UKTAG Lake Assessment Method

Macrophytes and Phytobenthos

Macrophytes (Lake LEAFPACS2)

by

Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG)

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Health and safety statement

WARNING. Working in or around water is inherently dangerous; persons using this standard should be familiar with normal laboratory and field practice. This published monitoring system does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user to establish appropriate health and safety practices and to ensure compliance with any national regulatory guidelines.

It is also the responsibility of the user if seeking to practise the method outlined here, to gain appropriate permissions for access to water courses and their biological sampling.

UKTAG Guide to Macrophytes in Lakes
Lake LEAFPACS2

1 Introduction

This classification method enables the assessment of macrophytes in lakes according to the requirements of the Water Framework Directive (WFD). The method, called Lake LEAFPACS2 replaces the classification tool Lakes LEAFPACS used in the first river basin planning cycle. Lakes LEAFPACS2 will be used by the Environment Agency, SEPA and Natural Resources Wales for reporting ecological status in the second river basin plans.

LEAFPACS2 forms one part of the quality element “macrophytes and phytobenthos”. Phytobenthos is assessed separately using benthic diatoms with a method called DARLEQ2 (available on the UKTAG website). The two results are combined to produce an overall classification for macrophytes and phytobenthos, using the worst class of either macrophytes or phytobenthos.

1.1 Metrics

The classification comprises five metrics describing different aspects of the lake macrophyte community. Macrophytes are larger plants of freshwater which are easily seen with the naked eye, including all vascular plants, bryophytes, stoneworts (Characeae) and macro-algal growths.

- **Lake Macrophyte Nutrient Index (LMNI)** – a taxon-specific nutrient response score. These values have been adjusted in LEAFPACS2
- **Number of functional groups of macrophyte taxa (NFG)** - a diversity metric, individual taxa are allocated to one of 18 “functional groups”*
- **Number of macrophyte taxa (NTAXA)** - a diversity metric, the number of scoring taxa recorded in the field survey
- **Mean percent cover of hydrophytes (COV)** – derived from lake macrophyte survey data
- **Relative percent cover of filamentous algae (ALG)** – derived from lake macrophyte survey data

Ecological Quality Ratios (EQRs) are derived for each of the metrics. They are a ratio of observed and expected values. The observed values come from lake surveys and the expected values are generated using a number of predictor variables which relate to the macrophyte community you would expect under relatively natural conditions.
The metric EQRs are combined according to a set of rules and the resulting overall EQR is normalised to a scale of 1 – 0, representing ecological status classes from High, Good, Moderate, Poor to Bad.

**“Functional group" is a group of organisms that share similar morphological traits.*

1.2 Environmental pressures to which the method is known to be sensitive

The method has been designed to detect the impact on lake macrophytes of nutrient enrichment. It may also be sensitive to the impact of other pressures or combinations of pressures, such as shoreline modification.

1.3 Geographic application

The method can be applied to lakes in England, Scotland, Wales (GB) and Northern Ireland (NI), although it is not used for WFD classification purposes in Northern Ireland.

1.4 Intercalibration

This is a process whereby European Member States were required to compare WFD class boundary values for their classification methods on a quality element basis (e.g. lake macrophytes) to ensure similar levels are set across all countries. The process involved adjustments to the class boundary values for many of the classification methods in use and this process has influenced some of the metrics in Lakes LEAFPACS2.

Once classification methods have been intercalibrated, they must be adhered to by Member States for the purposes of WFD assessment and reporting and cannot be changed.

2 Data Collection

2.1 Lake Macrophyte Survey

Lakes should be surveyed to obtain data from which to calculate the five metrics needed for LEAFPACS2. The survey method should conform to CEN 15460 : 2007 Water quality – Guidance standard for the surveying of macrophytes in lakes.

The recommended survey design is described below using a series of transects in sectors. In most lakes up to about 50ha in size, four sectors are sufficient. In very small lakes, fewer sectors are necessary and in lakes over 50ha, up to eight sectors should be surveyed.

A sector should comprise a 100 metre length of shoreline and should extend from the shore to the centre of the lake or to the maximum depth of colonisation of macrophytes, whichever is the shorter distance from the shore. It should include marginal and submerged vegetation shoreline transects, 5 'wader' transects at the water depths indicated, and a 'boat' transect, which requires up to 20 points along the transect to the depth of colonisation to be surveyed (see Figure 1). The length and number of recording points along the boat transect will depend upon the morphology of the lake bed; for those which shelve away steeply it will be impossible to fit 20 survey points along the transect.

The sectors should be arranged to give an approximately equal spread around the perimeter of the lake.

