Table 2) based on natural abiotic characteristics - altitude, alkalinity and mean depth - which are important factors in determining the composition and abundance of biological communities [e.g., 11].

The next steps involved collection of MS assessment methods, compiling of international datasets, setting / comparing of ecological status boundaries [9].

In short, this paper summarizes the process and results for the first phase of Lake IC (2003-2008) carried out under WFD. Hence, the stepwise progression of the article includes: 1) description of the methods and metrics intercalibrated, 2) the data and the specific methodologies applied in the setting and harmonization of ecological status boundaries 3) results of the lake IC for phytoplankton and macrophyte assessment methods; 4) some problems indentified in the first phase of the IC and future perspectives.

2. Lake ecological assessment methods and metrics intercalibrated

2.1. Phytoplankton biomass metrics

The phytoplankton community is formed by primary producers that respond sensitively to changes in water quality, particularly to increases of nutrient levels [12,13], making phytoplankton the most relevant biological element for assessment of eutrophication. The indicative value of phytoplankton biomass has long been recognized [14,15], and numerous indices and systems have been developed for using phytoplankton biomass metrics in assessments of nutrient loading [16,17].

Both chlorophyll-a concentration and phytoplankton biovolume are widely used descriptors of phytoplankton biomass in the national and international assessment systems [18,19,20]. However, both methods have advantages and technical limitations.

Chlorophyll-a is considered a simple and reliable indicator for phytoplankton biomass for the following reasons:

- Chlorophyll-a is the most abundant photosynthetic pigment and common to all photosynthetic organisms. Furthermore, the measurement is relatively simple, inexpensive and direct, it integrates all cell types and ages, and it can be quantitatively coupled to important optical characteristics of water [21];
- Since the foundational papers of Sakamoto [22] and Dillon and Rigler [23] there have been many studies showing strong empirical links between chlorophyll-a and nutrients [24] that are often used to underpin lake management decisions;
- One advantage of using chlorophyll-a is a good data availability across Europe in terms of geographic coverage, comparability of analytical methods and number of lakes [25].

However, the ratio of chlorophyll-a to phytoplankton biomass depends on external and internal factors, such as phytoplankton taxonomic composition, cell physiological conditions, temperature, nutrient concentrations and light intensity [26,27]. Microscopical counting and volume assessment of phytoplankton are widely used to estimate algal biomass. However, species volume measurement is laborious, highly dependent on the taxonomic skills of the researchers and the use of preserved samples. Fixation can alter cell volume depending on the species and the nature and concentration of the fixative used. Furthermore, uncertainty is very high with small organisms (<5 μm) as well as with filamentous and colonial Cyanobacteria [28,29].

Consequently both chlorophyll-a concentrations and phytoplankton biovolume were used as metrics characterizing algal biomass in the IC exercise (chlorophyll-a – in all regions, phytoplankton biovolume – additionally in the Alpine and Mediterranean regions).

2.2. Phytoplankton composition metrics

Changes in phytoplankton composition in lakes along the eutrophication gradient have been well-known for several decades in Europe and North-America. For instance, as nutrient concentrations increase, the dominance and abundance of cyanobacteria generally increase, often resulting in dense mono-specific blooms [13] and detrimental effects on water quality and ecosystem functioning. Therefore phytoplankton composition has been widely used for water quality assessment since 1940ies [15] and since then numerous indices were developed, some of which have been included in the WFD monitoring schemes. Several approaches can be distinguished in use of phytoplankton taxonomic metrics:

- Trophic score approach based on trophic preferences of each phytoplankton species or genus, expressed as a trophic value (or "score") of taxa, and in some case, indicator value. Trophic score approach is used in Norway [Brettum index, 30], Austria [revised Brettum index, 31], Germany [32], Sweden [33], and deep subalpine lakes of Italy [34];

