D31: Substantiated Ecological Targets

Work package N°35	**Substantiated ecological targets**
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Objective	Ecological criteria
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1 EXECUTIVE SUMMARY

This report addresses the ecological monitoring requirements of the EU Water Framework Directive (WFD). It aims to substantiate ecological water quality criteria and make recommendations for the improvement of environmental indicators and meta-indicators in relation to the monitoring and assessment of large, deep lakes and their catchments. For WFD purposes it is essential to select ecological indicators according to their sensitivity to specific pressures.

Substantiation of the ecological water quality criteria was carried out in three stages:

1) General criteria and recommendations for selecting and constructing environmental indicators were outlined
2) The most appropriate environmental indicators for particular pressures were identified
3) Approaches to combining the chosen indicators to construct an environmental meta-indicator were recommended

Task 2 was initially performed by carrying out an expert review on each of the WFD quality elements from which ecological indicators would be derived. Subsequently, a panel of experts quantitatively scored these elements by assessing their relative value in relation to each of the WFD categories of pressure. Ranking the scores identified the most effective biological and supporting elements for individual pressures.

Our analyses suggested that the following biological elements were the most useful for monitoring the ecological status of large, deep lakes: phytoplankton composition & abundance (nutrient pressure), profundal benthic invertebrate composition (deoxygenation pressure), macrophyte and littoral benthic invertebrate composition (abstraction, regulation of flow and morphological alterations pressures).

We recommended that the above biological indicators, in addition to a range of supporting hydro-morphological and physico-chemical elements, should form the core of any monitoring programme undertaken on such lakes and be combined in a single meta-indicator of ecological status for large, deep lakes.

The scheme we recommend is not a use-based status assessment. Most large, deep European lakes will also qualify for Protected Area status and this will require further, specific use-based indicators of status.

Deconstructing “ecological status” into a pressure context allows the development of a more transparent monitoring system. Explicit roles for quality elements not only make calibration of ecological classification schemes easier, it will also make it much simpler for lake and catchment managers to interpret monitoring results and identify the cause of change.

During the compilation of this report it became clear that other ecological criteria, in addition to those required by the WFD, were either essential or highly beneficial to the management of large, deep lakes and their catchments. For example microbiological quality and most socio-economic impacts are not directly represented. It was also concluded that lake physical models should be combined with ecological criteria to help managers predict the likely outcome of their management decisions on the environment. These issues are addressed further in report D36, entitled 'Additional Ecological Criteria'.

The output from this report will feed into the following Eurolakes reports: The Application of Physical Modelling Work (WP09), Management Strategies (WP28) and Final Recommendations (WP39).

Table of Contents

2 CONTRACTUAL REQUIREMENTS

2.1 OBJECTIVES AND INPUT TO THE WORKPACKAGE

Substantiating ecological water and ecosystem quality targets by elaborating recommendations for the improvement of environmental indicators and meta-indicators adapted to lakes and catchment areas. Input: WP 29 and WP 30.

2.2 DESCRIPTION OF WORK

As environmental indicators are used for various purposes, it is necessary to define general criteria and recommendations for selecting and constructing indicators, as well as index and parameters on which they are based. These basic criteria will be based on the main OECD recommendations: policy relevance and utility for stakeholders, analytical soundness, and measurability.

2.3 DELIVERABLE D31

Recommendations to select and construct an environmental meta-indicator adapted to lakes and catchment area respecting the guidelines of the OECD.

3 INTRODUCTION

Large, deep lakes are subject to a wide range of pressures and conflicting uses. Their catchments typically encompass dense population centres, intensive agriculture, and industry, and the lakes themselves have variety of uses. These include water supply, fisheries, recreation and tourism. All of these activities have the capacity to exert pressures on the system that may change the ecological status of the waterbody. It is the role of monitoring programmes, and specifically environmental indicators, to detect any such changes.

This report addresses the ecological monitoring requirements outlined in the EU Water Framework Directive (WFD). During the compilation of this report it became clear that other ecological criteria, in addition to those required by the WFD, were either essential or highly beneficial to the management of large, deep lakes and their catchments. It was also concluded that lake physical models should be combined with ecological criteria to help managers predict the likely outcome of their management decisions on the environment. These issues are addressed further in report D36, entitled ‘Additional Ecological Criteria’.

The output from this report will feed into the following Eurolakes reports: The Application of Physical Modelling Work (WP09), Management Strategies (WP28), Final Recommendations (WP39).

3.1 BACKGROUND TO WFD MONITORING

Article 1 of the WFD outlines the main purpose of the Directive, which is to achieve “sustainable, balanced and equitable water use” through the more explicit objective of “good ecological status” (European Commission, 2000).

The WFD outlines the two main types of monitoring required to assess ecological status:

1) **Surveillance monitoring.** This must be carried out on sufficient water bodies to enable an overall assessment of surface water status within each catchment to be made. The aim of this monitoring is to supplement and validate the risk assessment process within the WFD and identify long-term environmental changes. Surveillance monitoring covers all environmental indicators, or quality elements, outlined in the WFD (see Section 6.1) and, therefore, requires the construction of a meta-indicator of “ecological status”.

2) **Operational monitoring**. The aim of this type of monitoring is to establish the status of a water body considered to be at risk from a specific pressure. Only the indicator(s), or WFD quality element(s), most sensitive to the specific pressure need to be assessed. The most appropriate indicators for this purpose may be either an individual indicator or a combination of pressure-sensitive indicators, i.e. a pressure-specific meta-indicator.

From the above, it is clear that both forms of monitoring are focused on the risk assessment process. This assesses the risk of failing to meet environmental objectives (good status, or specific objectives for Protected Areas) and is based on an analysis of the pressures within a catchment and the impact of these pressures on a water body. In selecting ecological indicators for WFD monitoring purposes it is, therefore, essential to consider each indicator's sensitivity to specific pressures.

3.2 AIMS & OBJECTIVES

The aim of this report is to substantiate ecological water and ecosystem quality targets by elaborating recommendations for the improvement of environmental indicators and meta-indicators adapted to large, deep lakes and their catchments.

In this report we use the term "substantiate" to encompass all areas of ecological indicator development, including criteria for selecting indicators, the development of an ecological meta-indicator for status assessment and the development of ecological targets (e.g. WFD "good ecological status"). The report focuses on the first of these areas (i.e. "ecological criteria"), but provides recommendations for all three.

The substantiation was carried out in three stages:

1. general criteria and recommendations for selecting and constructing environmental indicators were outlined
2. the most appropriate environmental indicators for particular pressures were identified
3. approaches to combining the chosen indicators to construct an environmental meta-indicator were recommended

The report addresses the assessment of ecological status in lakes, but does not examine indicators of lake and catchment pressures directly. These are considered in other Eurolakes reports (e.g. 'Identifying Conflicting Uses' (D12) and 'Quantification of Uses' (D18)). However, some catchment pressures are considered indirectly through their impact upon lake water quality.
More refinement of methods are anticipated by using 1D turbulence mixing information from long-term calculations of WP 4.

3.3 REPORT STRUCTURE

The report is structured as follows:

Chapter 5
- Provides the methods and selection criteria used to assess the WFD quality elements

Chapter 6
- Reviews each of the quality elements from which ecological indicators are derived

Chapter 7
- Summarises the assessment of the indicators and suggests further means of substantiating them

Chapter 9
- Presents conclusions based on the above

4 METHODS FOR INDICATOR SELECTION

4.1 INTRODUCTION

Here we outline the methods used to substantiate ecological indicators for deep lakes, focusing on the indicator elements and lake pressures outlined in the WFD. Ecological status is defined in the WFD as “a measure of the quality of the structure and function of aquatic ecosystems” (European Commission, 2000). It is defined no further. Instead, one of the most technical annexes of the Directive, Annex V, details which “quality elements” should be used to measure it. Four biological quality elements (phytoplankton, macrophytes, benthic invertebrates and fish) are outlined as being of particular importance in quantifying ecological status, through specific measures of taxonomic composition, abundance, diversity and age structure. These are to be measured with up to seven hydromorphological and six physico-chemical elements.

In this report, the ecological quality elements highlighted in the monitoring requirements of the WFD are examined. Other potential indicators that are not listed in the WFD will be reported in WP36. Below are a few key definitions agreed among Eurolakes partners for terms used widely in this report. Their relationship to each other is illustrated in Figure 1.

Ecological Indicators (WFD quality elements)

Ecological indicators are parameters that are actually measured but have a significance beyond that directly associated with their absolute value.

Ecological criteria

Ecological criteria are criteria that are based on ecological classifications and which best describe the state of the system in relation to the ecological indicator under consideration. For example, if we consider the OECD lake classification system for total phosphorus [TP] (Vollenweider & Kerekes, 1982) in this context, the ecological criterion would be that a lake with TP concentrations of less than 10 $\mu g l^{-1}$ would be classified as “oligotrophic”.

Ecological targets

Ecological targets are environmental objectives that have been set by national or local authorities as part of an ecosystem management policy. The overall WFD target for large, deep lakes is good ecological and chemical status. The definition of ‘good’ involves comparison of current conditions with an “undisturbed” reference state. Within this overall target, ecological targets for individual quality elements must be refined and defined further, in part through an inter-calibration exercise. Ecological targets for Protected Areas are more specific and relate to the function of the lake, e.g. conservation, water supply, recreation. At most Eurolakes sites, sustainable targets are set for commercial fisheries too. Managers must take into account all the diverse uses and set any specific use-based targets accordingly.

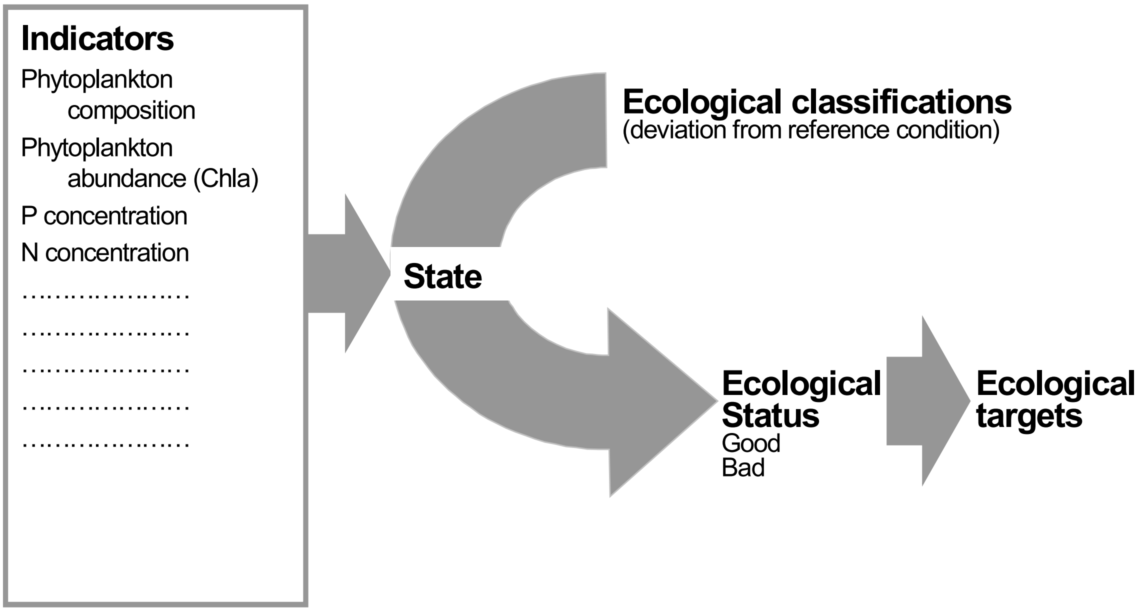

Figure 1. The role of indicators in assessing ecological status, as required under the EU Water Framework Directive.

4.2 METHODS

The Eurolakes project has made extensive studies of the existing monitoring, management and uses of each of the Eurolakes sites. These are among the most intensively monitored and managed deep lakes in the world and include Lake Geneva, Lake Constance, Lac du Bourget and Loch Lomond. Material from these sites combined with input from an expert panel of Eurolakes researchers was used to assess the best way of substantiating the existing WFD indicators. Initially, a qualitative review was carried out for each element. Then a quantitative scoring system was used to assess how well each of the elements was likely to reflect any change in the level of specific pressures outlined in the WFD. Finally, the information was synthesised to provide recommendations for further substantiating ecological indicators.

4.2.1 Qualitative Analysis of WFD Elements (Chapter 6)

Reviews of the WFD quality elements were carried out by individuals from the expert panel through literature review and expert assessment. Members of the expert panel have direct experience of monitoring lakes and/or in-depth research experience of the elements. The following topics were covered:

- Justification of importance (role in ecosystem structure and function)
- Applicability to WFD
- Classification and monitoring schemes
- Modelling potential

4.2.2 Quantitative scoring of WFD Elements as Pressure Indicators (Chapter 7)

Drawing on these literature reviews, a more quantitative scoring of WFD elements was then carried out by the expert panel, to assess how effective each element was as an indicator of a particular pressure. Seven WFD categories of pressure were considered, as outlined in Annex II of the WFD.

On the basis of the criteria prescribed by the project (OECD guidelines), and also incorporating ideas suggested by contacts and review of the literature, a suitability matrix was drawn up for assessing the relative value of individual indicators. The criteria were based on the main OECD recommendations: analytical soundness, measurability, policy relevance and utility for stakeholders. These criteria were expanded and refined to make the assessment process more transparent and useful.

Practical aspects of using the indicators were assessed first, using the following four criteria:

1. **Sensitivity** = how well is variation in the element correlated to change in the pressure? Further scoring in relation to items 2-3, below, was only undertaken for elements scoring 3 or 4 on the sensitivity scale (i.e. high levels of sensitivity)
2. **Measurable / Analytically sound** = how accurately and precisely can it be measured?
3. **Cost and Practicality** = how expensive is it and how easily can the method be implemented?
4. **Established Monitoring Scheme** = to what level has a monitoring scheme been developed and applied

Individual scores ranged from 0 (lowest) to 4 (highest), and scores against each of the above criteria were summed to provide a total score that would reflect the relative usefulness of a particular quality element as an indicator of a particular pressure.