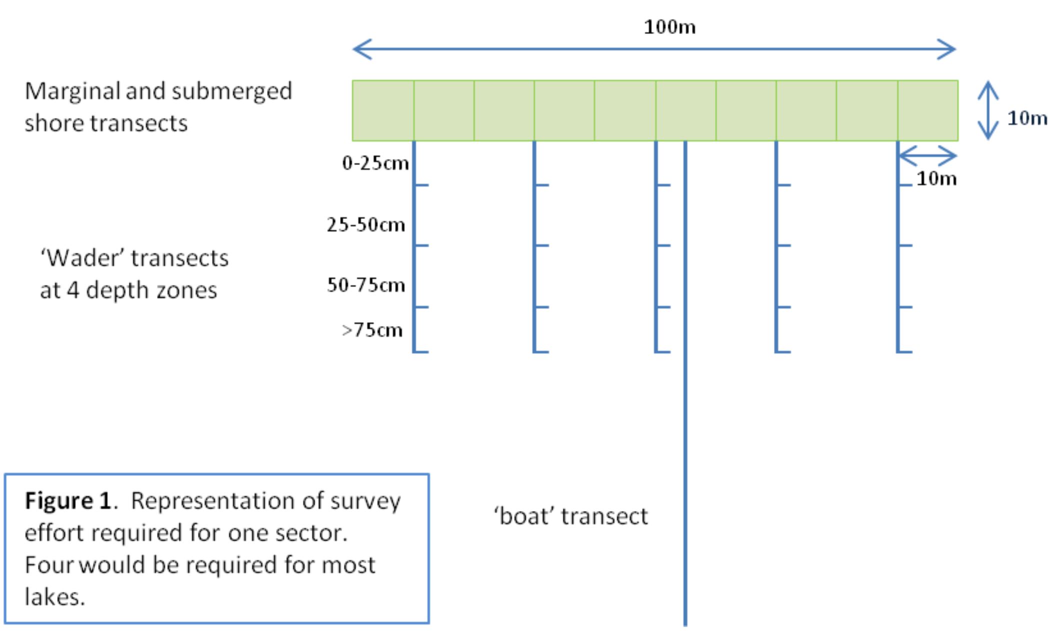

Figure 1. Representation of survey effort required for one sector. Four would be required for most lakes.

Surveys should be conducted in the months July, August or September although in central and southern England it may be possible to carry out surveys in late June if the growing season is sufficiently well advanced.

The presence of any taxa listed in Appendix A, Table 1 should be recorded at each recording point on each of the transects. Where it is not possible to identify a macrophyte to the taxonomic level listed it should be recorded using the next highest taxonomic level.

In addition, overall macrophyte biomass ratings (between 0-3) should be recorded at each point on the wader and boat transects. This provides an estimate of the overall macrophyte biomass at each transect point.

The Lake LEAFPACS2 spreadsheet calculator tool (see section 5) enables the data from each sector to be compiled to produce observed values for each of the five LEAFPACS2 metrics for the lake. Data from the boat and wader transects are considered to give a better indication of the lake macrophyte community and these are given greater weight in the overall metrics than the marginal surveys.

In some circumstances it may not be possible to carry out a boat transect in every sector. The spreadsheet calculator tool will accommodate different numbers of transects per sector and still calculate metrics. However, it must be appreciated that the recommended survey method is described above and deviations from this will result in a classification which is less reliable.

Only one survey in any year, usually comprising 4-8 sectors is necessary to produce an overall LEAFPACS2 classification.

2.2 Other data requirements – predictor variables

To enable the prediction of expected (also known as reference) values for the five Lake LEAFPACS2 metrics, additional information is required. These data are referred to as *predictor variables*.

2.2.1 Alkalinity, μeq/L

An annual mean alkalinity value for the lake is required in units of μeq/L. This should be obtained from analysis of lake water samples collected on a monthly basis. A longer time series of data could be used if available. In some lakes, there are marked seasonal fluctuations in alkalinity, and an annual average value is necessary to take account of this. The mean alkalinity value does not tend to change much from year to year. Alkalinity data provides an indication of the reference plant nutrient availability in the lake.

Note: This method uses alkalinity expressed as microequivalents per litre. Alkalinity is commonly reported as mg/l $CaCO_3$ (strictly speaking this is carbonate alkalinity). An alkalinity value in mg/l $CaCO_3$ can be converted to ueq/l by multiplying by 20.

2.2.2 Lake physical parameters

Lake physical parameters required are:

- Lake mean depth, m
- Lake altitude, m. This is the height of the surface of the lake above mean sea level

- Lake surface area, hectares

2.2.3 Freshwater sensitivity class

Freshwater Sensitivity Class (FWSC) describes the relative capacity of geology and soils to neutralise incoming acidity and hence limit acid loadings to fresh surface waters. It is a useful indication of the relative proportions of calcareous and non-calcareous, hard rock and soft rock geology and therefore also background levels of available nutrients. There are five classes ranging from F_1 (highly sensitive to acidity, low acid buffering capacity in catchment) to F_5 (low sensitivity to acidity, high acid buffering capacity in catchment). The classes are derived from the Centre for Ecology and Hydrology Freshwater Sensitivity Class map; Hornung *et.al.* (1995). It is necessary to determine the percentage of the catchment in each of the five classes. Note that all marl lakes should be considered as being in a hard geology catchment, irrespective of the calculated wFWSC (see also section 2.3)

2.3 Minimum data requirements

The accuracy of observed data and predictor variables will influence the final classification outcome. If lake mean depth is not available, a modelled or estimated value can be used, although it is important to be aware that lake macrophyte communities are quite different in lakes which are very shallow, to those which are very deep with steeply shelving shorelines. Therefore the mean depth is an important predictor of lake macrophyte community and needs to be as accurate as possible.