- Positive/negative indicator approach: individual taxa can be considered as positive, negative or indifferent in relation to nutrient pressures. The ratio of positive to negative species can be used as a metric of ecological status [e.g., 35];
- Taxonomic group approach is based on biovolume of a given algal group, or on the ratios between the biovolumes of several algal groups. For instance, the contribution of *Cyanobacteria* to the total biomass of phytoplankton is considered as a reliable, meaningful and easy-to-use indicator [36], because most of *Cyanobacteria* species show a strong preference for eutrophic conditions and those few species linked to oligotrophic conditions could be excluded, in order to increase the confidence of the metrics [37]. Indices based on several taxonomic groups are used in France and Spain. However, these indices need to be used with care, because all algal groups include species with different ecological preferences [37];
- Functional group approach: Reynolds et al. [38] published an extended description of phytoplankton assemblages that can be understood as functional groups: group of species with similar demands for several different combinations of physical, chemical and biological properties (depth of mixing layer, light, temperature, nutrient and grazing pressure) of the lake environment. Algae forming a single functional group also have similar morphologies as dimensions of the algal cells or colonies such as surface area, volume, and maximum linear dimension are powerful predictors of optimum dynamic performance [39]. Based on these findings, Padisák et al. [40] developed the assemblage index to assess ecological status of different lakes types which is applied now in the WFD monitoring scheme of Hungary and Greece.

Four phytoplankton taxonomic indices were intercalibrated within the Alpine region:

- Brettum index [30] based on the probability of occurrence of taxa within five trophic classes, modified by Dokulil [31] in Austria;
- Phytoplankton Trophic Lake Index (PTSI) based on type-specific indicator taxa lists and their trophic scores and weighting factors in Germany [32];
- Phytoplankton trophic indices $PTI_{species}$ and PTI_{ot} [34] for deep subalpine lakes of Italy, based on trophic scores of algal species and orders [34].

In the Mediterranean region, good status boundaries were set for three phytoplankton composition indices:

- The contribution of Cyanobacteria to the total biomass of phytoplankton is considered an eutrophication indicator for Mediterranean reservoirs,
- Catalán Index [41] is based on the percentage of biovolume of the groups of algae (e.g., Cryptomonads, Cyanobacteria, Dinoflagellates, Chrysophyte);
- The Mediterranean Phytoplankton Trophic Index (MedPTI) is calculated as the biovolume-weighted average of the trophic values of the species, weighted on their indicator values [42].

All three indices can be applied to all the MS, except MedPTI, developed for Italian reservoirs.

2.3. Macrophyte assessment systems

Macrophytes are considered as excellent indicators of lake ecosystem health because they respond to nutrients, light, toxic contaminants, metals, herbicides, turbidity, and water level change [43]. General advantages of using macrophytes are that they are non-mobile, do not require laboratory analysis, relatively low manpower demands, are easily sampled through the use of transects or aerial photograph, are easily used for calculating simple abundance metrics and are integrators of environmental condition. Therefore, Annex V of the WFD requires that the composition and abundance of macrophytes are to be used in the ecological assessment of lakes. Many European countries have undertaken efforts to create macrophyte-based lake assessment schemes. Three approaches can be distinguished in the classification schemes:

- In the first approach a classification is based on the relative abundances of sensitive, tolerant and indifferent species based on their occurrence along eutrophication gradient [44,45];
- Trophic indices calculated a the weighted average of the trophic scores related to the eutrophication gradient are used in several Nordic countries, e.g., Sweden [46];
- The Dutch [47], Irish [48] and Belgian [49] approaches are multimetric, using various aspects of the macrophyte community, e.g. Irish multimetric index includes both abundance descriptors (maximum depth

of colonisation, mean depth of presence) and composition characteristics (percentage relative frequency of Elodeids and Chara).

Two national macrophyte classification methods were intercalibrated in Alpine region.

- The Austrian method [50] focuses on the assessment of trophic state and general degradation. The established metrics "vegetation density", "vegetation limit", "zoning", trophic indication" (expressed by Macrophyte Index) and "species composition" (measured by Bray-Curtis distance) cover different aspects of the macrophyte vegetation.
- For the German method [44] macrophytes (Module 1) and diatoms (Module 2) are assessed separately and then combined to one Ecological Quality Ratio (EQR). In the Module 1 four metrics are used: Reference Index (relative abundance of the macrophyte species of three different type specific ecological species groups - reference indicators, indifferent taxa, and degradation indicators), depth of vegetation limit, dominant stands of specific species and depopulation of submerged macrophytes). In the Module 2 two diatom-based metrics are combined: Trophic-Index (TI) based on diatom trophic scores and Quotient of Reference Species (RAQ) based on relative abundance of the diatom species of two ecological groups (reference and degradation indicators).

