Verh. Internat. Verein. Limnol.
2009, vol. **30**, Part **7**, p. 1007–1012, Stuttgart, July 2009

Lake assessment strategy in European Union (EU): Case study of European large lakes

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Introduction

Assessment of the ecological quality of lakes and setting targets are key elements of lake management. The European Commission Water Framework Directive (WFD; EC 2000) requires development and harmonisation of the ecological status assessment systems for all surface waters (lakes, rivers, coastal, and transitional waters) and all biological quality indicators (phytoplankton, macrophytes, benthic fauna, and fish). The aquatic WFD classification for ecological status includes 5 criteria: "high," "good," "moderate," "poor," and "bad". Ecological status is measured as a deviation from type-specific reference conditions defined as a biological, chemical, and morphological condition associated with no or very low human pressure. Good status means a slight deviation from reference conditions, providing a sustainable ecosystem and acceptable conditions for human uses. The general mandate of the WFD is to achieve good status for all surface waters by 2015.

The implementation of the WFD raises challenges widely shared by the EU member states and includes an extremely demanding timetable, but an incomplete technical and scientific basis. A large number of fundamental issues need further elaboration to make the transition from principles to practical implementation. To address the challenges in a cooperative and coordinated way, the EU member states, Norway, and the European Commission agreed on a Common Implementation Strategy (EC 2001) for the Water Framework Directive. This process has resulted in a number of guidance documents that form the basis for the development of ecological classifications and Intercalibration process (EC 2003a, 2003b, 2003c, 2005a). The Intercalibration process has been coordinated and scientifically led by the European Commission Joint Research Centre in close collaboration with the WFD Ecological Status Working Group and the expert networks.

Our aim is to describe a novel approach for Europe-wide classification of the ecological quality of surface waters and harmonisation of the classification systems required by the WFD. We focus on the establishment of reference conditions and quality class boundaries for European lakes according to a phytoplankton indicator – the concentration of chlorophyll *a*. The approach is illustrated through a case study in which the ecological status of 54 European large lakes was evaluated according to the proposed criteria.

Key words: ecological status, intercalibration, lake assessment, Water Framework Directive

Lake Intercalibration exercise

To ensure comparability of the ecological classification scales and to obtain a common understanding of good ecological status of surface waters, the WFD requires an Intercalibration exercise that started in 2003 and is ongoing. The Intercalibration exercise for lakes consists of the following consecutive steps:

- Defining geographically homogenous regions and common types of lakes within them;
- Defining major pressures and selecting appropriate quality elements and metrics to address their impact;
- Data collection and quality screening;
- 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).

The WFD foresees the typology and Intercalibration to be carried out according to the limnofaunistic division of Europe into 25 ecoregions proposed by Illies (1978). After the analysis of data availability (Nõges et al. 2004, 2005), it was decided that for lakes the Geographical Intercalibration Groups (GIGs) should be larger, consisting of at least 2 countries, providing sufficient amount of lake data. Some member states (UK, France, and Germany) joined 2 or more GIGs, thus acting as links between different ecoregions. Five GIGs were estab-

0368-0770/09/1007 $ 1.50

lished (EC 2005b) including all EU member states and Norway (participates according to the European Economic Area (EEA) treaty between Norway and EU):

1. Alpine (Austria, France, Germany, Italy, Slovenia);
2. Atlantic (Ireland, UK);
3. Central/Baltic (Belgium, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Latvia, Lithuania, Netherlands, Poland, Slovakia, UK);
4. Mediterranean (Cyprus, France, Greece, Italy, Malta, Portugal, Romania, Spain);
5. Northern (Finland, Ireland, Norway, Sweden, UK).

Within each GIG, common lake types were selected for Intercalibration based on lake morphology, altitude, basin geology, and some climatic and hydrochemical parameters (EC 2003a, 2003b). The main purpose of typology was to enable the type-specific approach, which is the keystone in the ecological water quality assessment according to WFD. The common lake types for Intercalibration were set according to the following 3 principles:

1. Delineated by factors described in the WFD (geographic position, altitude, geology, size, and depth) and assurance that natural differences between lakes were clearly distinguished from anthropogenic pressures;
2. Shared by 2 or more countries within the GIG to enable Intercalibration;
3. Sufficient data to set reference conditions and class boundaries.