If it is not possible to obtain the proportion of the catchment in each FWSC, determine the relative proportion of the catchment which is hard rock geology and the proportion which is soft rock geology. In many cases the catchment will be relatively uniform, especially in smaller lakes. Use a value of 4.0 for lakes on predominantly soft, calcareous geology any value < 4 for lakes on hard geologies. Note that all marl lakes fall into the latter category irrespective of the calculated wFWSC.

Some lake macrophyte survey methodologies do not collect plant cover data. It is possible to calculate a LEAFPACs EQR without cover information, although the result must be interpreted with caution. This survey method is not recommended for WFD classification purposes.

3 Procedure for calculating the metric EQRs

EQRs are a ratio of observed and expected data. Observed values are taken from lake macrophyte surveys and expected values (also referred to as reference values) are predicted from the predictor variables listed in section 2.2.

The following sections outline the procedures for calculating EQRs for each metric, followed by the combination of the EQRs to produce an overall LEAFPACS2 EQR, enabling a status class to be obtained.

A Lake LEAFPACS2 speadsheet calculator spreadsheet tool is available to help automate this process (see section 5).

3.1 Observed metric values

3.1.1 Observed Lake Macrophyte Nutrient Index (LMNI)

LMNI is calculated from the macrophyte taxa recorded in the lake survey and their taxon-specific LMNI scores, provided in Table 1, Appendix A. Note that some species which will be recorded have not been assigned an LMNI score. Those without LMNI scores are mostly terrestrial or marginal taxa growing on the shoreline.
Assign the correct LMNI score to each taxon and calculate the Observed LMNI using the following equation;

$$\text{Observed value of LMNI} = \frac{\sum_{j=1}^{n} LMNI_j}{N}$$

where:

$LMNI_j$ is the Lake Macrophyte Nutrient Index score for taxon "j"
"N" is the total number of macrophyte taxa recorded which are listed in Table 1, Appendix A.

3.1.2 Observed number of functional groups (NFG)

Most of the lake macrophyte taxa recorded in the survey can be assigned a functional group (numbered 1-18). Refer to Table 1, Appendix A to assign the correct functional group to each macrophyte taxon recorded.

The observed value for NFG, is given by the number of different functional groups recorded in the lake survey.

3.1.3 Observed number of macrophyte taxa (NTAXA)

The observed value for NTAXA, is given by the number of taxa recorded in the lake which are also listed in Table 1, Appendix A.

3.1.4 Observed mean percent cover of hydrophytes (COV)

Lake macrophyte survey data is used to compile plant % cover values for each of the taxa recorded. Using the plant cover values calculated from the survey, the observed value for COV, based only on taxa recorded which are also in Table 1, Appendix A, is calculated using the following equation;

$$\text{Observed value of COV} = \frac{\sum_{j=1}^{n} \%COV_j}{N}$$

where:

%COV$_j$ is the percentage cover of hydrophyte taxon "j" in the lake;
"N" is the total number of macrophyte taxa listed in Table 1, Appendix A and recorded in the survey.

If no assessment of cover has been made, this metric cannot be used.

3.1.5 Observed relative percent cover of filamentous algae (ALG)

During the lake macrophyte survey, % cover of filamentous algae is recorded.
Using the filamentous algal cover values from the survey, the observed value for ALG is calculated using the following equation;

$$\text{Observed value of ALG} = \frac{\sum_{k=1}^{n} \%F_k}{\sum_{j=1}^{n} \%COV_j}$$

where:

%F$_k$ is the percentage cover of filamentous algal taxon "k" in the lake
%COV$_j$ is the percentage cover of hydrophyte taxon "j" in the lake;

3.2 Expected (reference) metric values

These values are calculated using predictor variables (see section 2.2) as follows;

3.2.1 Expected Lake Macrophyte Nutrient Index (LMNI)

The expected LMNI value is related to the Morpho-Edaphic Index (MEI) and a weighted Freshwater Sensitivity Class (wFWSC).

3.2.1.1 Morpho-edaphic index (MEI)

MEI is a relationship between lake alkalinity and mean depth and helps to provide an indication of the natural nutrient availability in a lake.

MEI is calculated as follows;

$$MEI = log10(\frac{alk + 40}{1000} \div D)$$

Where;

Alk = annual mean alkalinity, µeq/L

D = mean depth, m

40 = is a fixed number added to the alkalinity value to ensure negative alkalinity values are never used; creating a Log_{10} of a negative number is not possible.

3.2.1.2 Weighted Freshwater Sensitivity Class (wFWSC)

Weighted Freshwater Sensitivity Class (wFWSC), is calculated as follows;

$$wFWSC = F_1/100 + [F_2/100 \times 2] + [F_3/100 \times 3] + [F_4/100 \times 4] + [F_5/100 \times 5];$$

where F_1 to F_5 describes the % cover of the lake catchment assignable to each of the five sensitivity classes.

If FWSC data is unavailable, use a value of 4.0 for lakes on predominantly soft, calcareous geology any value < 4 for lakes on hard geologies. Note that all marl lakes fall into the latter category irrespective of the calculated wFWSC.