Two further criteria were then evaluated which were not essential to the assessment of each indicator, but were considered to have policy relevance and utility for stakeholders. They are closely linked to the practical implementation of policy aspects of the WFD, especially the achievement and maintenance of good status through pro-active management and the implementation of the ‘polluter pays’ principle. These were:

1. Modelling feasibility = a measure of current ability to numerically model the relationships between the element and the pressure
2. Anthropogenic – 'natural' discrimination = ability to discriminate between anthropogenic induced change and ‘natural’ change

Modelling feasibility is included because it indicates the possibility of managers being able to predict the impact of their actions on some water quality elements using numerical modelling. A good example of this is the use of nutrient input models that allow managers to determine the implications of altering land use within a catchment on phytoplankton abundance. In theory, this would then make quantitative measures of sustainable development feasible.

Biological systems, including lakes, are naturally dynamic. Being able to tell whether a change is natural or anthropogenic induced is of particular importance when an indicator is sensitive to a wide range of variables. Many of the WFD biological elements could be classified as generally sensitive to a wide range of pressures. They are also sensitive to top–down biological processes, and natural chemical and physical drivers. For a manager it is useful to realise that the system is under pressure caused by human activity and further he has to be able to exclude natural biological, chemical and physical drivers as the cause of change in the indicator. Often an anthropogenic-induced change is so obvious that the cause is clear, however this is not likely to be true at an early stage when changes may be minor. Clarifying the cause by eliminating natural physical, chemical and biological drivers is the key. As in the case of eutrophication an early diagnosis allows remedial action to be taken when it is most beneficial. Eliminating climatic and top-down grazer effects on phytoplankton production may allow earlier diagnosis of eutrophication problems.

An example of the matrices for each of the three main groups of quality elements is given below in Tables 1-3.

4.2.3 Synthesis of Qualitative and Quantitative Analysis (Recommendations on Construction of a Meta-indicator) (Chapter 7)

This section provides a brief synthesis of the best indicators for specific pressures and suggests the best way how integrating them.

Table 1. Suitability matrix for WFD hydro-morphological quality elements

Hydro-morphological quality elements	Sensitivity	Measurable / Analytically sound	Cost & practicality	Established Monitoring Scheme	Total score	Discrimination be-tween anthropogenic and 'natural' change	Modelling fea-sible
Hydrological regime							
Quantity and dynamics of water flow							
Residence time							
Connection to the ground water body							
Morphological conditions							
Lake depth variation (water level)							
Quantity, structure and substrate of the lake bed							
Structure of the lake shore							

Table 2. Suitability matrix for WFD Physical & chemical quality elements

Physical & chemical quality elements	Sensitivity	Measurable / Analytically sound	Cost & practical-ity	Established Monitoring Scheme	Total score	Discrimination be-tween anthropogenic and 'natural' change	Modelling feasible
Transparency							
Thermal conditions							
Oxygenation conditions							
Salinity							
Acidification status							
Nutrient conditions							
Specific pollutants							

Table 3. Suitability matrix for WFD biological quality elements

Biological quality elements	Sensitivity	Measurable / Analytically sound	Cost & practicality	Established Monitoring Scheme	Total score	Discrimination between anthro-pogenic and 'natu-ral' change	Modelling feasible
Phytoplankton composition							
Phytoplankton abundance							
Other aquatic flora composition							
Other aquatic flora abundance							
Benthic invertebrate fauna composition							
Benthic invertebrate fauna abundance							
Fish fauna composition							
Fish fauna abundance							
Fish fauna age structure							

5 QUALITATIVE ANALYSIS OF WFD ELEMENTS

An assessment of the key biological, chemical and physical elements for lake and river monitoring is presented, here. A justification of their importance is given, their relationship to the WFD is described, their use in monitoring schemes is reviewed and their possible use for predictive modelling is discussed. The work was done while keeping in mind the necessity to keep the list as short as possible from the practical point of view.

5.1 SUMMARY OF THE WFD MONITORING REQUIREMENTS

5.1.1 Quality elements for the classification of ecological status

5.1.1.1 Lakes

5.1.1.1.1 Biological elements

- Composition, abundance and biomass of phytoplankton
- Composition and abundance of other aquatic flora
- Composition and abundance of benthic invertebrate fauna
- Composition, abundance and age structure of fish fauna

5.1.1.1.2 Hydromorphological elements supporting the biological elements

- Hydrological regime
- Quantity and dynamics of water flow
- Residence time
- Connection to the ground water body
- Morphological conditions
- Lake depth variation
- Quantity, structure and substrate of the lake bed
- Structure of the lake shore

5.1.1.1.3 Chemical and physico-chemical elements supporting the biological elements

General

- Transparency
- Thermal conditions
- Oxygenation conditions
- Salinity
- Acidification status

- Nutrient conditions

Specific pollutants

- Pollution by all priority substances identified as being discharged intothe body of water

- Pollution by other substances identified as being discharged in significant quantities into the body of water

5.1.1.2 Rivers

5.1.1.2.1 Biological elements

- Composition and abundance of aquatic flora
- Composition and abundance of benthic invertebrate fauna
- Composition, abundance and age structure of fish fauna

5.1.1.2.2 Hydromorphological elements supporting the biological elements

- Hydrological regime
- Quantity and dynamics of water flow
- Connection to ground water bodies
- River continuity
- Morphological conditions
- River depth and width variation
- Structure and substrate of the river bed
- Structure of the riparian zone

5.1.1.2.3 Chemical and physicochemical elements supporting the biological elements

General

- Thermal conditions
- Oxygenation conditions
- Salinity
- Acidification status
- Nutrient conditions

Specific Pollutants

- Pollution by all priority substances identified as being discharged into the body of water

- Pollution by other substances identified as being discharged in significant quantities into the body of water

5.1.2 Definitions for high, good and moderate ecological status in rivers

5.1.2.1 Biological quality elements

Element	High status	Good status	Moderate status
Phytoplankton	The taxonomic composition of phytoplankton corresponds totally or nearly totally to undisturbed conditions. The average phytoplankton abundance is wholly consistent with the type-specific physicochemical conditions and is not such as to significantly alter the type specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the type specific physicochemical conditions.	There are slight changes in the composition and abundance of planktonic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. A slight increase in the frequency and intensity of the type specific planktonic blooms may occur.	The composition of planktonic taxa differs moderately from the type specific communities. Abundance is moderately disturbed and may be such as to produce a significant undesirable disturbance in the values of other biological and physico-chemical quality elements. A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months.
Macrophytes and phytobenthos	The taxonomic composition corresponds totally or nearly totally to undisturbed conditions. There are no detectable changes in the average macrophytic and the average phytobenthic abundance.	There are slight changes in the composition and abundance of macrophytic and phytobenthic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. The phytobenthic community is not adversely affected by bacterial tufts and coats present due to anthropogenic activity.	The composition of macrophytic and phytobenthic taxa differs moderately from the type-specific community and is significantly more distorted than at good status. Moderate changes in the average macrophytic and the average phytobenthic abundance are evident. The phytobenthic community may be interfered with and, in some areas, displaced by bacterial tufts and coats present as a result of anthropogenic activities.

Benthic invertebrate fauna	The taxonomic composition and abundance correspond totally or nearly totally to undisturbed conditions. The ratio of disturbance sensitive taxa to insensitive taxa shows no signs of alteration from undisturbed levels The level of diversity of invertebrate taxa shows no sign of alteration from undisturbed levels.	There are slight changes in the composition and abundance of invertebrate taxa from the type-specific communities The ratio of disturbance sensitive taxa to insensitive taxa shows slight alteration from type specific levels. The level of diversity of invertebrate taxa shows slight signs of alteration from type specific levels.	The composition and abundance of invertebrate taxa differ moderately from the type-specific communities. Major taxonomic groups of the type-specific community are absent. The ratio of disturbance sensitive taxa to insensitive taxa, and the level of diversity, are substantially lower than the type specific level and significantly lower than for good status.
Fish fauna	Species composition and abundance correspond totally or nearly totally to undisturbed conditions. All the type specific disturbance sensitive species are present. The age structures of the fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the reproduction or development of any particular species.	There are slight changes in species composition and abundance from the type specific communities attributable to anthropogenic impacts on physicochemical and hydromorphological quality elements. The age structures of the fish communities show signs of disturbance attributable to anthropogenic impacts on physicochemical or hydromorphological quality elements, and, in a few instances, are indicative of a failure in the reproduction or development of a particular species, to the extent that some age classes may be missing.	The composition and abundance of fish species differ moderately from the type specific communities attributable to anthropogenic impacts on physicochemical or hydromorphological quality elements. The age structure of the fish communities shows major signs of anthropogenic disturbance, to the extent that a moderate proportion of the type specific species are absent or of very low abundance.

5.1.2.2 Hydromorphological quality elements

Element	High status	Good status	Moderate status
Hydrological regime	The quantity and dynamics of flow, and the resultant connection to groundwaters, reflect totally, or nearly totally, undisturbed conditions.	Conditions consistent with the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.
River continuity	The continuity of the river is not disturbed by anthropogenic activities and allows undisturbed migration of aquatic organisms and sediment transport.	Conditions consistent with the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.
Morphological conditions	Channel patterns, width and depth variations, flow velocities, substrate conditions and both the structure and condition of the riparian zones correspond totally or nearly totally to undisturbed conditions.	Conditions consistent with the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.

5.1.2.3 Physico-chemical quality elements [1]

Element	High status	Good status	Moderate status
General conditions	The values of the physico-chemical elements correspond totally or nearly totally to undisturbed conditions. Nutrient concentrations remain within the range normally associated with undisturbed conditions. Levels of salinity, pH, oxygen balance, acid neutralising capacity and temperature do not show signs of anthropogenic disturbance and remain within the range normally associated with undisturbed conditions.	Temperature, oxygen balance, pH, acid neutralising capacity and salinity do not reach levels outside the range established so as to ensure the functioning of the type specific ecosystem and the achievement of the values specified above for the biological quality elements. Nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.
Specific synthetic pollutants	Concentrations close to zero and at least below the limits of detection of the most advanced analytical techniques in general use	Concentrations not in excess of the standards set in accordance with the procedure detailed in section 1.2.6 without prejudice to Directive 91/414/EC and Directive 98/8/EC. (<eqs)	Conditions consistent with the achievement of the values specified above for the biological quality elements.
Specific non synthetic pollutants	Concentrations remain within the range normally associated with undisturbed conditions (background levels = bgl).	Concentrations not in excess of the standards set in accordance with the procedure detailed in section 1.2.6 [2] without prejudice to Directive 91/414/EC and Directive 98/8/EC. (<eqs)	Conditions consistent with the achievement of the values specified above for the biological quality elements.

1 The following abbreviations are used: bgl = background level, eqs = environmental quality standard
2 Application of the standards derived under this protocol shall not require reduction of pollutant concentrations below background levels: (eqs>bgl)

5.1.3 Definitions for high, good and moderate ecological status in lakes

5.1.3.1 Biological quality elements

Element	High status	Good status	Moderate status
Phytoplankton	The taxonomic composition and abundance of phytoplankton correspond totally or nearly totally to undisturbed conditions. The average phytoplankton biomass is consistent with the type-specific physicochemical conditions and is not such as to significantly alter the type specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the type specific physicochemical conditions.	There are slight changes in the composition and abundance of planktonic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbance to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. A slight increase in the frequency and intensity of the type specific planktonic blooms may occur.	The composition and abundance of planktonic taxa differ moderately from the type specific communities. Biomass is moderately disturbed and may be such as to produce a significant undesirable disturbance in the condition of other biological quality elements and the physico-chemical quality of the water or sediment. A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months.
Macrophytes and phytobenthos	The taxonomic composition corresponds totally or nearly totally to undisturbed conditions. There are no detectable changes in the average macrophytic and the average phytobenthic abundance.	There are slight changes in the composition and abundance of macrophytic and phytobenthic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbance to the balance of organisms present in the water body or to the physicochemical quality of the water. The phytobenthic community is not adversely affected by bacterial tufts and coats present due to anthropogenic activity.	The composition of macrophytic and phytobenthic taxa differ moderately from the type-specific communities and are significantly more distorted than those observed at good quality. Moderate changes in the average macrophytic and the average phytobenthic abundance are evident. The phytobenthic community may be interfered with, and, in some areas, displaced by bacterial tufts and coats present as a result of anthropogenic activities.

Benthic invertebrate fauna	The taxonomic composition and abundance correspond totally or nearly totally to the undisturbed conditions. The ratio of disturbance sensitive taxa to insensitive taxa shows no signs of alteration from undisturbed levels The level of diversity of invertebrate taxa shows no sign of alteration from undisturbed levels	There are slight changes in the composition and abundance of invertebrate taxa compared to the type-specific communities. The ratio of disturbance sensitive taxa to insensitive taxa shows slight signs of alteration from type specific levels. The level of diversity of invertebrate taxa shows slight signs of alteration from type specific levels.	The composition and abundance of invertebrate taxa differ moderately from the type-specific conditions Major taxonomic groups of the type-specific community are absent. The ratio of disturbance sensitive to insensitive taxa, and the level of diversity, are substantially lower than the type specific level and significantly lower than for good status
Fish fauna	Species composition and abundance correspond totally or nearly totally to undisturbed conditions. All the type specific sensitive species are present. The age structures of the fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the reproduction or development of a particular species.	There are slight changes in species composition and abundance from the type specific communities attributable to anthropogenic impacts on physicochemical or hydromorphological quality elements. The age structures of the fish communities show signs of disturbance attributable to anthropogenic impacts on physicochemical or hydromorphological quality elements, and, in a few instances, are indicative of a failure in the reproduction or development of a particular species, to the extent that some age classes may be missing.	The composition and abundance of fish species differ moderately from the type specific communities attributable to anthropogenic impacts on physicochemical or hydromorphological quality elements. The age structure of the fish communities shows major signs of disturbance, attributable to anthropogenic impacts on physicochemical or hydromorphological quality elements, to the extent that a moderate proportion of the type specific species are absent or of very low abundance.

5.1.3.2 Hydromorphological quality elements

Element	High status	Good status	Moderate status
Hydrological regime	The quantity and dynamics of flow, level, residence time, and the resultant connection to groundwaters, reflect totally or nearly totally undisturbed conditions.	Conditions consistent with the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.
Morphological conditions	Lake depth variation, quantity and structure of the substrate, and both the structure and condition of the lake shore zone correspond totally or nearly totally to undisturbed conditions.	Conditions consistent with the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.