In the Central Baltic region, most MS were still working on their assessment methods during the process of IC. However, six MS had developed their national metrics to an extent allowing the IC exercise to be carried out for two lake types. In summary, the MS have different ideas about how to assess the status of lakes using macrophyte composition. Differences exist in the parameters used (e.g. maximum colonised depth and macrophyte cover), scaling of abundance, but also on technical level, e.g. which species are indicative for reference conditions, and in the assessment methodology:

- Flemish macrophyte assessment system [49] appraises various aspects of lake macrophyte community such as relative abundance of reference taxa and disturbance indicators, diversity of growth forms and development of submersed vegetation;
- Estonian macrophyte assessment system [9] integrates information on maximum colonisation depth limit of submergent plants, dominant taxa, relative abundance of macrophyte taxa / taxonomic groups *Potamogeton perfoliatus* / *P. lucens*, charophytes / bryophytes, ceratophyllids / lemnids and large filamentous alga. Classification is built in a descriptive way, for example, high status is indicated by depth limit < 4m, dominance of charophytes / bryophytes (relative abundance 2-4), low abundance of ceratophyllids / lemnids and absence of large filamentous alga;
- Latvian macrophyte assessment system [9] based on presence and abundance of indicator taxa and total macrophyte cover of lakes;
- Dutch macrophyte assessment system [47] includes metric for species composition and metric of growth forms, constructed based on the expected abundance in reference conditions. For assessment all scores are summed and compared to the reference score;
- UK LEAFPACS method [51] uses three key aspects of the macrophyte community to assess lake ecological status: species composition (expressed as Lake Macrophyte Nutrient Index or LMNI), the number of taxa / functional groups and the relative cover of hydrophytes and macroalgae in the lake. Each metric is expressed as an EQR and the final EQR is based on a weighting because the relative importance of the above metrics changes over a natural trophic state gradient.

All Northern region member states have developed their national macrophyte assessment methods, based on similar principles - the response of submerged macrophytes to the major environmental pressure of eutrophication:

- In Ireland, Free Macrophyte Index [48] includes six components: Maximum depth of colonisation, Mean depth of presence, RF% (percentage relative frequency) Elodeids, RF% Chara, Plant trophic score, RF% Tolerant taxa. All metrics are scaled from 0 to 1 and the average value is used for the assessment;
- Norwegian trophic index [45] based on a classification of species as sensitive, tolerant or indifferent to eutrophication, based on their occurrence along eutrophication gradient. The indices subtract the number of tolerant species from the number or abundance of sensitive species. For use in boundary settings, the change

in occurrence and abundance of the large isoetids *Isoetes lacustris*, *I. echinospora*, *Littorella uniflora* and *Lobelia dortmanna* in low alkaline lakes and *Chara* spp. in high alkaline lakes were used;

- Swedish trophic index [46] is based on a trophic macrophyte index has been developed and is now incorporated in national regulations [52]. The trophic index is based on the response of macrophytes (*Characeae*, mosses and vascular plants except helophytes) to the eutrophication gradient. The trophic index is a weighted average of all species' indicator values in a lake. The species used for classification were those showing sudden drops in their occurrence along eutrophication gradient.

3. Lake intercalibration process

3.1. Phytoplankton biomass intercalibration

In 2003, when the IC exercise started, MS had not fully developed phytoplankton assessment methods. So instead of harmonizing the boundaries of the MS assessment methods (as foreseen by the WFD), IC, in fact, established the boundaries for phytoplankton biomass assessment metrics - chlorophyll-a and phytoplankton biovolume.

The IC exercise for lakes consists of the following consecutive steps:

- Setting of reference criteria and selection of reference lakes;
- Defining of reference conditions and the boundary between "high" and "good" quality classes (H/G);
- Defining the boundary between "good" and "moderate" quality classes (G/M).

Setting of reference conditions and High-Good boundary

Selection of lakes with no or very minor human impacts was used for describing reference conditions for phytoplankton biomass metrics. Each GIG developed a list of criteria to select reference sites based on factors such as catchment use, population density, absence of major point sources and other pressures in the catchment [9]. Some countries used additionally paleolimnological data (e.g. UK, Ireland, and Austria), historical data (Austria, Germany) and modelling of nutrient load (Alpine GIG) to validate the choice of reference sites. Despite some discrepancies in reference criteria and their values between the GIGs caused by different data availability and geographic conditions, a common understanding on reference conditions was developed that could be described by absent industrialization, urbanization and intensive agriculture in the catchment, and only minor human impacts.

According to the reference criteria, 360 reference lakes were selected across the EU. Additional screening by water quality criteria (nutrient, chlorophyll-a) and expert judgement was broadly used in the final review of reference lake lists. The biggest number of reference lakes (241) was defined in the Northern GIG, while the lowest numbers in the Central Baltic GIG (40) and Mediterranean GIG (11, only reservoirs) which can be explained both by data availability and the level of anthropogenic stress in those regions.