Using MEI and wFWSC, expected LMNI is calculated as follows where the formula used depends upon the value of wFWSC;

wFWSC	Expected LMNI
≥ 4.0 (i.e. well buffered catchments with soft, calcareous geology)	$= 4.969 + 1.272MEI + 0.193MEI^2$
< 4.0 (i.e. poorly buffered catchments or those with hard calcareous geology including all marl lakes)	$= 4.969 + 1.272MEI + 0.193MEI^2 - 0.55$

3.2.2 Expected number of functional groups (NFG)

Calculate using the following formula:

Lake location and value of wFWSC	Expected NFG
If lake in GB, wFWSC < 4.0	$= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40)) + 0.132 + 0.356)$
If lake in GB, wFWSC ≥ 4.0	$= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40)) + 0.132)$
If lake in NI, wFWSC < 4.0	$= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40)) + 0.356)$
If lake in NI, wFWSC ≥ 4.0	$= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40)))$

Where;

Alk = annual mean alkalinity, ueq/L

H = Lake altitude, m

S = Lake surface area, hectares

GB = England, Scotland and Wales, **NI** = Northern Ireland

3.2.3 Expected number of macrophyte taxa (NTAXA)

Calculate using the following formula according to the geographical location of the lake and the value of wFSC:

Lake location and value of wFSC	Expected NTAXA
If lake in GB, wFWSC < 4.0	$= EXP(1.488 – (0.098\log_{10}H) + (0.185\log_{10}S) + (0.194\log_{10}(Alk + 40)) + 0.149 + 0.287)$
If lake in GB, wFWSC ≥ 4.0	$= EXP(1.488 – (0.098\log_{10}H) + (0.185\log_{10}S) + (0.194\log_{10}(Alk + 40)) + 0.149)$
If lake in NI, wFWSC < 4.0	$= EXP(1.488 – (0.098\log_{10}H) + (0.185\log_{10}S) + (0.194\log_{10}(Alk + 40)) + 0.287)$

If lake in NI, wFWSC ≥ 4.0	$= \mathrm{EXP}(1.488 - (0.098\log_{10}H) + (0.185\log_{10}S) + (0.194\log_{10}(Alk + 40)))$

Where;

Alk = annual mean alkalinity, ueq/L

H = Lake altitude, m

S = Lake surface area, hectares

GB = England, Scotland and Wales, **NI** = Northern Ireland

3.2.4 Expected mean percent cover of hydrophytes (COV)

An expected COV value of 8.2% should be used.

Exclude this metric, if no assessment of cover has been made during the macrophyte survey, or if the survey comprises strandline surveys only.

3.2.5 Expected relative percent cover of filamentous algae (ALG)

An expected ALG value of 0.05 should be used.

3.3 Calculating EQR for each metric

3.3.1 Lake Macrophyte Nutrient Index (LMNI) EQR

Calculate EQR_{LMNI} using the following equations according to the value of expected LMNI:

Expected LMNI	**EQR_{LMNI}**
≥ 5	$= \frac{observed\ LMNI - 10}{expected\ LMNI - 10}$
< 5	$= \frac{observed\ LMNI - (expected\ LMNI + 5)}{expected\ LMNI - (expected\ LMNI + 5)}$

3.3.2 Number of functional groups (NFG) EQR

Calculate EQR_{NFG} using the following equation:

EQR_{NFG} = observed NFG ÷ expected NFG
unless the observed NFG = 0 in which case EQR_{NFG} = 0.

3.3.3 Number of macrophyte taxa (NTAXA) EQR

Calculate EQR_{NTAXA} using the following equation:

EQR_{NTAXA} = observed NTAXA ÷ expected NTAXA
unless observed NTAXA = 0 in which case EQR_{NTAXA} = 0.

3.3.4 Mean percent cover of hydrophytes (COV) EQR

Calculate EQR_{COV} using the following equation:

EQR_{COV} = √ observed COV ÷ √ expected COV

3.3.5 Relative percent cover of filamentous algae (ALG) EQR

Calculate EQR_{ALG} according to the observed ALG value as follows;

Observed ALG > 0.05	$\mathbf{EQR_{ALG}} = \dfrac{Observed\ ALG - 1}{0.05 - 1}$
Observed ALG ≤ 0.05	$\mathbf{EQR_{ALG}}$ = 1

3.4 Combining the ecological quality ratios to determine the overall EQR ($EQR_{LEAFPACS}$)

The EQRs for the different metrics need to be combined to produce an overall EQR ($EQR_{LEAFPACS}$) according to the following rules and equations.

Step 1

This step is to adjust the EQR_{LMNI} according to whether it is greater than (better than) or less than (worse than) the EQRs relating to the plant diversity, EQR_{NTAXA} and EQR_{NFG}. It produces a diversity adjusted EQR for LMNI ($^{A}EQR_{LMNI}$).

	Diversity adjusted EQR_{LMNI} ($^{A}EQR_{LMNI}$)
If, the smaller of EQR_{NFG} and EQR_{NTAXA} is < EQR_{LMNI}	= (EQR_{LMNI} + (a x 0.5)) ÷ 1.5

	Where a = the smallest of EQR_{NFG} and EQR_{NTAXA}
Otherwise	= EQR_{LMNI}

Step 2
This step measures $^{A}EQR_{LMNI}$, against the EQRs relating to plant cover, EQR_{COV} and EQR_{ALG}, enabling the derivation of the final overall LEAFPACS EQR ($EQR_{LEAFPACS}$).