5.1.3.3 Physico-chemical quality elements [3]

Element	High status	Good status	Moderate status
General conditions	The values of physico-chemical elements correspond totally or nearly totally to undisturbed conditions. Nutrient concentrations remain within the range normally associated with undisturbed conditions. Levels of salinity, pH, oxygen balance, acid neutralising capacity, transparency and temperature do not show signs of anthropogenic disturbance and remain within the range normally associated with undisturbed conditions.	Temperature, oxygen balance, pH, acid neutralising capacity, transparency and salinity do not reach levels outside the range established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements. Nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.
Specific synthetic pollutants	Concentrations close to zero and at least below the limits of detection of the most advanced analytical techniques in general use.	Concentrations not in excess of the standards set in accordance with the procedure detailed in section 1.2.6 without prejudice to Directive 91/414/EC and Directive 98/8/EC. (<eqs)	Conditions consistent with the achievement of the values specified above for the biological quality elements.
Specific non synthetic pollutants	Concentrations remain within the range normally associated with undisturbed conditions (background levels = bgl).	Concentrations not in excess of the standards set in accordance with the procedure detailed in section 1.2.6 [4] without prejudice to Directive 91/414/EC and Directive 98/8/EC. (<eqs)	Conditions consistent with the achievement of the values specified above for the biological quality elements.

3 The following abbreviations are used: bgl = background level, eqs = environmental quality standard

4 Application of the standards derived under this protocol shall not require reduction of pollutant concentrations below background levels

Quality Element	Rivers	Lakes
Biological		
Phytoplankton	6 months	6 months
Other aquatic flora	3 years	3 years
Macro invertebrates	3 years	3 years
Fish	3 years	3 years
Hydromorphological		
Continuity	6 years	
Hydrology	continuous	1 month
Morphology	6 years	6 years
Physico-Chemical		
Thermal Conditions	3 months	3 months
Oxygenation	3 months	3 months
Salinity	3 months	3 months
Nutrient Status	3 months	3 months
Acidification Status	3 months	3 months
Other Pollutants	3 months	3 months
Priority Substances	1 month	1 month

Table 4. Physical and chemical elements defining lake status

Scientific fields	Quality elements
hydro-meteorology	inflow annual mean
	inflow dynamics
	residence time
	water level dynamics/seiches
	groundwater exchange
morphology	bathymetric type
	substrate type
	shoreline quality (structural)
	shore:surface spatial-ratio
	volume-ratio epi-, meta- & hypolimnion
	areal-ratio epi-, meta- & hypolimnion
	interbasin connectivity
physics	mixing behaviour
	transparency
	thermal conditions
	currents
chemistry	salinity
	nutrients
	buffer capacity
	oxygen
	toxics

Table 5. Biological elements defining lake status

Scientific fields	Quality elements
Phytoplankton	phytoplankton abundance phytoplankton composition phytoplankton blooms
Fish	fish abundance fish composition fish age structure
Macrophytes	macrophytes abundance macrophytes composition
Phytobenthos	abundance composition
Benthic littoral inverte-brates	abundance composition
Benthic profundal invertebrates	abundance composition

5.2 ASSESSMENT OF KEY BIOLOGICAL, CHEMICAL AND PHYSICAL ELEMENTS

5.2.1 Morphology

5.2.1.1 Justification of importance

Most of the large-scale morphological processes in lakes develop on a very slow time-scale and are therefore *quasi* static boundary conditions for the ecological relevant processes in the lake. This and other boundary conditions such as the geographical position and the clime are the basis of the ecological potential of a lake. The ecological quality of a lake has to be considered in relation to its ecological potential.

As changes in ecological quality are normally considered on a much faster time-scale than the slow changes in the ecological potential, it is questionable whether such *quasi* static boundary conditions, as given by the morphology, can be considered as indicators at all, because they can't indicate any change in ecological quality.
However the morphological information might be crucial for the interpretation or formation of other indicators such as e.g. the deep water renewal. The bathymetry of a lake can have an essential influence on deep water renewal as well as mixing processes.

Some morphological processes that have large-scale effects take place on a faster time-scale. Such are e.g. regulation measures at the outflow, changes in the hydrodynamic regime of the littoral zone or the inflow of rivers caused by constructions or other anthropogenic changes. The impact of such morphological changes on the ecology of the lake can be considerable. Shoreline constructions such as walls can lead to reflection of waves and may as a consequence cause erosion in the littoral zone or adjacent shore areas. Some constructional measures as e.g. dams can influence the hydrodynamic regime in a way that sludge sedimentation occurs in some regions or fresh water supply is restricted. This shows that the structure of a lake shore can have at least locally a strong influence to the lake ecosystem and that there is a need for an indicator describing the shoreline quality.

5.2.1.2 WFD-associated characteristics

Annex V of the WFD outlines hydro morphological quality elements that need consideration in the classification of ecological status.

The morphology-related elements are:

- lake depth variation
- quantity, structure and substrate of the lake bed
- structure of the lake shore

The hydrology-related elements are:

- quantity and dynamics of water flow
- residence time
- connection to the ground water body

These elements are aimed to support the biological quality elements. The hydrological regime as well as the ecosystem is dependent on morphological parameters.

5.2.1.3 Classification and monitoring schemes

During the Eurolakes-Meeting in Tampere (Sept. 2001) the following list of morphological “indicators” was established:

- bathymetric type (*)
- substrate type
- shoreline quality (structural)
- shore:surface ratio
- volume-ratio epi-, meta- & hypolimnion (*)
- areal-ratio epi-, meta- & hypolimnion
- interbasin connectivity

The “indicators” marked with (*) where considered as “key indicators” the others as “supplemental”.

Most important for the Eurolakes project would be a definition of for characterisation of a “large deep lake”. It is suggested that the mean depth of such a lake should be at least 4 times the depth of the epilimnion, when it has its maximum thermal energy (usually in summer).

A characterisation of the bathymetric type can be done by means of the hypsographic curve and an evaluation of areas of steep and plane depth-configuration. A higher integration of the bathymetric information is given in the above mentioned volume- or areal-ratio. These however are not mere morphological parameters but do depend on the stratification properties of the lake.

Morphological information is often used indirectly in classifications. E.g. the Lake Number defined by Imberger and Patterson (1990) uses among other parameters the hypsographic curve leading to a characterization of the dynamic stability of the lake. Also when considering the wind fetch the size of the lake is an important parameter for the sea state.

The structural quality of the shoreline might be indicated by the percentage of shore length with and without constructions. However the rather complex hydrodynamic behaviour and its consequences might be not sufficiently taken into account this way.

It is evident, that most of the above mentioned morphological “indicators” do not have to be regularly monitored as they vary only on a very slow time-scale.

5.2.1.4 Models

In models the morphological information is mostly used as boundary condition or indirect information, e.g. the bathymetry in hydrodynamic models.

5.2.1.5 References

Imberger, J., and J. C. Patterson. 1990. Physical limnology. Adv. Appl. Mech. 27: 303-475.

5.2.2 Transparency

5.2.2.1 Justification of importance

There are three factors that influence transparency, the water itself, colouring matter in the water, and turbidity associated with particles in the water. The amount of turbidity in particular is heavily influenced by a range of variables, natural and anthropogenic, and can vary both temporally and spatially within a given water body. The response to turbidity is reviewed here, as it is this parameter that is most associated with pressures from human activity. Transparency and turbidity are inversely related, with an increase in turbidity resulting from human activity always resulting in a decrease in transparency.

Eutrophication will reduce transparency, but where macrophyte populations are still present, transparency often changes little. Only when lake systems switch to phytoplankton dominance is there a major decrease in transparency. Where acidification occurs and aluminium is mobilised, flocculation will increase transparency and the water may be clearer in poor and undesirable states than it is in more desirable ecological states.

Aquatic macrophytes are profoundly influenced by turbidity, although influences due to human activity can be difficult to separate from other properties of a water body, e.g. colour and shading. Turbidity can be caused by suspended organic and inorganic matter, such as silts, clays, carbonate particles, fine organic particulate matter, plankton and other small organisms.

Increased turbidity generally results in a shift in community structure from submersed species to floating-leaved or emergent species. Turbid water cannot directly harm the growth of plants whose leaves are mainly above water level, such as emergent and most free-floating plants. Little is known of the precise influence of underwater changes in light intensity and quality on the distribution of life forms and species. Some plants of a particular habit may tolerate, or even prefer sustained low intensities and/or deficiencies in certain wavelengths.

5.2.2.2 Classification and monitoring schemes

Measures to assess the transparency of water bodies are typically only taken as part of particular studies and surveillance, e.g. in relation to phytoplankton and macrophyte populations in lakes. Suspended solids measurements are used to assess water quality for a range of reasons typically linked to river quality criteria, e.g. in relation to sewage treatments and the Freshwater Fisheries Directive. No example has been found where the measure is linked directly to turbidity/transparency criteria for aquatic macrophytes.

Nephelometric Turbidity Units (NTU) is a measure of water turbidity commonly employed in the US. It is calculated by measuring the dispersion of a light beam passed through a sample of water. It has been found that the amount of scattering caused by fine particles, silt and suspended matter is proportionate to the amount of turbidity present. This process, therefore, gives a good indication of the relative turbidity of a water sample. The measurement of NTU does not give the *sizes* of the particles, nor does it indicate the *amount* of particles present. It is a qualitative, rather than quantitative way of measuring turbidity.

The Secchi disc also provides a simple and valuable surrogate for transparency and it is widely used in lakes and other lentic water bodies. It relies on a weighted circular disc (20 cm diameter) with alternate quadrants of white and black lowered into the water on a line. The average distance taken from the depth at which the disc disappears from view and the depth at which it reappears from view is known as the Secchi depth.

The most widely recognised classification in terms of transparency is that developed during the OECD programme on eutrophication (OECD 1982). This outlined a classification scheme detailing boundary values of transparency (Secchi depth) in relation to total phosphorus and chlorophyll *a* concentrations (Table 6).

The sensitivity of submerged macrophyte species to turbidity can be expressed by the ratio of the depth maxima of the species to the Secchi transparency depth i.e. the Turbidity Tolerance Index (Davis and Brinson 1980).

The existing knowledge on the relationships between turbidity and macrophytes is limited. Whilst some degree of work has been undertaken on variables that may act as surrogates for turbidity (i.e. depth, as above), no concerted effort has been made to establish the responses of macrophyte species and communities to different causes and levels of turbidity.

More study is required to a) explore appropriate methods for the measurement of transparency, turbidity and colour, and b) establish transparency, colour and turbidity measures for reference sites and key species. More research into the reaction of biological communities to changes in transparency should be pursued.

5.2.2.3 References

Davis G J and Brinson M M, 1980 *Responses of submersed vascular plant communities to environmental change*: U.S. Department of the Interior Report FWS/OBS-79/33.

OECD, 1982 *Eutrophication of Water: Monitoring, Assessment and Control*, pp. 150. Paris: Organisation for Economic Cooperation and Development.

5.2.3 Nutrients

Nutrients are important factors regulating the growth of phytoplankton and other plants. There are macronutrients (e.g. phosphorus, nitrogen, carbon) and micronutrients (e.g. potassium, sodium, magnesium). This review focuses on the two nutrients most frequently associated with limiting algal growth: phosphorus and nitrogen.

5.2.3.1 Phosphorus

5.2.3.1.1 Justification of importance

Phosphorus is the main limiting nutrient in most undisturbed, deep temperate and boreal lakes and can be used as a relatively simple measure of the trophic status of the lake.

Total phosphorus consists of soluble orthophosphate and soluble organic phosphorus compounds as well as particulate inorganic and organic phosphorus. Phosphorus in the cells of organisms belongs to the category of particulate organic phosphorus. Particulate inorganic phosphorus includes complexes such as phosphorus bound to clay particles, most of which is biologically inactive.

Phosphorus is usually measured as total phosphorus (TP), phosphate phosphorus (PO_4-P) and dissolved reactive phosphorus (DRP). DRP differs from PO_4-P in that for the DRP measurement water is filtered. There are standard methods for measuring the above mentioned fractions and they are commonly used in the context of water management.

5.2.3.1.2 Classification and monitoring schemes

The use of PO_4-P and DRP concentrations are problematic in the assessment of trophic status. Low concentrations do not necessarily indicate a low trophic status as phosphorus may be bound to biomass. Sampling, transportation and storage of samples before analysis can significantly alter concentrations.

The most widely recognised classification in terms of total phosphorus concentrations is that developed during the OECD programme on eutrophication (OECD 1982). This outlined a classification scheme detailing boundary values of total phosphorus, chlorophyll *a* and transparency (Secchi depth) between trophic classes (Table 6, based on an interpretation by Newman (1988)).

Table 6. OECD classification scheme for lake trophic status

	Annual mean TP (µg/l)	Annual mean chlorophyll*a* (µg/l)	Annual maximum chlorophyll*a* (µg/l)	Annual meansecchi depth (m)
Ultra-oligotrophic	<4	<1	<2.5	>12
Oligotrophic	<10	<2.5	<8	>6
Mesotrophic	10-35	2.5-8	8-25	6-3
Eutrophic	35-100	8-25	25-75	3-1.5
Hyper-eutrophic	>100	>25	>75	<1.5

These classes are not solely applicable to deep European lakes, however, as they are based on data from a large number of lake types from lake regions across the globe, although there was a pre-dominance of large, deep lakes in the original dataset.

Lake depth, colour and altitude/latitude (geology/temperature) will affect how effectively nutrients are transformed into phytoplankton biomass; different lakes will, therefore, show variable sensitivities to nutrient enrichment.

5.2.3.2 Nitrogen

5.2.3.2.1 Justification of importance

Nitrogen is the main limiting nutrient in oceans. Some lakes are nitrogen limited, whilst temporally-separated co-limitation of nitrogen and phosphorus is considered to be relatively frequent. The behaviour of nitrogen strongly affects the situation. If there is lack of biologically available nitrogen and biologically active phosphorus is still present, nitrogen fixation by cyanobacteria may be possible, although is not necessarily certain, as it requires high energy inputs.

Nitrogen is present in waters in several inorganic and organic forms: dissolved molecular nitrogen (N_2), ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), dissolved organic nitrogen compounds (e.g. urea, peptides, proteins) as well as nitrogen bound to organic and inorganic particles and colloids (e.g. humus). N_2 can be transformed into a biologically active form by many cyanobacteria and other bacteria.