The reference value for phytoplankton biomass metrics was calculated as the median of the distribution of values in reference lakes. The H/G class boundary was set within a range between the 75^{th} and 95^{th} percentile of the values for the reference lakes, depending on the stringency of reference criteria used by the GIG.

Both the reference and boundary values were expressed as ranges (Table 2) to account for the natural variability across the countries in a GIG regarding climate, topography and catchment geology. The countries have to transpose the range of the common GIG types to their detailed national typologies following procedures agreed within GIGs.

Despite slightly different approaches, there was a good consistency in chlorophyll-a concentrations across different regions / lake types, and relationships between chlorophyll-a reference values and lake type characteristics. The results showed that depth, alkalinity and altitude were the main factors affecting reference conditions. The highest reference values were recorded for very shallow hard-water lakes of Central Baltic region (6.2-7.4 µg/l) and shallow humic lakes of Northern GIG regions (3.5-5.0 µg/l). High alkalinity, low depth, and humic content contribute to higher background nutrient and chl-a concentrations. In contrast, the lowest reference values occurred in deep, clear and low alkalinity lakes of the Northern GIG (1.0-2.0 µg/l) and deep mid-altitude Alpine lakes (1.5-1.9 µg/l).

Defining of G/M class boundary

Setting of the G/M class boundary turned out to be the most critical and difficult procedure in the IC process. Mainly two approaches were used for setting and/or validating the G/M boundary for phytoplankton biomass metrics:

– *Secondary effect approach* according to which the condition of phytoplankton can be considered "good" if there is only a negligible probability that accelerated algal growth would result in a significant undesirable disturbance (or secondary effects of eutrophication as decrease of macrophyte cover, oxygen depletion etc);
– *Species composition approach* according to which the condition of phytoplankton would not be consistent with "good" status if changes in the balance of taxa are likely to adversely affect the functioning or structure of the ecosystem.

Table 1 gives an insight to various approaches used by countries for setting the G/M boundary.

For illustration, in Central GIG, the G/M quality class boundary was defined by agreeing on allowable risks of three different undesirable effects induced by increased phytoplankton biomass:

– Decrease in maximum colonization depth of submerged macrophytes;
– Shift from macrophyte/phytobenthos dominated community with clear water to phytoplankton dominated community with turbid water;
– Shift in phytoplankton composition towards light competitors (Cyanobacteria).

Table 1. Approaches used to set Good-Moderate status boundary for phytoplankton biomass metrics

GIG	Approach	Method used
NOR	Species composition approach	Phytoplankton composition changes along the chlorophyll-a gradient
ATL	Secondary effect approach: - Decrease in max colonisation depth - Macrophyte composition changes - Impact on benthic fauna indicators	Relationships between TP, chlorophyll-a and macrophyte metrics (literature data) Relationships between TP, chlorophyll-a, macrophyte metrics, benthic fauna indicators (monitoring data) Break-points used for setting GM boundary
C/B	Secondary effects - Decrease in maximum depth; - Shift from macrophyte community to a phytoplankton Species composition approach - Increase of the probability of cyanobacterial blooms	Relationship between chl-a and colonized depth Relationship between chl-a and fractions of lakes with target macrophyte abundance, boundaries set at steep changes of curves Relationship between chl-a and probability of lakes with target algal blooms
ALP	Species composition approach Secondary effect approach Expert judgement	Relationship of phytoplankton biomass to the relative biomass proportion of sensitive taxa *Cyclotella* Eutrophication impact on macrophyte colonisation depth and species composition, fish fauna (Coregonides) (based on literature data) Based on adapting lake trophic classification (LAWA, 1999) based on data analyse, reference conditions and WFD interpretation (Nixdorf et al, 2005)
MED	Data from the sites proposed as G/M sites Secondary effect approach Species composition approach	95^{th} percentile of the distribution of the data from the sites proposed as G/M sites Relationship between biomass metrics and depletion of oxygen and decrease of Secchi depth Relationship between biomass metrics and main algal groups (Cyanobacteria, Chrysophyta)

All approaches followed the same conceptual model stipulated by the WFD and the defined G/M class boundaries show a rather coherent picture with chl-a values ranging from 4 to 15 µg/l. The highest values (21-25 µg/l) belong to very shallow, calcareous lowland lake type of Central Europe, in which all factors (depth, alkalinity, and altitude) contribute to higher background nutrient values.