	LEAFPACs EQR ($EQR_{LEAFPACS}$)
If, the smaller of EQR_{COV} and EQR_{ALG} is < $^{A}EQR_{LMNI}$	= ($^{A}EQR_{LMNI}$ + (b x 0.25)) ÷ 1.25 *Where b = the smallest of EQR_{COV} and EQR_{ALG}*
Otherwise	= $^{A}EQR_{LMNI}$

Step 3
$EQR_{LEAFPACS}$ is not on a scale from 0 to 1 but it can be standardised to follow this scale. This is carried out by applying the formulae listed below to the $EQR_{LEAFPACS}$ value, depending upon that value.

The standardised ecological quality ratio ($^{S}EQR_{LEAFPACS}$) should be calculated for as follows;

$EQR_{LEAFPACS}$	**$^{S}EQR_{LEAFPACS}$**
> 1.05	= 1
≤ 1.05 and ≥ 0.80	$= \frac{EQR_{LEAFPACS} - 0.80}{1.05 - 0.80} \times 0.20 + 0.80$
< 0.80 and ≥ 0.66	$= \frac{EQR_{LEAFPACS} - 0.66}{0.80 - 0.66} \times 0.20 + 0.60$
< 0.66 and ≥ 0.51	$= \frac{EQR_{LEAFPACS} - 0.51}{0.66 - 0.51} \times 0.20 + 0.40$
< 0.51 and ≥ 0.35	$= \frac{EQR_{LEAFPACS} - 0.35}{0.51 - 0.35} \times 0.20 + 0.20$
< 0.35 and ≥ 0.20	$= \frac{EQR_{LEAFPACS} - 0.20}{0.35 - 0.20} \times 0.20$
< 0.20	= 0

Step 4
The value of $^{S}EQR_{LEAFPACS}$ should then be assigned to an ecological status class according to the following categories.

$^{S}EQR_{LEAFPACS}$	Status
≥ 0.80 < 1.00	High
≥ 0.60 < 0.80	Good
≥ 0.40 < 0.60	Moderate
≥ 0.20 < 0.40	Poor
≥ 0 < 0.20	Bad

3.5 Data from multiple surveys

If surveys have been carried out in more than one year and a multiple year classification is required, take the average $^{S}EQR_{LEAFPACS}$ from each year to produce an overall $^{s}EQR_{LEAFPACS}$ for the lake.

4. Confidence of Classification

To determine the confidence of the classification the uncertainty of the EQR is determined. This uncertainty arises from a combination of within-waterbody spatial and temporal variability in the biological community and variability between surveyors. For the purpose of classification too few replicate surveys are available to measure this directly. Thus the method estimates the uncertainty using data from other water bodies using an approach described by Ellis & Adriaenssens (2006). The spatio-temporal variability (the standard deviation) of the survey EQR is estimated as a function of the mean Survey EQR in a water body.

To estimate uncertainty it is assumed that after a logit transformation the EQR uncertainty is Normally distributed around the true EQR value, with the predicted standard deviation. Then the confidence of class is computed using the Standard Normal Distribution.

Confidence of Class can be calculated using the Lake LEAFPACS2 spreadsheet calculator.

5. Lakes LEAFPACS2 calculator spreadsheets

The procedures for calculating the macrophyte metric EQRs, the overall EQR and the Confidence of Class can be carried out manually using a calculator and spreadsheet such as MS Excel. However, the task can be made simpler by using a spreadsheet calculator. MS Excel spreadsheets have been produced with a series of worksheets for data input and calculation of all components of the classification, including Confidence of Class. Instructions for use are provided within the spreadsheet calculator. The most recent version of the spreadsheet calculator can be found on UKTAG website.

NB As revisions are likely to be made and the calculator updated over time, it is important to check that the most recent version is being used.

Calculator spreadsheets provided on the UKTAG website are:

- Lake LEAFPACS2 metric calculator. This enables the calculation of metrics from raw survey data.
- Lake LEAFPACS2 EQR calculator. This enables the calculation of EQRs and Confidence of Class.

6. References

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Appendix A

Table 1: List of lake macrophyte taxa and associated information for the calculation of LEAFPACS2 metrics

Column 1	Column 2	Column 3	Column 4
Macrophyte taxa	**Lake macrophyte nutrient index score (LMNI)**	**Functional group number**	**Taxa indicated as filamentous algal taxa ("F")**
Alisma gramineum	7.65	13	
Apium inundatum	4.32	7	
Aponogeton distachyos	8.88	16	
Azolla filiculoides	7.25	1	
Baldellia ranunculoides	3.97	13	
Batrachospermum sp.	1.56		
Butomus umbellatus	7.97	13	
Callitriche brutia var. brutia	2.26	6	
Callitriche brutia var. hamulata	4.08	6	
Callitriche hermaphroditica	8.08	5	
Callitriche obtusangula	9.34	6	
Callitriche platycarpa	9.50	6	
Callitriche sp.	7.11	6	
Callitriche stagnalis	6.38	6	
Callitriche truncata	8.28	6	
Ceratophyllum demersum	7.99	5	
Ceratophyllum submersum	6.78	5	
Chara aculeolata	3.49	2	
Chara aspera	4.19	2	
Chara baltica	5.83	2	
Chara canescens	4.73	2	
Chara connivens	5.60	2	
Chara contraria var. contraria	5.06	2	
Chara contraria var. hispidula	6.41	2	
Chara curta	4.14	2	
Chara globularis	6.86	2	
Chara hispida	3.95	2	
Chara intermedia	5.04	2	