The concentrations of the biologically available forms of nitrogen, NH_4-N, NO_2-N and NO_3-N, in lakes are usually small compared to total nitrogen (TN). A small part of dissolved organic nitrogen is biologically available. Nitrogen releases from organisms as organic nitrogen compounds which are rapidly transformed into NH_4-N. In nitrification NH_4-N is first oxidised into NO_2-N and then into NO_3-N. The first step is much slower and therefore concentrations of NO_2-n are most often close to zero. In environments with low redox potential, denitrification occurs in which NO_3-N is reduced into N_2 (or nitrous oxide N_2O).

TN, NH_4-N, NO_2-N and NO_3-N are usually analysed and standard methods exist. Other nitrogen fractions can be measured but they are not very common in water monitoring.

According to present knowledge, both phosphorus and nitrogen limit the growth of phytoplankton and other plants simultaneously. The question of which nutrient is more important can be approached by means of ratios of nutrient concentrations (expressed as :g l^{-1}, not as molar concentrations) as follows:

TN/TP	(NH_4-N + NO_2-N + NO_3-N)/DRP	The limiting nutrient
< 10	< 5	Nitrogen
10 – 17	5 – 12	Phosphorus and nitrogen
> 17	> 12	Phosphorus

In addition to the effects on trophic status, it should be borne in mind that some forms of nitrogen in lakes may be toxic. NH_4-N exists at high pH values in the form of ammonia (NH_3), which is toxic and may cause e.g. fish kills. NO_2 is toxic, particularly to small children, causing methemoglobinemia, but fortunately the concentrations in lakes are normally very low.

There are no established lake classification schemes based on nitrogen concentrations.

5.2.3.3 References

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5.2.4 Oxygen

5.2.4.1 Justification of Importance

Oxygen is essential to the maintenance of animal life in rivers and lakes. Dissolved oxygen concentrations (DO) determine animal distributions, behaviour and physiological growth. Oxygen depletion is a characteristic of organic pollution. Dissolved oxygen conditions, therefore, represent an effective indicator of the impact of organic pollution pressures on the physico-chemical status of watercourses.

The mechanisms by which oxygen is supplied to water are by surface diffusion from the air, and from photosynthetic processes within the water. The rate of oxygen diffusion and synthesis, relative to oxygen consumption by respiration and chemical oxidation, determines the oxygen concentrations that benthic invertebrates and fish are exposed to. Oxygen solubility and the dynamics of oxygen distribution within the surrounding water column are also very important factors in determining concentrations. Oxygen solubility in a lake is governed by the prevailing water temperature and by atmospheric pressure.

Oxygen depletion occurs when the processes that use oxygen do so at rate in excess to that at which it can be absorbed. DO concentrations are, however, commonly lower than 100% saturation. The reasons are various and include respiration (by animals and plants) at night, organic decomposition by bacteria and inorganic chemical reactions. The risk of oxygen depletion is greatest in waters affected by a high discharge of organic matter and where substantial production of algae and other plants occur. As oxygen depletion threatens the survival of many invertebrate and fish species, measurements of the amount of organic matter or rates of oxygen depletion can be used to assess the water quality of rivers and lakes. A simple measure of the potential for deoxygenation is the biochemical oxygen demand (BOD), which measures the amount of oxygen consumed by microorganisms over a standard time period. It can range from <2 mgl^{-1} in very clear waters to values in the 100s of mgl^{-1} for raw sewage and 1000s of mgl-1 for silage and slurry.

In lakes, productivity and morphometry are of crucial importance in determining oxygen conditions. Lakes exposed to wind driven waves and mixing will be well aerated. In thermally-stratified deep lakes, oxygen concentrations in the hypolimnion decline over summer and are at their lowest in late summer before overturn. If there is insufficient mixing, then extreme concentrations of oxygen may occur, resulting in, for example, supersaturated conditions in the surface waters of nutrient-rich lakes with a high rate of photosynthesis during the day (especially in sunny and windless conditions) or anaerobic conditions in the deep hypolimnion of eutrophic lakes in summer.

Fish species can be separated by their oxygen requirements. As well as having different requirements between species, they have different requirements throughout their life stages (eggs, larvae, juveniles and adults). Generally, cool water preferring species (stenotherms) need higher dissolved oxygen concentrations than warm water species (eyrutherms). Fish metabolism and activity, and therefore oxygen requirements increase with temperature, so in summer they are at greater risk from oxygen depletion.

Field studies in which fish catches have been related to DO show that 3 mgl^{-1} is insufficient to maintain good, mixed fish populations. For most species feeding is diminished or stopped below this concentration and growth is reduced. If the community includes salmonids 5 mgl-1 was suggested as a target. The minimum concentrations of DO for long-term sustainability of the fish community are, however, now generally accepted to be higher than those given above (e.g. EU Directive 78/659/EEC).

For coregonids and salmonids, the required concentration of dissolved oxygen is 8–10 mgl^{-1}. For cyprinids, grayling *Thymallus thymallus*, chub *Leuciscus leuciscus*, gudgeon *Gobio gobio*, pike *Esox lucius*, lampreys, sticklebacks and percids, an oxygen concentration of 6–8 mgl^{-1} is considered sufficient. Carps, breams and tench *Tinca tinca* can survive in oxygen concentrations of less than 1 mgl^{-1}.

In deep lakes that experience thermal stratification, DO level in the hypolimnion layer can fall distinctly below that in the upper epilimnion. This situation can cause a vertically spatial separation of fish species within a lake.

5.2.4.2 Classification and monitoring schemes

There is no specific lake classification based on fish responses to oxygen conditions. Lake classification and monitoring schemes relating biology to oxygen conditions have focused on the profundal benthic invertebrate fauna of deep stratified lakes. The resultant lake typologies have usually been based on the relationship between summer and winter oxygen concentrations (which are themselves dependent on factors such as lake morphology, thermal regime, primary production and proportion of allochthonous materials with high BOD), and the ability of the benthos to survive these conditions. Early lake trophic classification systems of Thienemann and Naumann, focussed primarily on profundal chironomid taxa that indicated an oligotrophic to eutrophic/dystrophic gradient in the hypolimnion. These original lake classification schemes were subsequently modified and used to develop a Benthic Quality Index (BQI) for assessing the water quality status of Palaearctic lakes with a mixture of indicator species (Wiederholm 1980). In northern temperate waters, these models have proved to be useful as long as oxygen concentrations in the profundal zone remained high enough to support the chironomid communities (Brodersen and Lindegaard 1999).

The other major component of the profundal benthic community, the oligochaetes, have also been investigated as indicators of the oxygen/trophic status of deep lakes Wiederhom (1980) developed an index based on the ratio of oligochaetes to sedentary chironomids (O:C) as a measure of organic pollution.

The Swedish Environmental Protection Agency uses a range of measures of the benthic invertebrate communities to assess the ecological health of its lakes (www.internat.naturvardsverkt.se/). The profundal zone of deep stratifying lakes are monitored using the Benthic Quality Index (BQI) and the complementary O/C Index. The Swedish Environmental Protection Agency also give guidance on classifying oxygen levels in freshwaters according to the minimum oxygen level recorded during the year. They recommend that oxygen measurements need to be taken “regularly” over a three-year period The values given are not, however, related to specific ecological impacts.

Under the terms of the Water Framework Directive it is necessary to establish what are the favourable (High Status) and tolerable (Good Status) oxygen conditions needed to support the characteristic biological communities of the various lake and river ecotypes. Mean oxygen conditions hold little ecological relevance. The magnitude and extent of oxygen depletion, or its potential (B.O.D.), is of much greater ecological relevance. Adopting the Swedish EPA approach, therefore, appears sensible, as it is clear that the minimum oxygen concentrations a species is exposed to during the year is the critical factor in determining the survival of species. The Swedish EPA classification, does, however, require refinement. Dissolved oxygen concentrations need to be associated with specific biological outcomes and the classification needs to accommodate different ecotypes.

5.2.4.3 References

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5.2.5 Phytoplankton

5.2.5.1 Justification of importance

Primary productivity in large, deep lakes is dominated by the phytoplankton community. Secondary production, including that of the characteristic pelagic fish species of deep lakes, is ultimately derived from phytoplankton productivity. The phytoplankton community is also the most direct indicator of the state of a lake's environment in terms of nutrient conditions and is often the first community to respond to eutrophication pressures. There are numerous socio-economic problems associated with increases in phytoplankton abundance, particularly with associated increasing frequencies and intensities of toxic cyanobacteria blooms. These include detrimental effects on drinking water quality, filtration costs for water supply (industrial and domestic), water-based activities and conservation status (sensitive pelagic fish species, such as charr and coregonids). In some contexts, increasing phytoplankton abundance, could be considered as a positive feature. For example, increasing fishery productivity or a sink for increasing concentrations of atmospheric carbon.

In summary, the phytoplankton community is a key indicator of ecological status in deep lakes, and particularly represents nutrient conditions and the impacts of eutrophication on environmental, social and economic value.

5.2.5.2 WFD-associated characteristics

Annex V of the WFD outlines three phytoplankton-related quality elements that need consideration in the assessment of ecological status:

- Phytoplankton composition

- Phytoplankton abundance and its effect on transparency conditions
- Planktonic bloom frequency and intensity

Annex V also specifically characterises high status lakes as those where the frequency and intensity of blooms occur consistent with the type-specific physico-chemical conditions [they may occur naturally more frequently in deep lakes where stratification is more stable]. It also characterises moderate status lakes as those in which “persistent phytoplankton blooms” may occur during summer months.

These three criteria are considered further in the context of their specific use as an indicator of eutrophication pressures. In general, declining ecological quality is associated with increasing phytoplankton abundance, greater proportions of cyanobacteria and more frequent and intense phytoplankton blooms.

5.2.5.3 Phytoplankton composition

Nuisance cyanobacteria such as the large colonial and filamentous species *Microcystis*, *Aphanizomenon* and *Anabaena* are favoured by relatively stable stratification (Reynolds and Bellinger 1992) and high alkalinity (Shapiro 1990) and, therefore, form a significant natural component of the phytoplankton community in deep alkaline lakes. As nutrient concentrations increase, however, their dominance and abundance increases often resulting in dense, mono-specific blooms during summer (Reynolds 1984).

5.2.5.4 Phytoplankton Abundance

In general, as nutrient concentrations increase, phytoplankton abundance shows more frequent and sustained peaks throughout summer. Annual mean chlorophyll *a* concentrations are widely used as a measure of phytoplankton abundance and as a general symptom of eutrophication. Variability in how effectively nutrients are transformed into phytoplankton biomass will be significantly affected by factors, such as flushing rate (Bailey-Watts *et al.* 1990). Physical models of flushing could, therefore, be associated with sensitivity to eutrophication and potential phytoplankton standing crops.

5.2.5.5 Planktonic bloom frequency and intensity

The development of dense “bloom” populations of cyanobacteria is more predictable in very deep lakes, compared with shallow lakes, as bloom frequency and intensity is particularly affected by physical factors such as stratification intensity and the depth of light penetration. Threshold densities for bloom potential do exist for particular nuisance species (Reynolds 1998) and could be used to differentiate between ecological status classes.

5.2.5.6 Classification and monitoring schemes

Some of the first lake classification schemes developed based on phytoplankton composition were species quotient schemes based on indicator species. Recently direct, quantitative relationships between phytoplankton composition and nutrient conditions have been developed, but only for the relationship between surface sediment diatom assemblages and total phosphorus concentrations (Bennion 1994; Wunsam and Schmidt 1995). Diatom-phosphorus training sets are based on relative abundances within surface sediment sub-fossil assemblages and, therefore, do not represent true ecological optima. Individual species TP optima are also dataset specific and cannot generally be applied outside the region of development or for different lake types.

In terms of phytoplankton abundance, chlorophyll a concentrations and transparency (secchi disc depth) are the dominant measures used in monitoring and classification schemes. One of the first classification schemes developed using these as indicators of trophic status was that of Carlson (1977) which is still used by the US EPA in assessments of lake quality (US EPA 1998).

The most widely recognised classification in terms of chlorophyll a is, however, that developed during the OECD programme on eutrophication (OECD 1982). This outlined a classification scheme detailing boundary values of total phosphorus, chlorophyll *a* and secchi depths between trophic classes. These classes are not solely applicable to deep European lakes, however, as they are based on data from a large number of lake types from lake regions across the globe, although there was a predominance of large, deep lakes in the original dataset.

A common classification has also been developed for European lakes with annual mean and maximum chlorophyll *a* concentrations defined for complying (excellent and good status) and non-complying waters (fair, poor, bad status) (Premazzi and Chiaudani 1992). Threshold chlorophyll *a* concentrations for lakes subject to eutrophication have also been set across Europe in response to the UWWTD (Cardoso *et al.* 2001).

In summary, phytoplankton composition and abundance are good indicators of a response of the lake to changes in nutrient status and could be used, in these terms, as a component of a site's ecological quality status. Chlorophyll *a* concentrations represent a very simple and effective measure of phytoplankton abundance, a key ecological response to nutrient conditions. Current classification schemes do not distinguish disturbed from undisturbed sites and would require development in terms of identification of reference conditions. It could, however, be relatively easy and cheap to produce regional and ecotype-specific classifications. An additional advantage of using chlorophyll *a* is that it integrates the phytoplankton community response to all potentially limiting resources, irrespective of whether it is phosphorus, nitrogen, silicon or light. The disadvantage is that it is highly dynamic and monthly sampling during summer is recommended. It also provides no information on phytoplankton composition. In terms of impacts on ecological structure and the socio-economic value of lake ecosystems, phytoplankton abundance data needs to be complimented with compositional data. At the very least densities or biovolumes of major algal groups (particularly bloom-forming cyanobacteria genera) should be measured alongside chlorophyll *a* to provide the most practical and informative measure of the impact of nutrient enrichment on lake ecological status.

5.2.5.7 Models

Models simulating the impact of nutrients on the phytoplankton community can be divided into two main categories:

1. Empirical models
2. Ecological or food-web models

Empirical models, such as those developed within the OECD programme on eutrophication (OECD 1982) are usually log-log relationships between in-lake total phosphorus and chlorophyll *a* concentrations. In-lake TP concentrations can be estimated using data on lake depth, area, flushing rate and external TP loads using equations of Dillon & Rigler (1975) and Kirchner & Dillon (1975). By linking the two, it is, therefore, possible to model how changes in flushing rate and catchment land-use could affect phytoplankton abundance. Deep lakes tend to show a much more predictable response than shallow lakes and it is possible a relatively precise empirical model could be derived for large, deep European lakes to predict impacts of changing nutrient conditions.