Initially 34 common lake types were proposed by expert groups (Nõges et al. 2004), but after the analysis of metadata, types with a small number of sites were either deleted or merged to achieve a sufficient amount of data for setting class boundaries (van de Bund et al. 2004). Altogether, 15 common lake types were selected for Intercalibration (Table 1).

Table 1. Description of lake types included in the Intercalibration by Geographical Intercalibration Groups. AL – Alpine, A –Atlantic, CB – Central Baltic, N – Northern.

Type code	Lake type characterisation	Altitude (m a.s.l.)	Mean depth (m)	Alkalinity (meq/l)	Additional characteristics
Lake Alpine Geographical Intercalibration Group					
AL3	Lowland or mid-altitude, deep, high alkalinity, large	50–800	>15	>1	Lake size >50 ha
AL4	Mid-altitude, shallow, high alkalinity, large	200–800	3–15	>1	Lake size >50 ha
Lake Atlantic Geographical Intercalibration Group					
A1/2	Lowland, shallow, calcareous	<200	3–15	>1 meq/l	Non-humic
Lake Central Geographical Intercalibration Group					
CB1	Lowland, shallow, calcareous	<200	3–15	>1	Residence time 1–10 years
CB2	Lowland, very shallow, calcareous,	<200	<3	>1	Residence time 0.1–1 years
CB3	Lowland, shallow, small, moderate alkalinity	<200	3–15	0.2–1	Residence time 1–10 years
Lake Mediterranean Geographical Intercalibration Group					
M5/7	Reservoirs, deep, large siliceous, lowland, "wet areas"	0–800	>15	<1	Lake size >50 ha Annual mean precipitation >800 mm
M8	Reservoirs, deep, large, calcareous	0–800	>15	>1	Lake size >50 ha
Lake Northern Geographical Intercalibration Group					
N1	Lowland, shallow, moderate alkalinity, clear	<200 m	3–15	0.2–1	Colour <30 mg Pt/l
N2a	Lowland, shallow, low alkalinity, clear	<200 m	3–15	<0.2	Colour <30 mg Pt/l
N2b	Lowland, deep, low alkalinity, clear	<200 m	>15	<0.2	Colour <30 mg Pt/l
N3a	Lowland, shallow, low alkalinity, humic	<200 m	3–15	<0.2	Colour 30–90 mg Pt/l
N5a	Mid-altitude, shallow, low alkalinity, clear	200–800 m	3–15	<0.2	Colour <30 mg Pt/l
N6a	Mid-altitude, shallow, low alkalinity, humic	200–800 m	3–15	<0.2	Colour 30–90 mg Pt/l
N8a	Lowland, shallow, moderate alkalinity, humic	<200 m	3–15	0.2–1	Colour 30–90 mg Pt/l

The first phase of lake Intercalibration focused on the major pressure, eutrophication, and the most relevant quality element, phytoplankton. Chlorophyll *a* (chl-*a*) was selected as a simple indicator for phytoplankton abundance with sufficient data availability across Europe.

Defining reference conditions and H/G class boundary

Data for about 1200 lakes were pooled from national datasets into GIG databases. These databases contained both basic parameters (altitude, surface area, mean depth, alkalinity), water quality data (chl-*a*, nutrients, Secchi depth) and stress data (land use, population, and other impacts). Data quality was checked by revealing outliers and testing of well established relationships (e.g., between conductivity and alkalinity, chl-*a* and phosphorus).

A selection of lakes with no or very minor human impacts was used for describing reference conditions for chl-*a*. 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 (Table 2). 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 condi-

Table 2. Pressure criteria used for reference site selection in Lake Intercalibration Geographical Intercalibration Groups (GIGs).