Thus, despite considerable problems (limited data availability, inherently large heterogeneity of data), reference conditions and "good" status boundaries for phytoplankton biomass metrics were defined for all European ecoregions (Tables 2 and 3), following common conceptual framework.

Table 2. Results of the Lake Intercalibration of phytoplankton biomass metrics - reference conditions and good status boundaries of chlorophyll-a values (µg/l)

Region	Lake type code	Lake type characterisation	Reference conditions	High -Good boundary	Good - Moderate boundary
Alpine	AL3	Lowland or mid-altitude, deep, moderate to high alkalinity, large	1.5–1.9	2.1-2.7	3.8-4.7
	AL4	Mid-altitude, shallow, moderate to high alkalinity, large	2.7-3.3	3.6-4.4	6.6-8.0
Atlantic	A1/2	Lowland, shallow, calcareous	2.6-3.8	4.6-7.0	8.0-12.0
Central/ Baltic	CB1	Lowland, shallow, calcareous	2.6-3.8	4.6-7.0	8.0-12.0
	CB2	Lowland, very shallow, calcareous	6.2-7.4	9.9-11.7	21.0-25.0
	CB3	Lowland, shallow, siliceous	2.5-3.7	4.3-6.5	8.0-12.0
Mediter-ranean	M5/7	Reservoirs, deep, large siliceous, lowland, "wet areas"	1.4-2.0	*	6.7-9.5
	M8	Reservoirs, deep, large, calcareous	1.8-2.6	*	4.2-6.0
	N1	Lowland, shallow, moderate alkalinity, non-humic	2.5-3.5	5.0 – 7.0	7.5 – 10.5
Northern	N2a	Lowland, shallow, low alkalinity, non-humic	1.5-2.5	3.0 – 5.0	5.0 – 8.5
	N2b	Lowland, deep, low alkalinity, non-humic	1.5-2.5	3.0 – 5.0	4.5 – 7.5
	N3a	Lowland, shallow, low alkalinity, humic	2.5-3.5	5.0 – 7.0	8.0 – 12.0
	N5a	Mid-altitude, shallow, low alkalinity, non-humic	1.0-2.0	2.0 – 4.0	3.0 – 6.0
	N6a	Mid-altitude, shallow, low alkalinity, humic	2.0-3.0	4.0 – 6.0	6.0 – 9.0
	N8a	Lowland, shallow, moderate alkalinity, humic	3.5-5.0	7.0 – 10.0	10.5 – 15.0

Table 3. Results of the Lake Intercalibration of phytoplankton biomass metrics - reference conditions and good status boundaries of phytoplankton biovolume (mm³/l)

Region / metrics	Type code	Lake type characterisation	Reference conditions	High -Good boundary	Good - Moderate boundary
Alpine	AL3	Lowland or mid-altitude, deep, moderate to high alkalinity, large	0.2-0.3	0.3-0.5	0.8-1.2
	AL4	Mid-altitude, shallow, moderate to high alkalinity, large	0.5-0.7	0.8-1.1	1.9-2.7
Mediter-ranean	M5/7	Reservoirs, deep, large siliceous, lowland, “wet areas”	0.36	*	1.9
	M8	Reservoirs, deep, large, calcareous	0.76	*	2.1

3.2. Phytoplankton composition intercalibration

The result of the first IC exercise is the boundary setting for phytoplankton biomass metrics for two Lake Geographical Intercalibration Groups: Alpine and Mediterranean GIGs (Table 4). Three phytoplankton-based assessment systems were harmonised in the Alpine GIG (Austrian Brettum index, German PTSI, and Italian PTIot and PTIspecies indices), while the boundaries for three metrics (% of Cyanobacteria, Catalan index, Mediterranean PTI) were set in the Mediterranean region.

Different approaches to set boundaries were used by the Lake GIGs: Alpine region countries have already established national phytoplankton-based assessment methods, so the task of the IC was to ensure comparability of the methods and consistency of the methods to the requirements of the Directive. The IC was carried out in 3 steps:
- Setting of RC and HG boundary for the national metrics;
- Setting of GM boundary for the national metrics;
- Comparing of all 3 national indices using common metrics (ICCM).

In contrast, Mediterranean GIG has not established national methods, so work has included the following steps:
- Collection on datasets and agreement on the common metrics (% of Cyanobacteria, Catalan index);
- Setting of Reference conditions for the common metrics;
- Setting and Good/Moderate class boundaries for the common metrics.