Mechanistic ecological models that characterise relationships between the physico-chemical environment and the phytoplankton community are more appropriate to the aims of the EUROLAKES project. The PROTECH model, based on phytoplankton functional groups, predicts which species should dominate under particular environmental regimes (Elliott, Reynolds and Irish 2001; Reynolds 1999). Models such as these incorporate mixing regimes within lakes and are capable of simulating multiple nutrient limitation (phosphorus, silica, nitrogen) and grazer effects (see also Chen and Orlob (1975)).

5.2.5.8 References

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5.2.6 Phytobenthos

5.2.6.1 Justification of importance

The phytobenthos is an important component of primary production in lakes, although its contribution to overall primary production decreases with increasing lake depth. In deep lakes, the phytobenthos is, however, still an important component of littoral food webs, and will influence the structure of littoral macrophyte, invertebrate and fish communities. For example, an increasing abundance of epiphyton, in response to nutrient enrichment, has long been considered an important factor in the loss of submerged macrophytes (Phillips, Eminson and Moss 1978; Sand-Jensen and Søndergaard 1981) and the phytobenthos itself constitutes a significant source of energy for most littoral invertebrate grazers.

Despite its potential significance, the phytobenthos has received relatively little attention in terms of its use as an indicator of lake quality. The fact, however, that the phytobenthos does respond to both water column nutrient concentrations and habitat quality, is accessible from the lake shore, and is less dynamic than the phytoplankton community has led to increasing interest in its use as a monitoring tool for lakes (US EPA 1998).

In large, European deep lakes in general, it can probably be concluded that phytobenthos is not a key parameter.

5.2.6.2 WFD-associated characteristics

Annex V of the Water Framework Directive specifically outlines phytobenthos composition and abundance as two criteria that need defining for type-specific, undisturbed conditions in lakes. Eutrophication of the overlying water does generally result in enhanced growth of attached algae and shifts in community composition. Species associated with low phosphorus (the diatoms *Achnanthidium minutissimum* and *Gomphonema tenellum*) and low nitrogen (nitrogen-fixing species, such as the diatoms *Epithemia adnata* and *Rhopalodia gibba* and cyanobacteria such as *Anabaena* spp.) waters have been shown to disappear following nutrient enrichment (Fairchild, Lowe and Richardson 1985). If nutrient enrichment proceeds further, phytoplankton can shade the phytobenthos, reducing abundance and shifting community composition to species tolerant of low light levels. The detailed response of the phytobenthos to nutrient conditions is, however, much more complex than for phytoplankton. Nutrients diffuse much more slowly into attached communities, with strong gradients through boundary layers and the attached community. Benthic algae can also obtain nutrients from the substrates that they are attached to.

Only recently have attempts been made to develop quantitative relationships between the phytobenthos community and nutrient conditions. Danilov and Ekelund (2000) analysed epiphyton and epilithon species diversity from seven Swedish lakes. They concluded that epiphyton diversity showed little relationship with nutrient concentrations, but epilithon diversity was consistently related and could be used as an indicator of nutrient status. King *et al*. (2000) examined distributions of 138 epilithic diatom species from 17 lakes in the English Lake District and showed that total phosphorus and calcium concentrations were the most important variables explaining species distributions.

5.2.6.3 Classification and monitoring schemes

No lake classification schemes based on phytobenthos composition or abundance have been developed. Phytobenthos is recommended as one of seven potential biological parameters in Tier 2 of the US EPA lake monitoring and classification scheme (US EPA 1998). The scheme highlights the potential of phytobenthos, but does point out that responses to pollution or disturbance are not adequately known and require further development.

Surface sediment diatom assemblages include the phytobenthos community. Direct, quantitative relationships between diatom species and total phosphorus concentrations have been developed across Europe (Bennion 1994; Wunsam and Schmidt 1995) and will soon be easily available online as the European Diatom Database. This combined response of phytoplankton and phytobenthos communities is probably the most established representation of lake ecosystem response to eutrophication and would be highly compatible with palaeolimnological methods for the setting of reference conditions.

Phytobenthos abundance is generally measured as chlorophyll *a* per unit area of substrate. Quantitative analyses of phytobenthos abundance is much more difficult than for phytoplankton, due to problems in standardising sampling area and the greater proportion of detrital material within phytobenthos communities.

5.2.6.4 Models

No models have been established associating phytobenthos composition or abundance in lakes to specific hydro-morphological or physico-chemical parameters.

5.2.6.5 References

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5.2.7 Benthic profundal invertebrates

5.2.7.1 Justification of importance

The profundal zone provides the greatest expanse of habitat for invertebrates in large deep lakes. The community in the profundal is less diverse than the littoral fauna and as there is no primary production in this zone the fauna is dominated by detritivores; Chironomidae and oligochaeta are common. Sedimentary processes, the deposition of phytoplankton and autochthonous carbon sources, drive the seasonal dynamics of these organisms, (Jónasson, 1978). They have the same useful characteristics as littoral invertebrates in reflecting both physical characteristics of their habitat and water quality.

Given the group's general usefulness as an indicator (Rosenburg & Resh 1993), that they have distributions which reflect basin shapes (Brinkhurst 1974) and their strong link with the pelagic food chain, via sedimentary processes, it would seem that they would be a potential choice for elucidating the role of water movement in detrivorous systems.

5.2.7.2 WFD-associated characteristics

Annex V of the Water Framework Directive specifies that invertebrate abundance and composition must be monitored, although it does not specify whether both littoral and profundal or either alone is sufficient.

Profundal invertebrates are sensitive to eutrophication and organic pollutants, acidification and oxygen concentration at the lake bed. These sensitivities are reflected in both species composition and abundance. Overall abundance tends to increase with nutrient enrichment followed by the decreases in the relative abundance of key species altering community composition.

5.2.7.3 Classification and monitoring schemes

There is a long history of using profundal benthos to classify lakes, see (Brinkhurst 1974) for a review. These systems usually compare between lakes and were based on the species composition. High levels of skill are required to identify these species and this has prevented their inclusion in most lake classification and monitoring schemes today. Grabs or corers are used to collect samples. The difficulties caused by substrate variability, effecting the comparison of catches between sites in the littoral, is not a problem for profundal sampling where the sediment is relatively fine and homogenous. However sorting of samples can be time consuming and difficult.
Despite taxonomic difficulties, in Scandinavia this fauna are used extensively in classifying and monitoring lakes (Swedish EPA 2000). Indices are used thereby avoiding the need for detailed classification of animals, e.g. Oligochaeta to Chironomidae ratio, an indicator of oxygen concentration and organic load.

Possibly the most interesting classification scheme for application to Eurolakes sites is the BEAST model developed for the Great Lakes in North America to monitor benthos in single large lakes (Reynoldson *et al* 1995). Using a system of reference conditions it is suitable for WFD implementation. It is based on the RIVPACS model, originally developed for rivers, it orders sites on the basis of their invertebrate composition and relates specific assemblages to site characteristics.

5.2.7.4 Models

No known quantitative models exist for relating profundal benthos to physical parameters in lakes. Existing descriptive models such as BEAST could handle more specific information about the physical condition of sites. Modelling site characteristics is the most useful application of models to these groups.

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5.2.8 Fish

5.2.8.1 Justification of importance

Three biological characteristics of fish in European deep lakes make them particularly important as ecological indicators of lake condition: their position in the food chain; their longevity and that they are facultative aquatic organism.

In large European lakes, fish are consumers that are mostly at, or very near, the top of the food thus a measure of the status of the fish populations could integrate effects resulting of the altered status of the organisms at lower trophic levels. Being long-lived compared with invertebrate species they integrate change over a longer period of time which may be important for the measurement of some indicators of change. For example for toxic pollutants that bioaccumulate with trophic level and over time, fish species would clearly be strong candidates for monitoring status. Fish are more likely to be effective in this regard than are avian or mammalian species because the movement of fish is restricted to interconnecting water both birds and mammals can move between catchments.

Most fish species are highly fecund but with high mortality, variations in either mortality or conversely age class strength may be a significant measure of ecological condition of a site. In addition different species occupy different sub-units of the food chain. These characteristics could be used to enhance their efficacy as ecological status indicators species. At the community level changes in species composition represent a simple measure of anthropogenic effects. Increased species number may indicate undesirable effects in the form of introductions. Lower species numbers may represent over-exploitation or pollution.

Fish also have a socio-economic status. In many systems fish are harvested for food and in all of the European deep water lakes there is a sport fishery for some species that has at the least an important local economic impact that would change if there were radical change in fish populations. Partly associated with this is that fish also have a higher public and legislative conservation profile than do freshwater plant and invertebrate species, this is particularly true of fishes from the families, salmonidae, coregonidae and cyprinidea.

5.2.8.2 Classification and monitoring schemes

Currently fish are rarely used to classify ecological change in lakes. The reason for this is that the sampling required to accurately estimate population size in large waterbodies is in general perceived to pose practical difficulties. However, in some systems indirect measures of population size could be readily derived from commercial or sporting catch data, where there is water abstraction from the system recording of the consequent entrapment of fish can provide a simple relative populations estimate. In addition population estimation by hydroacustic techniques is an area of rapid research and development. Other measures of fish communities such as species composition also provide valuable information and are readily obtained.

5.2.8.3 Models

Models relating fish populations directly to environmental conditions or change are generally descriptive rather than numerical. Increased nutrient status is known to cause the loss of populations of salmonid and corigonid fish species from communities. Increases in thermal regimes, water turbidity and productivity are known to correlate with increases in Cyprinid fish population size. Additional obligate freshwater species in a freshwater fish community are almost always the result of anthropogenic introductions.

5.2.9 Macrophytes

5.2.9.1 Justification of importance

Primary productivity by macrophytes in large, deep lakes is limited to the littoral zone community, dominated by submerged and floating-rooted species, down to the euphotic isobath. In lakes such as Loch Lomond this is approximately 10 m depth – more in clearer lakes and less in lakes of greater turbidity. The depth profile of deep European lakes usually severely limits the extent of this open-to-colonization zone (usually to 10% of lake area or less). Secondary factors such as wave disturbance on exposed shores often limit the actual extent of colonization still further. Although macrophytes may not play a prominent role in the production of such lakes, they may still provide a useful indicator of lake biointegrity. This is for several reasons:

1. Submerged and floating macrophytes are an integral component of the littoral ecosystem in many lakes. Macrophyte vegetation provides bioarchitecture, cover, feeding and breeding sites and primary production for many other biota: information relevant to whole-ecosystem biointegrity is therefore gained by monitoring the plants.

2. Macrophytes are relatively long living organisms (months to years) which must “sit and take” what the environment throws at them, because of their very limited

motility (usually limited to propagule movement). They thus provide a longer-term prospect for integrating the impacts of environmental change or other factors affecting lake ecosystem biointegrity.

3. Macrophytes are relatively cheap and easy to sample (though specialised equipment such as sonar, grabs, or divers may be needed to monitor deep-water vegetation), and easy to identify (though some groups require specialist assistance to reach species-level identification). There is usually no need for laboratory analysis.

In summary, attributes of the macrophyte community can be a key indicator of ecological status in deep lakes, even though the ecological role of this biota is less prominent than in shallow lakes.

5.2.9.2 WFD-associated characteristics

Because the EC Water Framework Directive requires Member States to employ ecologically-based classification systems ("broad, integrated biologically-based systems which provide an assessment of ecosystem health") for surface waters, biological monitoring procedures to assess system biointegrity have recently assumed a much greater importance than was hitherto the case. Macrophytes are identified by WFD as one of the key groups of biota suitable for biomonitoring of lakes for ecological classification purposes.

Annex V of the WFD specifies two attributes of the macrophyte community that need consideration in the assessment of lake ecological status:

- Macrophyte community composition
- Macrophyte abundance

Existing multimetric lake bioassessment schemes tend to use these attributes, but may also incorporate information on, for example, macrophyte assemblage as bioindicators of eutrophication (as developed by the TRS scheme for example: see below, Palmer et al1992, Palmer 2001)

In terms of macrophyte status, Annex V characterises high status lakes as those where

- The taxonomic composition corresponds totally or nearly totally to undisturbed conditions. There are no detectable changes in the average macrophytic abundance.

Good status lakes are those where:

- There are slight changes in the composition and abundance of macrophytic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of higher forms of plant life resulting in undesirable disturbance to the balance of organisms present in the water body or to the physicochemical quality of the water.

Moderate status lakes are those where:

- The composition of macrophytic and phytobenthic taxa differ moderately from the type-specific communities and are significantly more distorted than those observed at good quality. Moderate changes in the average macrophytic and the average phytobenthic abundance are evident.

Classification and monitoring schemes using macrophytes to monitor lake biointegrity

A number of possible schemes using macrophytes for classifying and monitoring the biointegrity of lakes, ponds reservoirs have been developed (e.g. Palmer et al., 1992; Kennison et al 1998: in the UK; Canfield et al 1983 in the USA). In the UK recent progress has been made by the “hindcasting” work of the University of Liverpool (e.g. Moss et al 1994), and their current ECOFRAME project looks promising as a lake monitoring system, which incorporates macrophytes, but is currently limited to shallow lakes. Other useful progress has been made with lake macrophyte-based systems in Northern Ireland (e.g. Hale & Rippey 2001). See Table 7 for summaries of these and other schemes.

There has also been a substantial amount of work, mainly in Europe on macrophyte biomonitoring in rivers and, to a lesser extent, lakes (Caffrey 1986; Ali et al 1999; De Lange & van Zon 1983; Daniel & Haury 1993; Demars & Harper 1996; Ellenberg 1973; Environment Agency 1996; Haslam et al 1987; Holmes 1983; Haury 1996; Haury & Peltre 1993; Haury et al 1996; Husak & Vorechovska 1996; Kohler 1975; Kohler & Schiele 1984; Newbold & Holmes 1987; Robach et al 1996; Schmedtje & Kohmann 1987; Standing Committee of Analysts 1987; Janauer 2001; Smolders et al 2001).