GIG	Pressure criteria
Alpine	Insignificant contribution of anthropogenic to total nutrient loading, validated by nutrient loading calculations
	>80–90 % natural forest, wasteland, moors, meadows, pasture
	No deterioration of associated wetland areas
	No (or insignificant) changes in the hydrological and sediment regime of the tributaries
	No direct inflow of (treated or untreated) waste water
	No (or insignificant) diffuse discharges
	No (or insignificant) change of the natural regime (regulation, artificial rise or fall, internal circulation, withdrawal)
	No introduction of fish where they were absent naturally (last decades)
	No fish-farming activities
	No mass recreation (camping, swimming, rowing)
Atlantic	Absence of major modification to catchment e.g. intensive afforestation
	No discharges present that would impair ecological quality.
	Abstraction at level that would not interfere with ecological quality
	Water level fluctuation: within natural range.
	Absence of shoreline alteration e.g. roads and harbours Groundwater connectivity within natural range.
	No impairment by invasive plant or animal species
	Stocking of non-indigenous fish not significantly affecting the structure and functioning of the ecosystem.
	No impact from fish farming.
	No intensive use for recreation purposes
Central	90 % of catchment landuse natural (or semi-natural) Population density <10 km^{-2} no point sources in the catchment
Mediterranean	70 % of the catchment area classified as "natural areas" (80 % in Portugal)
	very low occurrence of anthropogenic pressure in the catchment area
	Upstream accumulated demand of water for domestic use must be <3 % of annual loading; <1.5 % for industrial use; and <10 % for agricultural irrigation
	Low/moderate fishing and navigation pressures
	low/moderate water level fluctuations
Nordic	Agriculture: <5–10 % in catchment (<5 % Norway, <10 % Finland, Sweden, UK)
	Population density <5 p.e. km^{-2} (Norway), <10 p.e km^{-2} (Sweden) or absence of major settlements in catchment
	Absence of large industries in catchment
	Absence of major point sources in catchment

tions 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, chl-*a*) and expert judgement was broadly used in the final review of reference lake lists. The highest number of reference lakes (241) was defined in the Northern GIG, while the lowest numbers were 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 chl-*a* was calculated as the median of the arithmetic mean of chl-*a* concentrations in reference lakes. The H/G class boundary was set within a range between the 75th and 95th percentile of the mean chl-*a* 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 3) 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 more detailed national typologies following procedures agreed upon within GIGs.

Despite slightly different approaches, there was a high consistency in chl-*a* concentrations and relationships between chl-*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, 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 was the most critical and difficult procedure in the Intercalibration process and required various approaches by the countries (Table 4). Mainly, the secondary effect approach was used for setting and/or validating the G/M boundary, 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 and/or
– Changes in the composition of taxa would adversely affect the structure or functioning of the ecosystem.

For illustration, in Central GIG, the G/M quality class boundary was defined by agreeing on allowable risks of 3 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;

Table 3. Reference conditions and ecological status class boundary values for chlorophyll *a* (µg/l) set under the Common Implementation Strategy of the European Commission Water Framework Directive (2000).

	Type	Reference conditions	"High"/"Good" boundary	"Good"/"Moderate" boundary
Alpine	AL3	1.5–1.9	2.1–2.7	3.8–4.7
	AL4	2.7–3.3	3.6–4.4	6.6–8.0
Atlantic	A1/2	2.6–3.8	4.6–7.0	8.0–12.0
Central	CB1	2.6–3.8	4.6–7.0	8.0–12.0
	CB2	6.2–7.4	9.9–11.7	21.0–25.0
	CB3	2.5–3.7	4.3–6.5	8.0–12.0
Mediter-	M5/7	1.4–2.0	*	6.7–9.5
ranean	M8	1.8–2.6	*	4.2–6.0
Northern	N1	2.5–3.5	5.0–7.0	7.5–10.5
	N2a	1.5–2.5	3.0–5.0	5.0–8.5
	N2b	1.5–2.5	3.0–5.0	4.5–7.5
	N3a	2.5–3.5	5.0–7.0	8.0–12.0
	N5a	1.0–2.0	2.0–4.0	3.0–6.0
	N6a	2.0–3.0	4.0–6.0	6.0–9.0
	N8a	3.5–5.0	7.0–10.0	10.5–15.0

*not assessed because the WFD requires only setting "good" ecological potentials for reservoirs

Table 4. Approaches used in Geographic Intercalibration Groups to set the "good"/"moderate" class boundary for lakes according to chlorophyll *a* values.