Setting of Reference values and the High/Good quality class boundary

Broadly similar approaches were used for setting reference values and H/G boundary for phytoplankton composition metrics. Spatial approach was the basic method including:
- Selection of reference lakes according to pressure and impact criteria;
- Calculation of reference values as median of reference lake population.

Alpine GIG additionally used modelling of natural trophic state (Germany), and regression of composition indices with already intercalibrated biomass metrics (chlorophyll-a – Italy, phytoplankton biomass – Austria).

Setting of Good/Moderate quality class boundary

The first step of boundary setting procedure was a conceptual model about how the biological quality element is expected to change. The next step was the boundary-setting using different approaches:
- Mediterranean GIG has set G/M ecological potential boundary as the 95th percentile of the distribution of the data from the sites proposed as G/M sites for the IC register;
- Alpine GIG based boundary setting was based on several methods:
    - Boundaries were set on the basis of already intercalibrated metrics, e.g., annual biovolume (Brettum index) and chlorophyll-a values (PTI index);

- The class boundaries were validated according to the change of taxonomic composition as described in the WFD normative definitions for the ecological status classes (Brettum index);
- Expert judgment and link to the trophic classifications (PTSI index).

Comparison of phytoplankton composition indices
The actual comparison of the indices in the Alpine GIG was carried out *via* common metrics:
- All three trophic indices were expressed as normalised EQRs;
- The arithmetic mean of the three normalised EQRs was used as a common metric to enable comparability between the three national metrics;
- Thus the EQRs of national assessment methods were translated to the common metrics EQR and compared against this common method;
- Harmonisation was done by using an acceptable band of 5% of the whole range of normalised EQR (±0.05 EQR).

Mediterranean GIG set the boundaries for the common metrics following common principles and using GIG joint dataset, so there was no need for comparison. Member states will adapt the common IC type boundaries in the national assessment systems for national water body types.

Table 4. Results of the Lake Intercalibration of phytoplankton composition metrics

Country	National parameters intercalibrated	Type	Class boundaries	
			High-Good boundary	Good-Moderate boundary
Alpine region				
Austria	Brettum index	*AL3*	4.12 - 4.34	3.64–3.83
Austria	Brettum index	*AL4*	3.96 - 3.87	3.20–3.34
Germany	PTSI	*AL3*	1.25	1.75
Germany	PTSI	*AL4*	1.75	2.25
Italy	PTI_{ot}	*AL 3**	3.43	3.22
Italy	PTI_{ot}	*AL4*	3.37	3.01
Italy	$PTI_{species}$	*AL 3***	4.00	3.50
Mediterranean region				
GR, FR, PT, ES, RO	% of Cyanobacteria	*M5/7*		9.2
CY, GR, FR, IT, ES, RO	% of Cyanobacteria	*M8*		28.5
GR, FR, PT, ES, RO	Catalan index	*M5/7*		10.6
CY, GR, FR, IT, ES, RO	Catalan index	*M8*		7.7
Italy	Med PTI index	*M5/7*		2.32
Italy	Med PTI index	*M8*		2.38

**mean depth >100m, **mean depth <100m*

3.3. Macrophyte assessment system intercalibration

As the result of the first IC exercise the macrophyte-based ecological assessment systems were compared and harmonised within 3 regions: Alpine, Central/Baltic and Northern GIGs (Table 5). Only part of the MS took part in the IC process due to the lack of the assessment systems: so two countries (Austria and Germany) compared and harmonised their assessment methods in the Alpine GIG, six countries - in the Central Baltic GIG, and four countries - in the Northern GIG.

Setting of reference conditions and boundaries

MS have set reference conditions and class boundaries using a number of different ways but in general following WFD definitions.

Setting of reference conditions was mainly based on selection of lakes with no or very minor human impacts:

- This approach was used in the Alpine GIG where common set of general and specific reference criteria was developed to aid the selection of more than 150 reference lakes;
- The large set (427 lakes) was developed in the Northern GIG, reference conditions was calculated as median (IE) or 75^{th} percentile (SE) from reference lake values;
- Additional approaches were used in the Central/ Baltic GIG due to the low number of reference lakes, e.g., historical records (EE, BE, UK) and knowledge on plant communities response to eutrophication pressure (NL, BE, UK).

Setting of good class boundaries was based on WFD normative definitions and conceptual models of species composition changes. The basic idea is the change from dominance:

- Good status – significant decrease in relative abundance of sensitive taxa (reference species), but they are still dominant, even if species composition differs significantly from type-specific reference conditions;
- Moderate status – tolerant and disturbance taxa dominate the lake macrophyte community.