Two current classification schemes exist in the UK which use macrophytes for rivers and lake bioassessment: the Mean Trophic Rank (MTR) scheme in rivers (Environment Agency 1999); and the Trophic Ranking Score (TRS) system in lakes (Palmer et al. 1992). Neither scheme is reference-based, so neither meets WFD requirements, although work has begun on developing MTR into a reference-based classification scheme for rivers, using macrophytes (Environment Agency 2000a; Palmer 2001). Reference-based schemes are incorporated in other parts of the world in multimetric systems for assessing lake biointegrity, notably:

- the Lakes and Reservoirs Bioassessment and Biomonitoring (LRBB) protocols in the USA (US EPA 1998); and
- the Swedish Environmental Quality Criteria (SEQC) for lakes and watercourses (Swedish EPA 2000)
- ECOFRAME (currently under development for European shallow-water lakes)

Murphy et al (2002) have recently critically examined the value of these and similar schemes for WFD implementation purposes.

Swedish Environmental Quality Criteria (SEQC) for lakes and watercourses

The SEQC is a tested multimetric scheme for assessing freshwater biointegrity which provides a means of interpreting and evaluating environmental data using a range of ecological indicators and criteria. The two main aspects of the assessment involve: (i) an appraisal of the state of the environment *per se* in terms of the quality of the ecosystem, and (ii) an appraisal of the extent to which the recorded state deviates from a reference state (i.e. a 'changed state' assessment). The scheme incorporates the use of macrophyte community attributes as a metric (one of 9 physical, chemical or biological metrics applicable to lakes within the scheme). Deviation from reference states is expressed on a five-point scale (1-5). Class 1 includes conditions with little or no deviation from the reference values (negligible anthropogenic impacts), intermediate classes indicate effects of increasing magnitude, and Class 5 indicates very significant impacts from local sources. Reference values will necessarily vary relative to ecosystem type.

The use of aquatic macrophytes in SEQC biomonitoring is based upon the assessment of species richness (number of species present) and indicator ratio (the average TRS scores for species present in the lake), using floating-leaved and submerged plants. Abundance metrics are not used. Deviation from reference conditions are outlined for a fairly complex typology (utilising indicator ratios, which reflect the normal occurrence of species in relation to the nutrient status of the water). As such, the system has been developed with a heavy emphasis placed upon the Trophic Ranking System (TRS) developed for aquatic macrophytes by Palmer et al. (1992). More specifically, deviation is assessed on the basis of the difference (if any) between reference species richness or indicator ratio between reference and impacted sites.

Additionally, lakes can be typed by area (km^2), altitude (m above sea level), and region (Northern and Southern Sweden), and the relevant species richness, and/or indicator ratio defined. Work has been undertaken to determine the deviation of impacted conditions from reference values.

ECOFRAME

Macrophytes form one element of this shallow-water lake assessment system, still under development in February 2001, and untested at present

The scheme uses assessment of plant abundance and plant dominance, covering 10% of the lake area taking random samples using a rake (a minimum of 25 rake samples for small lakes; up to a maximum of 100 rake samples for large lakes). This allows estimations to be made of (i) general taxonomic status (based on defined community types); (ii) plant dominance (multiple species; monospecific (or with only traces of other species); or plants undetectable); (iii) plant abundance (on a defined quantitative scale)

US EPA Lake and Reservoir Bioassessment and Biocriteria

LRBB uses submerged aquatic macrophytes as one of 7 biological monitoring elements for US lake bioassessment. LRBB is a well-tested multimetric scheme, in which bioassessment of lake condition is achieved by using additive indices which integrate the habitat and biological scores acquired from site monitoring (up to 3 habitat scores and 3 or more biological index scores can be generated). The basic procedural steps are:

1. Sampling of the biological groups (assemblage) targeted by the protocols; recording abundance or other relevant attributes as prescribed for each species or group of species.
2. Calculating of chosen metrics for each assemblage: e.g. number of species, number of intolerant species, percent abundance of filter feeders).
3. Comparing each metric value to its expected value under reference conditions, and assign a numeric score corresponding to "good" (similar to reference, ""fair" (different from reference), or "poor" (substantially different from reference").
4. Summarising the scores of all metrics of an assemblage to derive total score for the assemblage.
5. Comparing total score to the biological criterion based in part on the expected total score under reference conditions.

Macrophytes play a major role in the tiering approach used in LRBB monitoring. Tiering of the bioassessment approach permits the method to be customised to the requirements, level of effort, and resource availability of the user. In increasing order of complexity and resource requirements the tiers involve the following:

- Tier 1A: Trophic state indices and macrophyte cover. Sampled once during index assessment period. Inference limited to regional assessment.
- Tier 1B: Trophic state indices and macrophyte cover. Sampled repeatedly during growing season.
- Tier 2A: Uses 1A or 1B plus two or more *integrating* biological assemblages: macrophytes, macroinvertebrates, sedimented diatoms, fish. Sampled once during index period.
- Tier 2B: Uses 1B plus two or more *short-term* biological assemblages: phytoplankton, zooplankton, periphyton. Sampled repeatedly during growing season.

The metrics used for submerged macrophytes are:

- % cover or biomass in available habitat colonised
- % cover or biomass in vegetated areas
- no. of taxa
- % cover or biomass of dominant species
- no. of exotic species
- % cover or biomass of exotic species

The LRBB protocols comment: “Macrophytes respond more slowly to environmental changes than do phytoplankton or zooplankton and might be better integrators of overall environmental conditions This would allow a single sampling event per year, during the time of maximum abundance of macrophytes. Both floating leaved and emergent plants can be assessed from aerial photographs, which permit estimates of total area covered and percent cover (density) within stands”. For the purposes of lake assessment, emergent vegetation is considered by LRBB as an indicator of lake habitat, but floating and submerged vegetation are lake biota.

5.2.9.3 Models

No mathematical models have been developed to link lake macrophyte community attributes to environmental criteria which are suitable to meet WFD bioassessment requirements.

Some work has been done modelling attributes of macrophyte communities such as biomass, structure and diversity in relation to environmental factors (e.g. Scheffer et al. 1993; Murphy 2002; Murphy et al 2002 subm.; Murphy & Hootsmans 2002; Weisner et al 1997; Rorslett 1991; Muhammetoglu & Soyupak 2000). Other relevant work, which includes moderate-depth temperate lakes, is that of Weiher & Boylen (1994) who produced models to predict diversity of aquatic plants in Adirondack (New York) lakes. Again, however this work is not directly useable for WFD purposes in European lakes.

Very recent work in Switzerland (Auderset Joye et al 2003 in press) has attempted to model the response of individual macrophyte species to environmental conditions in shallow-water lakes and ponds, using linear regression (LR e.g. Draper & Smith, 1981) and Generalised Additive Models (GAM: Hastie & Tibshirani, 1990; Bio etal. 1998, Lehmann 1998). While promising, this study found significant relationships for only a small proportion of species tested. GIS-based platforms for showing model outputs have also been developed in this context (e.g. Lehmann et al 1997) and show distinct promise for further development.

TRS is probably the closest thing to a useful quantitative model for WFD purposes, being based on TWINSPAN classification of a large number of lake macrophyte assemblages, with subsequent definition of mean water chemistry conditions appropriate to each defined class. It is worth pointing out that the TRS scheme was developed to identify sites of conservation importance based on an association with conductivity of water. TRS is therefore not necessarily very responsive to the changes brought about by nutrient enrichment, and this may increase the need for it to be further developed/adapted with the needs of WFD in mind.

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Table 7. Schemes used for lake and watercourse biomonitoring which utilise macrophytes as sole indicator, or as one of a set of bioindicators.

Name	System Monitored	Organisms Involved	Country/ Region	Brief Description	Usefulness	Reference
Remote Sensing	Lakes	Phytoplankton Macrophytes	Italy Ireland	Use of low altitude airborne remote sensing to effectively monitor the quality of lake water. This is done by the examination of back scattered light from beneath the surface of the lake.	Well suited to the needs of a routine national lake monitoring programme, of potential use for both macrophyte and phytoplankton assessment. Spatial resolutions of current satellite may limit application to large areas.	Dekker, A.G., Malthus, T.J. and Hoogenboom, H.J. (1995). The remote sensing of inland water quality. *In:* Danson, F.M. and Plummer, S.E. (eds.) *Advances in Environmental Remote Sensing*. John Wiley, Chichester, 123 -142; O' Mongain, E., Collins, A., Green, S., O'Riain, G. and Caffrey, J. (1999). Remote Sensing of Lakes - Improved Chlorophyll Calibration and Data Processing. Environmental Protection Agency, Wexford.
SERCON (System for Evaluating for Conservation)	Rivers	Mammals / Birds / Amphibia / Invertebrates / Macrophytes / Algae / Fungi / Protozoa / Bacteria	UK	Broad-based system. Its principal focus is on physical, chemical and the biological features. Evaluates data on thirty five attributes, each attribute is scored, then weighted and combined by SERCON to give a composite index for each criterion. A classification system (A - E) of conservation value is then produced.		Boon, P.J., Holmes, N.T.H., Maitland, P.S., Rowell, T.A. and Davies, J. (1997). A system for evaluating rivers for conservation (SERCON): Development, structure and function. In: Boon, J. and Howell, D.L. (eds.) *Freshwater Quality: Defining the Indefinable?* Edinburgh: The Stationary Office.

Name	System Monitored	Organisms Involved	Country/ Region	Brief Description	Usefulness	Reference
System Aqua	Rivers / Lakes	Macrophytes / Algae / Fish / Macroinvertebrates Nesting Birds	Sweden	Five criteria are used to evaluate biodiversity. Indicators are scored from 0 to 5 where 5 indicates the highest biodiversity. A numerical index value, based on weighted scores of assessed indicators, is obtained for each criterion. The proportion of indicators used reflects the confidence of the assessment.		Willen, E., Andersson, B. and Soderback, B. (1997) System Aqua: A biological assessment tool for Swedish Lakes and Watercourses. In: Boon, J. and Howell, D.L. (eds.) *Freshwater Quality: Defining the Indefinable*? The Stationary Office, Edinburgh
Trophic Ranking Score (TRS) Trophic Ranking Score (TRS)	Lakes	Macrophytes	UK/ Sweden	Based on the number and identity of submerged and floating species (mosses are excluded). An additional figure is used to calculate deviations from reference values. This figure indicates the dependence of various species on the level of nutrients in the	TRS developed in the UK to assess conservation status of standing waters. Of uncertain application to the WFD as original scheme based on conductivity rather than nutrients per se.	Palmer, M.A., Bell, S.L. and Butterfield, I. (1992). A botanical classification of standing waters in Great Britain: applications for conservation and monitoring. *Aquatic Conservation: Marine and Freshwater Ecosystems*. **2**, 125-143.

Name	System Monitored	Organisms Involved	Country/ Region	Brief Description	Usefulness	Reference
STOWA (Strichting Toegepast Onderzoek Waterbeheer) Scheme	Surface waters	Phytoplankton/ Macrophytes/ Zooplankton	.The Netherlands	Discussion/ development scheme for ecological assessment of Lakes	van der Kruijff, J.F.N. (1993).Stowa Ecologische beoordeling en beheer van oppervlaktewater. Beoordelingssysteem vor meren en plassen op basis van vegetatie en fytoplankton. STOWA kunt u uitsluitend, Utrecht, Netherlands; van der Kruijff, J.F.N. (1994). Ecologische beoordeling en beheer van oppervlaktewater. Beoordelingssysteem voor zand-, grind- en kleigaten op basis van fyto- en zooplankton, macrogyten en epifytische diatomeeen. STOWA kunt u uitsluitend, Utrecht, Netherlands.	
Site Condition Monitoring (SCM)	Lakes	Macrophytes	United Kingdom	Identification of the range of macrophyte species and communities present using standard JNCC methodology.	Grapnel sampling and visual survey mapping should be compatible with SNH Site Condition Monitoring of designated interest features. The method can also be used to help monitor trophic status by using Palmer's (1989) trophic ranking scores.	Draft Report: Scottish Natural Heritage
Identification of bioindicator species of the state of trophic pollution	Reservoirs	Macrophytes/ phytoplankton/ zooplankton/ benthic macroinvertebrates/ fish	Brazil (Parana)	Identification of early warning species to indicate impacts of eutrophication, and of aquatic assemblages characterising the trophic statuses within the reservoirs along the Rio Paraná.	The project is in the planning and implementation stages, but builds on previous datasets and local expert knowledge.	Thomaz, S.M. (2000). *Identificação de espécies bio-indicadoras de estado trófico e poluição*. Fundo nacional de desenvolvimento Científico e tecnológico (Fndct); Solicitação De Financiamento.

Name	System Monitored	Organisms Involved	Country / Region	Brief Description	Usefulness	Reference
Water quality indicators	River basins	Riparian vegatation/ macrophytes	Argentina	Production of vegetation groupings and characterisation by associated phosphorus, conductivity and water turbidity values	Small scale study	Sabbatini, M.R., Lamberto, S.A., Irigoyen, J.H., Valle, A.F., Andrada, A.C., Gil, M.E., Eulalio, P.A., Aramayo, E.M., and Sidorkewicj, N.S. (2001). Vegetação riparia e macrófitas aquáticas como bioindicadores da qualidade da água na bacia hirográfica do sauce grande, Argentina. *VII Congresso Brasileiro de limnologia: Bioversidade e recursos hídricos, pp. 177.*
Biological techniques of still water quality assessment (PSYM)	Ponds and small lakes (<5 ha)/ Canals/ temporary waters/ ditches/ brackish lagoons	Benthic Invertebrates/ macrophytes	England and Wales	The study linked the biota listed to water chemistry values, and assessed impaired and reference sites by reference to a number of metrics (possibly the first use of this approach in the UK context). Metrics selected were those not generally correlated with natural variation (e.g. species richness).	The geographical location (for method development) makes the methodology largely unsuitable for SEPA/EA purposes. In addition, the predictive power of a majority of the metrics selected is relatively low.	Biggs, J., Williams, P., Whitfield, M., Fox, G. and Nicolet, P. (2000) *Biological techniques of still water qualty assessment: Phase 3. Method development.* Environment Agency R&D technical report E110. Environment Agency, Bristol.