Column 1	Column 2	Column 3	Column 4
Macrophyte taxa	**Lake macrophyte nutrient index score (LMNI)**	**Functional group number**	**Taxa indicated as filamentous algal taxa ("F")**
Chara rudis	3.93	2	
Chara sp.	5.57	2	
Chara virgata	4.29	2	
Chara virgata var. annulata	4.07	2	
Chara vulgaris	5.56	2	
Crassula helmsii	5.57	5	
Damasonium alisma	6.19	13	
Elatine hexandra	3.81	11	
Elatine hydropiper	5.34	11	
Eleocharis acicularis	8.68	4	
Eleocharis multicaulis	3.03	4	
Eleogiton fluitans	2.03	15	
Elodea callitrichoides	7.64	5	
Elodea canadensis	7.45	5	
Elodea nuttallii	6.19	5	
Eriocaulon aquaticum	1.47	4	
Filamentous algae	6.70		F
Fontinalis antipyretica	4.19	3	
Fontinalis squamosa	3.09	3	
Groenlandia densa	5.35	5	
Hippuris vulgaris	5.23	7	
Hottonia palustris	6.29	7	
Hydrocharis morsus-ranae	6.51	8	
Hydrodictyon reticulatum	8.42		F
Hypericum elodes	3.56	11	
Isoetes echinospora	2.47	4	
Isoetes lacustris	2.22	4	
Isoetes sp.	2.22	4	
Juncus bulbosus	2.42	4	
Lagarosiphon major	3.51	5	
Lemna gibba	7.66	1	
Lemna minor	8.52	1	
Lemna minuta	10.00	1	
Lemna trisulca	7.96	1	

Column 1	Column 2	Column 3	Column 4
Macrophyte taxa	**Lake macrophyte nutrient index score (LMNI)**	**Functional group number**	**Taxa indicated as filamentous algal taxa ("F")**
Leptodyction riparium	8.71	3	
Limosella aquatica	3.80	11	
Littorella uniflora	3.73	4	
Lobelia dortmanna	2.16	4	
Ludwigia palustris	3.82	11	
Luronium natans	3.52	13	
Lythrum portula	4.31	11	
Menyanthes trifoliata	5.17	10	
Myriophyllum alterniflorum	2.66	7	
Myriophyllum aquaticum	6.87	7	
Myriophyllum spicatum	6.23	7	
Myriophyllum verticillatum	5.32	7	
Najas flexilis	2.89	14	
Najas marina	5.24	14	
Nitella confervacea	3.28	2	
Nitella flexilis agg.	5.19	2	
Nitella gracilis	3.56	2	
Nitella mucronata	5.67	2	
Nitella opaca	2.36	2	
Nitella sp.	4.66	2	
Nitella translucens	2.73	2	
Nitellopsis obtusa	5.23	2	
Nuphar lutea	7.47	12	
Nuphar pumila	4.82	12	
Nuphar x spenneriana	3.65	12	
Nymphaea alba	6.84	12	
Nymphoides peltata	6.75	10	
Persicaria amphibia	8.25	10	
Pilularia globulifera	3.59	4	
Potamogeton alpinus	4.48	16	
Potamogeton berchtoldii	6.58	14	
Potamogeton coloratus	3.46	16	
Potamogeton compressus	5.18	14	
Potamogeton crispus	7.50	17	

Column 1	Column 2	Column 3	Column 4
Macrophyte taxa	**Lake macrophyte nutrient index score (LMNI)**	**Functional group number**	**Taxa indicated as filamentous algal taxa ("F")**
Potamogeton epihydrus	1.00	16	
Potamogeton filiformis	3.68	15	
Potamogeton friesii	4.71	14	
Potamogeton gramineus	2.85	16	
Potamogeton lucens	4.37	17	
Potamogeton natans	4.71	16	
Potamogeton obtusifolius	6.97	14	
Potamogeton pectinatus	7.19	15	
Potamogeton perfoliatus	4.42	17	
Potamogeton polygonifolius	2.39	16	
Potamogeton praelongus	3.92	17	
Potamogeton pusillus	7.54	14	
Potamogeton rutilus	5.49	14	
Potamogeton trichoides	5.79	14	
Potamogeton x cooperi	4.93	17	
Potamogeton x griffithii	2.57	16	
Potamogeton x lintonii	7.21	14	
Potamogeton x nitens	3.48	17	
Potamogeton x salicifolius	5.89	17	
Potamogeton x sparganifolius	3.71	16	
Potamogeton x suecicus	4.62	15	
Potamogeton x zizii	4.04	16	
Ranunculus (sub sect. Batrachian) sp.	5.31	18	
Ranunculus aquatilis agg.	6.30	18	
Ranunculus aquatilis var diffusus	4.20	18	
Ranunculus aquatilis var. aquatilis.	5.81	18	
Ranunculus circinatus	8.70	5	
Ranunculus fluitans	5.65	18	
Ranunculus hederaceus	8.33	11	
Ranunculus lingua	6.79	10	
Ranunculus omiophyllus	5.51	11	
Ranunculus peltatus subsp. baudotii	6.48	18	
Ranunculus peltatus subsp. peltatus	6.49	18	
Ranunculus penicillatus subsp. penicillatus	4.21	18	