Intercalibration approaches

MS started the IC process with already established macrophyte assessment methods. Two approaches were used to compare and harmonise the MS assessment methods:

- Northern GIG developed common metric (ICCM) and compared the boundaries of the MS systems, using this common metrics;
- Alpine and Central Baltic GIGs used direct comparison of the assessment methods where each assessment system was applied to the set of the sites and further the results of the different assessment systems were compared between the MS.

In the Central Baltic GIG, national methods were compared one by one *versus* all the others:

- A common database with an agreed structure was composed, which all MS within the C/B GIG could use for comparison and assessment;
- All sites in the database were assessed by all national assessment methods, classification results were compared and tested;
- Where necessary, method boundaries were adapted and compared again with the other MS methods.

Additionally, relationships between macrophyte metrics and eutrophication pressure were investigated and the performance of macrophyte methods on reference sites was tested.

The principles of the macrophyte methods IC in the Northern GIG were:

- An IC common metric was derived for comparison and harmonization of the four national macrophyte taxonomic composition metrics. This metric combines compositional information linked to a ranking of species based on their association with lakes of differing fertility (expressed as annual mean TP).
- Further each MS identified reference sites within the common data set (total of 427 lakes). Using these sites, a regression model linking the most available environmental typology variables to the reference common metric score was determined. The type specific reference models were then used to calculate site specific reference values of common metrics;

- As a next step, boundaries of national metrics were expressed as common metric EQR to enable comparability between the four national metrics. It has been agreed that on the common metric EQR scale, an acceptable range of variation for the boundaries is ±0.05 EQR units.

Table 5. Results of the Lake Intercalibration of macrophyte assessment methods

Region / Memberstate	National classification systems intercalibrated	Common lake intercalibration types	Ecological Quality Ratios	
			HG	GM
Alpine region				
Austria	Austrian macrophyte assessment system: Module 1	AL3, AL4	0.80	0.60
Germany	German macrophyte/phytobenthos assessment system: Module 1	AL3	0.78	0.51
Germany	German macrophyte/phytobenthos assessment system: Module 1 + 2	AL4	0.71	0.47
Central Baltic region				
Belgium	Flemish macrophyte assessment system	CB1, CB2, CB3	0.80	0.60
Germany	German macrophyte assessment system: Reference Index	CB1, CB2	0.75	0.50
Estonia	Estonian macrophyte assessment system	CB1, CB2, CB3	0.80	0.60
Latvia	Latvian macrophyte assessment system	CB1, CB2, CB3	0.80	0.60
Netherlands	Dutch macrophyte assessment system: KRW-maatlat	CB1, CB2	0.80	0.60
United Kingdom	UK macrophyte assessment system: LEAFPACS	CB1, CB2	0.80	0.60
Northern region				
Ireland	Free Macrophyte Index	All types*	0.90	0.68
Sweden	Macrophyte Trophic index (Ecke)	Type 101	0.98	0.79
		Type 102	0.98	0.88
		Type 201	0.94	0.83
		Type 202	0.96	0.83
Norway	Macrophyte Trophic Index (Mjelde)	Type 101	0.94	0.61
		Type 102	0.96	0.65
		Type 201	0.91	0.72
		Type 202	0.90	0.77
		Type 301	0.92	0.69
United Kingdom	UK macrophyte assessment system: LEAFPACS	All types	0.80	0.60

*Type 101 - low alkalinity, non-humic; Type 102 - low alkalinity, humic; Type 201 – moderate alkalinity, non-humic; Type 202 – moderate alkalinity, humic; Type 301 - high alkalinity, non-humic; Type 301 - high alkalinity, humic

In the Alpine region, IC of macrophyte-based classification methods was carried out on two national sets of methods (AT, DE), which included a number of different metrics. The main principles were:

- The direct comparison of assessment methods was used as a general principle to intercalibrate the results of two national assessment methods;
- Harmonization of the two methods was carried out by normalizing the EQR values (linear scale, equidistant class widths; the H/G boundary corresponds to EQR_{norm} of 0.8, the G/M boundary to EQR_{norm} 0.6, etc.). A deviation of ±0.05 EQR-units for the class boundaries of the good status was considered acceptable.