Name	System Monitored	Organisms Involved	Country/ Region	Brief Description	Usefulness	Reference
Environmental Quality Criteria for lakes and watercourses	Lakes and watercourses	Phytoplankton/ macrophytes/ periphyton/ benthic macroinvertbrates	Sweden	The system uses a metrics based approach to provide a basis for assessing the status of aquatic areas in terms of physical/ chemical factors such as eutrophication, oxygen levels and oxygen-consuming substances, visibility, acidification and metals.	Well suited to the needs of a coherent lake biomonitoring programme, utilising all of the target biota, and covering a range of geographical regions which may be comparable to the Scottish situation. The approach allows the assessment of changed-state conditions	Swedish Environmental Protection Agency (2000). Environmental quality criteria for lakes and watercourses. Swedish Environmental Protection Agency: Report 5050, Stockholm
Nationwide monitoring program on the aquatic environment	Lakes	Macrophytes/ phytoplankton/ zooplankton/ fish	Denmark	Freshwater and brackish lakes monitoring, coupled with water chemistry monitoring.	Relatively small-scale study, still underway.	Baattrup-Pedersen, A., Anderson, B., Brandrud, T.E., Karttunen, K., Riss, T., and Toivonen, H. (2001) *Macrophytes*, in Skriver, J. (ed.) (2001). Biological monitoring in Nordic rivers and lakes. National Environmental Research Institute, Denmark. Pp. 53-60.
NORDPACS (development of predictive algorithms from survey work)	Rivers/ Lakes	Macroinvertebrates/ macrophytes/ fish	Denmark/ Finland/ Norway/ Sweden	Development of predictive algorithms from field sampling and model testing, with the inclusion of physical and chemical data.	Under development	Skriver, J. (ed.) (2001). *Biological monitoring in Nordic rivers and lakes*. National Environmental Research Institute, Denmark.

Name	System Monitored	Organisms Involved	Country/ Region	Brief Description	Usefulness	Reference
LRBB (Bio-assessment & Biocritera Protocols)*	Lakes/ reservoirs	Macrophytes/ phytoplankton/ benthic macroinvert-brates/ zoo-plankton/ fish	United States	The system uses a metrics based approach, and a tiered sampling system to assess the status of lakes and reservoirs relative to reference condition waterbodies. It is intended to provide managers and field biologists with functional methods to allow the implemenation of bio-assessment and biocriteria programs	The approach appears well suited to the needs of a coherent lake biomonitoring programme, utilising all of the target biota. The approach allows the assessment of changed-state conditions, appears to be well tested, and uses robust analyses.	USEPA. 1998. Lake and reservoir bioassessment and biocriteria technical guidance document. EPA 841-B-98-007. U.S. Environmental Protection Agency, Office of Water, Washington, DC., which can be viewed at: http://www.epa.gov/owow/monitoring/tech/lakes.html
Classification of Ecological Status	Lakes/ Rivers	Macrophytes	Austria	The system monitors macrophyte species present, and canopy architecture and also uses a biomass assessment to indicate trophic state.	May be fitted into WFD requirements	Janauer, G.A. (2001). *Macrophytes and the classification of the ecological status in rivers and lakes*, in Bäck, S. and Karttunen, K. (eds.) (2001). Classification of ecological status of lakes and rivers. Nordic Council of Ministers, Copenhagen, pp. 20-22.

Name	System Monitored	Organisms Involved	Country/ Region	Brief Description	Usefulness	Reference
Classification of Lakes	Lakes	Phytoplankton/ macrophytes/ littoral macro-invertebrates	UK (N. Ireland)	A study of the communities of the three biota in relation to hydromorphological and physio-chemical parameters, with a comparisson between reference and impacted site conditions.	Methodologies developed with reference to WFD requirements, but work still in preliminary stages. Range of lakes studied not fully representative of those in Scotland.	Rippey, B., Doe, S., McElarney, Y., Neale, M., Hale, P. and Crone, V. (2001). *Classification of lakes and communities of phytoplankton, macrophytes and littoral macroinvertbrates*, in Bäck, S. and Karttunen, K. (eds.) (2001). Classification of ecological status of lakes and rivers. Nordic Council of Ministers, Copenhagen, pp. 69-73.
ECOFRAME	Lakes (shallow water)	Phytoplankton/ Zooplankton/ Macrophytes/ Fish/ Macroin-vertbrates	United Kingdom	The scheme proposes the sampling of key organisms to define the ecological status of a lake in conjunction with water physiochemical sampling, using unimpaired reference conditions to allow changed state detection The scheme also takes into account geographical components that can be used to designate ecotypes and cover the region from the Arctic to the Mediterranean.	These scheme has been built around the requirements of the WFD and sampling Only shallow water lakes are considered, and development has not used the minimum lake size required by SEPA/EA. minor adjustments may allow the scheme to be used in deeper lakes.	EC-funded Project under development; co-ordinated by University of Liverpool, UK.

5.2.10 Riverine / Littoral benthic invertebrates

5.2.10.1 Justification of importance

Benthic invertebrates form a number of important links in both river and littoral, lake ecosystems; between primary producers and higher organisms, such as fish, and through detritivorous pathways. Littoral and profundal zones of large lakes, including the main Eurolake sites, have distinct benthic invertebrate communities. These communities are diverse, with wide range of functional feeding groups reflecting the wider range of food resources present. Importantly littoral invertebrates feed on autochthonous and allochthonous food sources.

Benthic macroinvertebrates are useful as indicators as they integrate both physical habitat and water quality parameters. Recognised as a particularly sensitive group they have been used extensively as bio-indicators (Resh & Rosenberg, 1993). Work has concentrated on flowing water systems but it is expected that a lot of the experience gained can be applied to the less well studied littoral communities of lakes.

In large, European deep lakes in general, it can be concluded that littoral invertebrates are a key parameter and have the potential to be modelled in relation to physical lake processes and anthropogenic impacts effecting the littoral zone, especially local point source inputs, e.g. sewage outfalls.

5.2.10.2 WFD-associated characteristics

Annex V of the Water Framework Directive specifically outlines benthic invertebrate composition and abundance as two criteria that need defining for type-specific, undisturbed conditions in lakes and rivers. Also specified is the ratio of sensitive to non-sensitive species.

These measures are sensitive to eutrophication, nutrient enrichment, toxic chemicals, acidification and habitat modification (Resh & Rosenberg, 1993, Swedish EPA, 2000).
It is not clear from the Directive whether both littoral and profundal benthos needs to be sampled. Most rapid assessment techniques use littoral macro-benthos as it is taxonomically easier to handle and may be sampled from the shore. Littoral invertebrates can be used as indicators of a lake's overall health, Gerritsen *et al* (2000), but this approach requires further development. In large deep water lakes it is not sensible to ignore profundal or littoral processes and so at most of the main Eurolakes sites both groups are already monitored (O'Hare *et al,* 2000).

5.2.10.3 Classification and monitoring schemes

Lake classification schemes and monitoring methodologies, incorporating the parameters mentioned above have recently been developed in the USA, Ireland and Scandinavia.

These draw extensively on work from lotic systems. Most schemes draw comparisons between lakes as a means of identifying sites subject to degradation. This approach is less useful in the Eurolakes, where littoral invertebrates may best be used to identify problem spots within a single lake. The use of benthic invertebrates is most advanced in rivers, with many European countries already using indices of benthic invertebrate community structure as a measure of river health.

Although strong seasonal differences are evident in littoral communities of invertebrates, they do have the advantage over macrophytes of being present all year round. Sampling techniques are well developed and robust. Kick net sampling is the most usual rapid assessment technique, providing **semi-quantitative data**. Other methods are available, although not widely used for rapid assessment. They make use of grab samplers or airlift samplers, some of which provide quantitative data in some circumstances, but in the case of the grab samplers are not suitable for use on all substrate matrices. Usually only animals that can be seen with the naked eye (macro-invertebrates, or macro-benthos) are quantified. It is also possible to reduce effort further by not identifying animals to species level as human impacts can be determined from genus or family data.

Qualitative Indices
Indices are derived from the relative abundance of different invertebrate groups at a sampling location. These indices can use whole communities or sensitive groups such as EPT (Ephemeroptera , Plecoptera, Trichoptera). It is possible to relate specific values of a continuous variable (pH) to the presence / absence of selected groups, e.g. acidification sensitive Ephemeroptera.

Metrics
The metrics approach is an advanced but untested form of the indices approach and uses regression analysis to relate specific characteristics of invertebrate communities for classifying lakes or identifying pollutants. (Gerritsen *et al* 2000).

Ordination Approaches
These models group sites by invertebrate community. The sites can then be related to a matrix of environmental variables. A database of reference pristine sites is then compared to degraded sites and communities associated with specific types of degradation. This approach has yet to be applied to littoral invertebrates, but has been used extensively for lotic systems. There has been a recent, world wide, expansion of this approach following the success of its application to rivers in the UK (Wright *et al* 2000).

5.2.10.4 Models

Most models are qualitative and empirical and use invertebrates as a categorical measure of water quality rather than relating them directly to amounts of specific pollutants. Some metrics could be viewed as quantitative models relating benthic invertebrates to pollutants but the relationships are not well tested.

Often classification models are prone to high levels of 'noise'. Part of this noise could be explained by physical variables such as transport processes in the littoral zone. Such an approach has been used successfully in river systems to model the abundance of invertebrates in relation to the hydraulic regime (Extence *et al* 1999).

5.2.10.5 References

Extence CA, Balbi DM, Chadd RP (1999) River flow indexing using British benthic macroinvertebrates: A framework for setting hydroecological objectives. Regulated Rivers: Research & Management 15 (6): 543-574

Gerritsen, J., Jessup, B., Leppo, E.W. and White, J. (2000) Development of lake condition indexes (LCI) for Florida. Prepared for Florida Department of Environmental Protection, Tallahassee, FL.

O'Hare, M.T. J. Post, U. Lemmin, A. Witthöft-Muehlmann & S. Viboud (2000) D2: Existing Monitoring Strategies. Eurolakes Report.

Rosenberg D.M. & Resh V.H. (eds) (1993) Freshwater biomonitoring and benthic macroinvertebrates. Chapman & Hall, New York.

Swedish EPA (2000). Environmental quality criteria for lakes and watercourses. Swedish Environmental Protection Agency: Report 5050, Stockholm

Wright J.F., Sutcliffe D.W. & Furse M.T. (eds.) (2000) Assessing the biological quality of fresh waters: RIVPACS and other techniques. Freshwater Biological Association, Ambleside

6 RECOMMENDATIONS TO SELECT & CONSTRUCT A META-INDICATOR

Given below is a quantitative assessment of the WFD quality elements ability and usefulness at indicating pressures on large, deep lakes. The methods used are given in Chapter 5 and the assessment is mainly based on information given in Chapter 6.
The pressures are referred to in the WFD and are common to all the Eurolakes sites. The WFD does not require that all elements be monitored. By eliminating quality elements which are not useful at indicating particular pressures, ecological targets can be substantiated by focusing on elements which are useful.

6.1 QUANTITATIVE SCORING OF WFD ELEMENTS AS PRESSURE INDICATORS

For each pressure a matrix was constructed, evaluating the usefulness of the WFD quality elements at indicating its impact. All the original matrices are presented in Appendix I. Each summary suggests the best biological elements and supporting elements (hydro-morphological and physico-chemical). These short summaries and the matrices are based on our current state of knowledge of the relationships between these pressures and biological processes.

<u>Nutrient pressure</u>
The most sensitive biological quality elements for assessing status in terms of nutrient pressures are phytoplankton composition and abundance. The most sensitive supporting elements (hydromorphological, physical and chemical elements) are nutrient conditions, transparency and oxygen conditions (Annex 1). Of the supporting elements, nutrient conditions received the highest total score. Oxygen conditions also have a high total score because it had high scores for cost and measurability whereas transparency could also be recommended because it has a very established scheme and it allows comparison with historical data and can be cost effective. We would, therefore, recommend that phytoplankton should be developed further as the most sensitive biological quality element and used in combination with nutrient condition and transparency to assess change in this pressure.

<u>Deoxygenation pressure</u>
Two biological quality elements appeared to be the most correlated to deoxygenation pressures and are recommended: phytoplankton abundance (as cause) and profundal benthic invertebrate composition (as effect). Care should be taken in the use of phytoplankton abundance as the WFD quite explicitly requires indicators of “impact”, which as the cause, it is not. Phytoplankton abundance should, therefore, be considered more strictly as an indicator of the deoxygenation pressure in large deep lakes. The most sensitive supporting element (hydromorphological, physical and chemical elements) is oxygen conditions (Annex 1).

<u>Toxic pollutants</u>
Brackets have been extensively used in the tables relating to toxic pollutants because their effects are dependant from a very large number of parameters among them: type and concentration of pollutant, how long it has been in contact with the organisms, type, instar and health of organisms, environmental conditions (T°C, light, salinity, pH).

Toxic pollutant may also have delayed effects. Analysis of sublethal effects should therefore be promoted. In summary, all biological elements are potentially useful. They can be complementary, integrating responses over different time scales.

Abstraction pressure

Two biological quality elements are highly correlated to abstraction pressures and will be recommended: macrophyte composition (particularly in wetlands) and littoral benthic invertebrate composition. Both are sensitive to fluctuations in lake and groundwater level associated with abstraction and are complementary as they are sensitive to fluctuations at different temporal scales.
The most sensitive supporting elements (hydromorphological, physical and chemical elements) are quantity and dynamics of flow, residence time and water level (Annex 1) and are usually more direct measures of the pressure than the biological elements.
Large deep lakes are likely to be relatively resilient to abstraction pressure, compared with shallow lakes because of their inherent long residence time.

‘Regulation of flow’ pressures

Two biological quality elements appeared to be the most correlated to pressures caused by flow regulation and will be recommended: macrophyte and littoral benthic invertebrate composition. They are complementary as they are sensitive to fluctuations at different temporal scales.
The most sensitive supporting elements (hydromorphological, physical and chemical elements) are quantity and dynamics of flow and water level (Annex 1) and are usually more direct measures of the pressure than the biological elements.

‘Morphological alteration’ pressures

Two biological quality elements appeared to be the most correlated to pressures caused by morphological alteration and will be recommended: macrophyte and littoral benthic invertebrate composition.
The most sensitive supporting elements (hydromorphological, physical and chemical elements) are structure of the lake shore, quantity, structure and substrate of the lake bed, water level and lake depth variation (Annex 1), although the latter two relate only to alterations of inflows or outflows. Structure of the lake shore is a more direct measure of the pressure than the biological elements.