GIG	Approach to set the G/M boundary
Alpine	Defining a 2- to 3-fold increase of phytoplankton biomass of reference conditions as tolerable within the "good" status Based on trophic classification (Lawa 1999) and equal class widths on a logarithmic scale Validating boundaries against the occurrence of undesirable secondary effects related to increased phytoplankton biomass as well as with the decline of the relative biomass proportion of sensitive taxa *Cyclotella*
Central	Several secondary effects to cross-check the validity of the G/M class boundary: – Decrease in maximum depth inhabited by submerged macrophytes; – Shift from macrophytes/benthos-dominated community with clear water to a phytoplankton-dominated community with turbid water; – Increase of the probability of cyanobacterial blooms.
Mediterranean	95^{th} percentile of the distribution of the data from the sites proposed as G/M sites for the IC register Validation of boundaries by secondary effect approach (shift in species composition, depletion of oxygen, decrease of Secchi depth)
Nordic	Phytoplankton composition changes along the chlorophyll a gradient: the G/M boundary at the break point in the curve of impact indicating taxa, i.e. at the threshold beyond which the impact indicating taxa increase more rapidly with the pressure

– Shift in phytoplankton composition toward light competitors (Cyanobacteria).

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 chl-*a* were defined for all European ecoregions (Table 3), following common conceptual framework.

Case study: assessment of the ecological status of large lakes of Europe

The ecological status of 54 European large lakes was evaluated according to the proposed criteria (Table 5). The lake Intercalibration data sets and European Environment Agency data base (WATERBASE) were used for the assessment of the large lakes of Europe. "Large lake" was defined as a lake with an area more than 100 km²; however, the largest lakes of countries were also included in the assessment (Arresø, Denmark, 41 km^2). Lake types were assessed by alkalinity, depth, area, and water colour; the ecological status was evaluated by chl-*a* and confirmed by data on total phosphorus (TP) and Secchi depth. For lakes with long-term data series (Mälaren

Table 5. Ecological status of European large lakes as assessed by chlorophyll *a* concentrations.

Status	Lakes
High	Höytiäinen, Inarijärvi , Juojärvi Kiantajärvi, Kivijärvi, Konnevesi, Puulavesi, Koitere, Näsijärvi, Pielinen, Pihlajavesi, Viinijärvi, Yli-Kitka (all Finland), Lough Corrib (Ireland), Lago di Garda, Lago di Trasimeno (Italy), Druskai (Lithuania), Mjøsa, Randsfjorden (Norway), Vänern, Vättern (Sweden)
Good	Haukivesi, Juurusvesi, Kallavesi, Kemijärvi, Keitele, Nilakka, Oulujärvi, Päijänne, Porttipahdan Tegojärvi, Pyhäjärvi, Saimaa, Vesijärvi (Finland), Bodensee, Müritz (Germany), Lago di Como, Lago Maggiore (Italy)
Less than Good	Arresø (Denmark), Lappajärvi, Lokan Tekojärvi, Vanajavesi (all Finland), Peipsi, Võrtsjärv (Estonia), Lac Leman (France), Balaton, Tisza (Hungary), Lubans (Latvia), IJsselmeer, Markermeer (Netherlands), Lough Derg, Lough Ree (Ireland), Śniardwy (Poland), Mälaren, except Bjrkfjärden (Sweden)

since 1965, Vänern since 1973) the average value for the previous years was used to make assessment comparable.

In 71 % of the lakes the water quality could be classified as high or good, in all or almost all parts of the lake. High status lakes were characterized by low chl-*a* concentrations (e.g., Vättern – long-term average value 1.0 µg/l), low TP concentrations (0.03–0.015 mg/l), and catchments dominated by natural landscape. Good status lakes showed slightly increased chl-*a* (4–10 µg/l) and TP values (0.02–0.04 mg/l). Sixteen lakes showed less than good status. Among them, 2 groups could be distinguished: lakes with moderate deviation from the reference conditions (e.g., Lac Leman with 6 µg/l of chl-*a*) and bad/poor status lakes under strong anthropogenic impact (e.g., highly eutrophic Dutch lakes IJsselmeer and Markermeer, with average chl-*a* values of 42 and 63 µg/l, respectively). The results of the case study validate the results of the boundary settings, showing distinct groups of lakes in terms of water quality data and anthropogenic stresses.

Acknowledgements

The technical and linguistic editing of the manuscript by the editorial staff of the Aquatic Ecosystem Health & Management Society (AEHMS) is gratefully acknowledged.

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