4. Methodological concerns and future directions

Several gaps and shortcomings in the current results of the EU-wide IC were identified:

4.1. Limited progress in development of assessment methods

According to the timeline set out in WFD, all assessment systems had to be place already in 2006. In practice progress on development of assessment methods was much slower and caused a substantial delay of the IC process:

- Only few MS have developed complete phytoplankton assessment methods, so it was not possible to carry out the comparison on BQE level, but only separately for biomass metrics (all regions) and composition metrics;
- Approximately 50% of the MS have not participated in the current IC of macrophyte assessment methods (e.g., France, Italy, Slovenia, Denmark, Lithuania), so there is necessity to intercalibrate these methods in the second phase of the IC exercise;
- Very few countries have developed benthic fauna and fish fauna assessment methods, therefore IC process started only in the second phase of the IC (2008-2011).

4.2. Methods not covering the complete BQE

WFD foresees the list of metrics to be included in the assessment methods, e.g., taxonomic composition, abundance and planctonic blooms for phytoplankton BQE, taxonomic composition and abundance for macrophyte and phytobenthos BQE etc. So far only few MS have developed methods including all metrics envisaged by the WFD:

- Most phytoplankton assessment systems address only biomass aspect, few countries have taken an effort to derive phytoplankton composition metrics, while none has addressed planctonic blooms;
- Most of the macrophyte assessment methods in the Central Baltic and Northern GIG do not include quantitative aspect of macrophyte community (macrophyte abundance) but deal only with species composition, therefore the future task would be to include also macrophyte abundance metrics, possibly depth of colonization;
- At now only UK and German have a method based on diatoms.

4.3. Fundamental differences in the assessment methods

In many cases fundamental differences in the assessment methods were observed:

- Diverse lake habitats taken into account, e.g. some macrophyte communities comprised only submerged vegetation while some cover also emerged or even riparian vegetation;
- Various pressures addresses by assessment systems (e.g. eutrophication *vs.* general degradation or hydromorphological modifications);
- Different community characteristics - structural, functional or physiological - were used in assessment methods which can render their comparison problematic. For example, biodiversity indices may give a different view on structural characteristics of the community compared to species composition indices.

4.4. Data quality and availability

– One of the main problems encountered in the IC process was the heterogeneity of the data. Inevitably with such a large dataset collected from various countries, there were differences in field and lab methods (e.g. sampling frequency and depth) which introduced a large variation of data and increased the statistical uncertainty of the present relationships and boundary setting and comparison;
– Especially Macrophyte data in the MS have been collected and reported in many different ways (e.g. diverse abundance scales, % from littoral or total area, etc.), so creating a large heterogeneity of data which considerably hinder successful IC process;
– Additional problem was quality of data and relevant information about the data (including sampling and analyses methods).

4.5. Insufficient number of reference lakes

Mainly a "reference site" approach – selection of lakes with no or very minor human impact – was used for setting chlorophyll-a reference conditions in Europe. Nevertheless, the principal problem was the scarcity of references lakes, especially in central/Baltic and Mediterranean regions where unimpacted condition no longer exists or data were not available as monitoring focuses mainly on impacted lakes.

4.6. Insufficient comparability between MS/ regions/water categories

The level of comparability seemed to be too variable between GIGs, since different methods and different criteria were used to assess the level of agreement between methods of the MS over all the GIGs. There was general agreement that further work was required on developing common comparability criteria.

In Intercalibration Phase 2 (2008-2011) the gaps assessed in the first phase of IC should be closed:

- Any biological quality elements that have not been intercalibrated or not fully intercalibrated in the first phase (for example, phytoplankton) should be fully intercalibrated in Phase 2;
- Furthermore, all MS in the GIG need to participate in the IC;
- To come to a common understanding for reference conditions in the same type, similar methodologies should be adopted for the characterization of very low pressure levels of reference conditions for all water categories;
- In order to improve the comparability of the results, the IC procedure has been refined, now defining more clearly the individual IC steps and introducing a number of checking criteria (e.g. pressures addressed by different MS methods, data comparability, etc.).

The new IC results will be completed and published in 2012 in time for the second WFD river basin management plans due in 2015.

5. Conclusions

The results of the first step of Lake IC exercise are the setting of reference conditions and class boundaries for phytoplankton biomass metrics for all Lake IC types and all geographical regions of the EU. Harmonisation of phytoplankton composition metrics was carried out in Alpine and Mediterranean regions, while only Alpine, Northern and Central/Baltic countries have succeeded to develop and harmonize macrophyte-based assessment methods. The aim of the second phase of IC is to close these gaps and improve the comparability of the results in time for the second river basin management plans due in 2015.

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