Column 1	Column 2	Column 3	Column 4
Macrophyte taxa	**Lake macrophyte nutrient index score (LMNI)**	**Functional group number**	**Taxa indicated as filamentous algal taxa ("F")**
Ranunculus penicillatus subsp. pseudofluitans	6.68	18	
Riccia fluitans	6.35	1	
Ricciocarpus natans	5.32	1	
Ruppia cirrhosa	7.03	15	
Ruppia maritima	7.85	15	
Ruppia sp.	8.08	15	
Sagittaria sagittifolia	6.01	12	
Sparganium angustifolium	2.52	13	
Sparganium emersum	6.06	13	
Sparganium natans	2.79	13	
Sphagnum (aquatic indet.)	2.74	3	
Spirodela polyrhiza	9.62	1	
Stratiotes aloides	6.20	8	
Subularia aquatica	1.80	4	
Tolypella glomerata	5.32	2	
Ulva (Enteromorpha) flexuosa	9.05		F
Utricularia australis	2.87	9	
Utricularia intermedia sens.lat.	1.61	9	
Utricularia minor	2.36	9	
Utricularia ochroleuca	1.04	9	
Utricularia sp.	3.34	9	
Utricularia stygia	1.30	9	
Utricularia vulgaris	4.24	9	
Zannichellia palustris	8.69	15	

Appendix B: Worked example

The following data were obtained from a GB lake survey.

Taxon identified as present in the lake	% cover in sampled area	Lake macrophyte nutrient index score	Number of functional group
Chara aspera	10	4.19	2
Elodea canadensis	1	7.45	5
Hippuris vulgaris	5	5.23	7
Nitellopsis obtusa	2	5.23	2
Nymphaea alba	10	6.84	12
Potamogeton obtusifolius	5	6.97	14

In addition, the following predictor variables were obtained:

Variable	Value
Lake altitude (H)	15 metres
Mean depth (D)	2.7 metres
Area (S)	3.1 hectares
Reference alkalinity (Alk)	1700 µeq L^{-1}
weighted Freshwater Sensitivity Class (wFWSC)	4.1

1. Observed metric values

a. Observed LMNI

Assign the correct LMNI score to each taxon and calculate the Observed LMNI using the following equation;

$$\text{Observed value of LMNI} = \frac{\sum_{j=1}^{n} \text{LMNI}_j}{N}$$

Observed LMNI = 35.91 ÷ 6 = <u>5.99</u>

b. Observed NFG

The observed value for NFG, is given by the number of different functional groups recorded in the lake survey.

Observed NFG = 5

c. Observed NTAXA

The observed value for NTAXA, is given by the number of taxa recorded in the lake survey.

Observed NTAXA = 6

d. Observed COV

Lake macrophyte survey data is used to compile plant % cover values for each of the taxa recorded using the following equation;

$$\text{Observed value of COV} = \frac{\sum_{j=1}^{n} \%COV_j}{N}$$

Observed COV = 33 ÷ 6 = 5.5

e. Observed ALG

There were no filamentous algal taxa observed.

2. Expected (reference) metric values

a. Expected LMNI

The expected LMNI value is related to the Morpho-Edaphic Index (MEI) and a weighted Freshwater Sensitivity Class (wFWSC).

i. MEI

MEI is calculated as follows;

$$MEI = log10(\frac{alk + 40}{1000} \div D)$$

MEI $= \log 10\ (1.74 \div 2.7)$
$= \log 10\ 0.644$
$\underline{= -0.191}$

ii. wFWSC

The value for wFWSC provided is 4.1. This is greater than 4.0, therefore the expected LMNI is calculated using;

wFWSC	**Expected LMNI**
≥ 4.0 (i.e. well buffered catchments with soft, calcareous geology)	$= 4.969 + 1.272MEI + 0.193MEI^2$
< 4.0 (i.e. poorly buffered catchments or those with hard calcareous geology)	$= 4.969 + 1.272MEI + 0.193MEI^2 - 0.55$

Expected LMNI $= 4.969 + 1.272MEI + 0.193MEI^2$
$= 4.969 + (1.272 \times -0.191) + (0.193 \times -0.191 \times -0.191)$
$\underline{= 4.73}$

b. Expected NFG

wFWSC ≥ 4.0 and the lake is in GB therefore use the following to calculate expected NFG;

Lake location and value of wFWSC	**Expected NFG**
If lake in GB, wFWSC < 4.0	$= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40)) + 0.132 + 0.356$
If lake in GB, wFWSC ≥ 4.0	$= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40)) + 0.132$
If lake in NI, wFWSC < 4.0	$= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40)) + 0.356$
If lake in NI, wFWSC ≥ 4.0	$= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40))$

Expected NFG $= EXP(0.703 – (0.049\log_{10}H) + (0.133\log_{10}S) + (0.287\log_{10}(Alk + 40)) + 0.132$

$= \mathit{EXP}\ (0.703 – 0.0576 + 0.065 + 0.93 + 0.132)$

= 5.887

c. Expected NTAXA

wFWSC ≥ 4.0 and the lake is in GB therefore use the following to calculate expected NTAXA;