6.2 SYNTHESIS OF QUALITATIVE AND QUANTITATIVE ANALYSIS (RECOMMENDATIONS ON CONSTRUCTION OF A META-INDICATOR)

The synthesis of our analyses of the WFD quality elements suggests the following biological elements are the most useful; phytoplankton composition & abundance, macrophyte composition and profundal and littoral benthic invertebrate composition (Table 8). They should form the core of a monitoring programme for deep lakes, in effect a meta-indicator.

Phytoplankton composition and abundance scored highly as indicators of pressure on the pelagic system (open water). Both measures have been included in monitoring schemes for many years and their role in the system is well understood. Both are, however, greatly affected by natural perturbations in the physical environment (mixing and stratification), which may make interpretation difficult. There is, therefore, a great need to develop ecological classification schemes that can overcome this difficulty and highlight possible need for the inclusion of another biological element further up the food chain that is a less dynamic (see Additional Ecological Criteria D36). This natural dynamism also stresses the need to develop links with physical lake models. Phytoplankton abundance in particular has been modelled quantitatively in relation to drivers (nutrients, retention time, sedimentation). Investment in modelling phytoplankton composition has been more limited and further improvements to both are feasible.

Benthic invertebrates are particularly sensitive to pressures on the deep (profundal) waters of large deep lakes. There has been some development of ecological classification schemes, but limited quantitative modelling work.

Macrophytes and littoral benthic invertebrates are sensitive to pressures on the littoral zone of large deep lakes. Their inclusion in lake monitoring schemes has been limited so far, as most emphasis in lake monitoring has been on water quality in the open water. Investment is required to develop their use further. Equally serious investment would be necessary to numerically model the impact of the pressures on these elements of the biota. It is believed, however, that changes in these biological elements could be used relatively easily to differentiate between natural and human disturbance. In almost all cases collection of information on the status of supporting elements is essential to understanding the type and magnitude of pressures on the system.

Table 7. Biological and supporting (hydromorphological and physico-chemical) quality elements selected as the most ideal for assessing status for specific pressures, in terms of operational requirements under the WFD for large, deep lakes

Type of Pressure	Specific Pressure	Biological Elements	Supporting Elements
Diffuse and point source pollution	Nutrients	Phytoplankton composition and abundance	Nutrient conditions and transparency
	Deoxygenation	Phytoplankton abundance and profundal benthic invertebrate composition	Oxygen conditions
	Other Annex VIII toxic pollutants	All useful depending on pollutant	Specific pollutants
Abstraction		Macrophyte and littoral benthic invertebrate composition	Quantity & dynamics of flow, residence time and water level
Regulation of flow		Macrophyte and littoral benthic invertebrate composition	Quantity and dynamics of flow and water level
Morphological alterations		Macrophyte and littoral benthic invertebrate composition	Structure of the lake shore Quantity, structure and substrate of the lake bed Water level and lake depth variation

7 DISCUSSION

For WFD purposes it is essential to select ecological indicators according to their sensitivity to specific pressures. Development of reference conditions and ecological classification schemes can only follow once this pressure context is agreed. Development of ecological classification schemes prior to this risks producing redundancy and gaps in relation to monitoring the impacts of specific pressures.

Checking of cross-correlation, or redundancy, between indicators is best minimised by careful choice, design and calibration of the monitoring tools. For most pressures a number of quality elements are complementary in that they represent impacts over different spatial or temporal scales and could, therefore, be combined in a meta-indicator for that pressure.

Another important area for consideration when selecting pressure-sensitive ecological indicators, is the ability to quantitatively model their relationship with the pressure. This is to predict any future outcomes of changes in the pressure associated with catchment management, particularly to assess whether ecological targets can be met with any specific programme of measures, i.e. furthering sustainable development. For several of the indicators we have highlighted, some quantitative modelling is possible, but there is clearly much scope for development.

It is also apparent that more background knowledge on the functioning of key processes within the system would facilitate the setting of ecological targets for individual indicators. More detailed information on how recent improvements in lake physics modelling can be integrated with ecological criteria will be given in ‘Additional Ecological Criteria’ D36.

One potential gap in the pressure-specific indicator scheme that we have outlined is a single indicator that the public can identify with, which integrates overall ecosystem quality. Fish composition and age structure may be particularly appropriate for this purpose.

There are other obvious gaps in what the selected indicators can represent. It is clear from Table 8 that the ecological quality elements, outlined in the WFD, can only be used as direct indicators of environmental impact. Pathogens, or microbiological quality, and most socio-economic impacts are not directly represented. There may, however, be strong, indirect relationships between ecological quality elements and socio economic functions, which could be taken into account in the choice of indicator organisms (e.g. phytoplankton composition and abundance and water supply costs).

The scheme we recommend is not, however, an ecosystem-service, or use-based status assessment. Most large, deep European lakes will also qualify for Protected Area status under a number of existing EC directives and this will require further, specific use-based indicators of status. One key ecosystem service that large, deep lakes provide, which we feel is not covered by the WFD, or other current legislation, is flood storage capacity. It is poorly represented by all the biological quality elements, yet unarguably has major environmental, social and economic impacts across Europe. If such an explicit role was considered important, then elements such as wetland macrophytes and shore condition, could be developed and calibrated specifically for this purpose (e.g. % natural wetland flood plain remaining).

We have recommended construction of a meta-indicator based on these individual “pressure-specific” indicators. As well as ensuring adequate representation of all widely recognised pressures, deconstruction of the term “ecological status” into a pressure context allows the development of a more transparent monitoring system. Explicit roles for quality elements not only make calibration of classification schemes easier (deciding what is good or bad), it also makes it much simpler for lake and catchment managers to interpret monitoring results and identify the cause of change.

There are a number of possible options for amalgamating individual indicators into an overall meta-indicator” of ecological status, such as whether an average score is taken, whether all indicators have to be at “good status”, or whether only a certain proportion have to be at “good status”. These all require testing in an inter-calibration exercise before any recommendations can be made as to which is most appropriate.

8 ANNEX OF TABLES

The tables are an attempt to evaluate how quality elements are meaningful as indicators of pressure types. Scoring was done according the following meanings of the evaluation criteria:

Sensitivity =	how well is variation in the element correlated to change in the pressure?
Measurable / Analytically sound =	how precise it is to measure?
Cost & practicality =	financial and technical difficulties
Total score =	sum of scores to rank usefulness
Established Monitoring Scheme = and used	level to which monitoring scheme has been developed
Anthropogenic – 'natural' discrimination = change	Discrimination between induced change and 'natural'
Modeling feasible =	current ability to numerical model the relationships between the element and the pressure

Ranking: 0 to 4

Surface water type: lakes **Pressure**: Nutrients

Hydro-morphological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modelling feasible
Quantity and dynamics of water flow	0							
Residence time	0							
Connection to the ground water body	0							
Morphological conditions	0							
Lake depth variation (water level)	0							
Quantity, structure and substrate of the lake bed	1							
Structure of the lake shore	0							

Physical & chemical quality elements	Sensitivity of element to pressure	Measurable/ Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Transparency	3	3	3	4	13		1	3
Thermal conditions	0							
Oxygenation conditions	3	4	2	4	13		1	2
Salinity	0							
Acidification status	1							
Nutrient conditions	4	3	4	3	14		3	3
Specific pollutants	1							

Biological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring scheme possible	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
phytoplankton composition	4	3	2	2	11		1	3
phytoplankton abundance	3	3	3	3	12		2	3
Other aquatic flora composition	2							
Other aquatic flora abundance	2							
benthic invertebrate fauna (profoundal) composition	2							
benthic invertebrate (profoundal) fauna abundance	2							
fish fauna composition	2							
fish fauna abundance	2							
fish fauna age structure	1							

Surface water type: lakes **Pressure**: Deoxygenation

Hydro-morphological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Quantity and dynamics of water flow	1							
Residence time	1							
Connection to the ground water body	1							
Water level	0							
Lake depth variation	0							
Quantity, structure and substrate of the lake bed	1							
Structure of the lake shore	0							

Physical & chemical quality elements	Sensitivity of element to pressure	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Transparency	1							
Thermal conditions	1							
Oxygenation conditions	4	4	3	4	15		3	2
Salinity	0							
Acidification status	0							
Nutrient conditions	2							
Specific pollutants	1							

Biological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring scheme possible	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
phytoplankton composition	2							
phytoplankton abundance	3	3	1	3	10		2	3
Other aquatic flora composition	1							
Other aquatic flora abundance	1							
benthic invertebrate fauna (profundal) composition	3	2	2	2	9		1	1
benthic invertebrate (profundal) fauna abundance	3	2	1	2	8		1	1
fish fauna composition	3	2	1	2	8		1	1
fish fauna abundance	2			1				
fish fauna age structure	1							

Surface water type: lakes **Pressure**: Toxic Pollutants

Hydro-morphological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Quantity and dynamics of water flow	1							
Residence time	2 ?							
Connection to the ground water body	(a) 3 ? (b) 1 ?	1	0	1	5 ?		4	3
Water level	1							
Lake depth variation	0							
Quantity, structure and substrate of the lake bed	1							
Structure of the lake shore	0							

Physical & chemical quality elements	Sensitivity of element to pressure (correlation)	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Transparency	1							
Thermal conditions	0							
Oxygenation conditions	2							
Salinity	0							
Acidification status	2							
Nutrient conditions	1							
Specific pollutants	4	(3)	(3)	(1)	(11)		4	(3)

Biological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring scheme possible	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
phytoplankton composition	(3)	3	1	1	(8)		(2) (a)	(1)
phytoplankton abundance	(3)	3	1	1	(8)		(2) (a)	(1)
Other aquatic flora composition	(3)	3	1	(2)	(9)		(2) (a)	(1)
Other aquatic flora abundance	(3)	3	1	1	(8)		(2) (a)	(1)
benthic invertebrate fauna composition	(3)	(3)	1	(2)	(9)		(2) (a)	(1)
benthic invertebrate fauna abundance	(3)	(3)	1	1	(8)		(2) (a)	(1)
fish fauna composition	(2)							
fish fauna abundance	(3)	2	1	(2)	(7)		(2) (a)	(1)
fish fauna age structure	(3)	1	1	1	(6)		1	(1)

- Brackets mean that scoring may concern some only of the different types of pollutants
- Discrimination can be performed from clues gained from tissue analysis and after exclusion of other pressure, nutrient in particular.

Surface water type: lakes **Pressure**: Abstraction

Hydro-morphological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Quantity and dynamics of water flow	4	4	4	3	15		3	4
Residence time	3	4	4	3	14		3	4
Connection to the ground water body	1							
Water level	3	4	4	4	15		3	4
Lake depth variation	1							
Quantity, structure and substrate of the lake bed	1							
Structure of the lake shore	1							

Physical & chemical quality elements	Sensitivity of element to pressure	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Transparency	1							
Thermal conditions	1							
Oxygenation conditions	1							
Salinity	2							
Acidification status	1							
Nutrient conditions	1							
Specific pollutants	1							

Biological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring scheme possible	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modelling feasible
phytoplankton composition	1							
phytoplankton abundance	1							
Macrophytes and other aquatic flora composition	3	3	1 (a)	2	9		3	2
Other aquatic flora abundance	2							
benthic invertebrate fauna (littoral) composition	3	3	1	2	9		2	2
benthic invertebrate (littoral) fauna abundance	2							
fish fauna composition	2							
fish fauna abundance	2							
fish fauna age structure	2							

(a) In a catchment context, wetland macrophyte composition can be an effective indicator of abstraction pressures (Kennedy, 2002)

Surface water type: lakes **Pressure**: Regulation of flow

Hydro-morphological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Quantity and dynamics of water flow	4	4	4	3	15		3	4
Residence time (annual)	1							
Connection to the ground water body	1							
Water level	3	4	4	4	15		3	4
Lake depth variation	1							
Quantity, structure and substrate of the lake bed	1							
Structure of the lake shore	1							

Physical & chemical quality elements	Sensitivity of element to pressure	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Transparency	1							
Thermal conditions	1[a]							
Oxygenation conditions	1[a]							
Salinity	1							
Acidification status	1							
Nutrient conditions	1							
Specific pollutants	1							

Biological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring scheme possible	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modelling feasible
phytoplankton composition	1							
phytoplankton abundance	1							
Other aquatic flora composition	3	3	1	2	9		3	2
Other aquatic flora abundance	2							
benthic invertebrate fauna (littoral) composition	(3)[(b)]	3	1	2	9		2	2
benthic invertebrate (littoral) fauna abundance	2							
fish fauna composition	1							
fish fauna abundance	1							
fish fauna age structure	2							

(a) In the context of the catchments of large deep lakes, release of freshets (pulses) of cold and/or deoxygenated water from upstream dams can have significant impacts on the ecology of downstream rivers (or shallow lakes).
(b) Sensitivity is high for frequent regulation of flow

Surface water type: Large, deep lakes **Pressure**: Morphological alterations

Hydro-morphological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		Anthropogenic 'natural' discrimination	Modelling feasible
Quantity and dynamics of water flow	1							
Residence time (annual)	2[a]							
Connection to the ground water body	1							
Water level	(4)[a]	4	4	4	(16)		3	3?
Lake depth variation	(3)[b]	4	4	2	(13)		4	2?
Quantity, structure and substrate of the lake bed	3	3	1	1	8		2	2?
Structure of the lake shore	4	3	3	2	12		4	2

[a]High sensitivity only in terms of outflow alterations e.g. dams or dredging
[b]High sensitivity in terms of inflow or outflow alterations e.g. Rhine inflow, dams

Physical & chemical quality elements	Sensitivity of element to pressure	Measurable / Analytically sound	Monitoring Scheme Development	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
Transparency	1							
Thermal conditions	1							
Oxygenation conditions	1							
Salinity	1							
Acidification status	1							
Nutrient conditions	1							
Specific pollutants	1							

Biological quality elements	Sensitivity	Measurable / Analytically sound	Monitoring scheme possible	Cost & practicality	total score		anthropogenic 'natural' discrimination	Modeling feasible
phytoplankton composition	1							
phytoplankton abundance	1							
Other aquatic flora composition	3	3	3	2	11		3	2
Other aquatic flora abundance	3	3	3	2	11		3	3
benthic invertebrate fauna (littoral) composition	3	3	2	2	10		2	2
benthic invertebrate (littoral) fauna abundance	3	3	1	2	9		(3)	2
fish fauna composition	2							
fish fauna abundance	2							
fish fauna age structure	2							