Lake location and value of wFSC	Expected NTAXA
If lake in GB, wFWSC < 4.0	=EXP(1.488 – (0.098log$_{10}$H) + (0.185log$_{10}$S) + 0.194log$_{10}$(Alk + 40)) + 0.149 + 0.287
If lake in GB, wFWSC ≥ 4.0	=EXP(1.488 – (0.098log$_{10}$H) + (0.185log$_{10}$S) + 0.194log$_{10}$(Alk + 40)) + 0.149
If lake in NI, wFWSC < 4.0	=EXP(1.488 – (0.098log$_{10}$H) + (0.185log$_{10}$S) + 0.194log$_{10}$(Alk + 40)) + 0.287
If lake in NI, wFWSC ≥ 4.0	=EXP(1.488 – (0.098log$_{10}$H) + (0.185log$_{10}$S) + 0.194log$_{10}$(Alk + 40))

Expected NTAXA = EXP(1.488 – (0.098log$_{10}$H) + (0.185log$_{10}$S) + 0.194log$_{10}$(Alk + 40)) + 0.149

=*EXP*(1.488 – 0.115 + 0.0909 + 0.6287 + 0.149)

= 9.4057

d. Expected COV

An expected COV value of 8.2% should be used.

e. Expected ALG

An expected ALG value of 0.05 should be used.

3. Calculating EQR for each metric

a. EQR$_{LMNI}$

Expected LMNI < 5, therefore EQR is calculated using the following;

$$EQR_{LMNI} = \frac{observed\ LMNI - (expected\ LMNI + 5)}{expected\ LMNI - (expected\ LMNI + 5)}$$

= (5.99 – (4.73+5)) ÷ (4.73 – (4.73 + 5))

= 0.748

b. EQR_{NFG}

EQR_{NFG} = observed NFG ÷ expected NFG
= 5 ÷ 5.887
= 0.849

c. EQR_{NTAXA}

EQR_{NTAXA} = observed NTAXA ÷ expected NTAXA
= 6 ÷ 9.4057
= 0.638

d. EQR_{COV}

EQR_{COV} = √ observed COV ÷ √ expected COV
= √ 5.5 ÷ √ 8.2
= 2.345 ÷ 2.864
= 0.819

e. EQR_{ALG}

Observed ALG ≤ 0.05, therefore, EQR_{ALG} = 1

The observed and expected metric values are summarised below, along with associated EQRs;

Parameter	Observed value	Reference value	EQR
LMNI	5.99	4.73	0.75
NFG	5.00	5.89	0.85
NTAXA	6.00	9.41	0.64
COV	5.50	8.20	0.82
ALG	0.0	0.05	1.00

4. Combining EQRs to determine $EQR_{LEAFPACS}$

The EQRs for the different metrics need to be combined to produce an overall EQR ($EQR_{LEAFPACS}$) according to the following rules and equations.

Step 1 – diversity adjusted EQR ($^{A}EQR_{LMNI}$)

	Diversity adjusted EQR_{LMNI} ($^{A}EQR_{LMNI}$)
If, the smaller of EQR_{NFG} and EQR_{NTAXA} is < EQR_{LMNI}	$= \frac{EQR_{LMNI} + a \times 0.5}{1.5}$ Where a = the smallest of EQR_{NFG} and EQR_{NTAXA}
Otherwise	= EQR_{LMNI}

The EQR_{NTAXA} (0.64) is the smaller of EQR_{NTAXA} and EQR_{NFG} and is less than EQR_{LMNI} (0.75), therefore

$^{A}EQR_{LMNI}$ = EQR_{LMNI} + (0.64 x 0.5) ÷ 1.5
= 0.713

Step 2 – final $EQR_{LEAFPACS}$

	LEAFPACs EQR ($EQR_{LEAFPACS}$)
If, the smaller of EQR_{COV} and EQR_{ALG} is < $^{A}EQR_{LMNI}$	$= \frac{^{A}EQR_{LMNI} + b \times 0.25}{1.25}$ Where b = the smallest of EQR_{COV} and EQR_{ALG}
Otherwise	= $^{A}EQR_{LMNI}$

The smaller of EQR_{COV} and EQR_{ALG} is EQR_{COV} (0.82). This value is not less than $^{A}EQR_{LMNI}$, therefore $EQR_{LEAFPACS}$ = $^{A}EQR_{LMNI}$ = 0.713

Step 3 – standardises EQR ($^{S}EQR_{LEAFPACS}$)

$EQR_{LEAFPACS}$	$^{S}EQR_{LEAFPACS}$
> 1.05	= 1
≤ 1.05 and ≥ 0.80	$= \frac{EQR_{LEAFPACS} - 0.80}{1.05 - 0.80} \times 0.20 + 0.80$
< 0.80 and ≥ 0.66	$= \frac{EQR_{LEAFPACS} - 0.66}{0.80 - 0.66} \times 0.20 + 0.60$
< 0.66 and ≥ 0.51	$= \frac{EQR_{LEAFPACS} - 0.51}{0.66 - 0.51} \times 0.20 + 0.40$
< 0.51 and ≥ 0.35	$= \frac{EQR_{LEAFPACS} - 0.35}{0.51 - 0.35} \times 0.20 + 0.20$
< 0.35 and ≥ 0.20	$= \frac{EQR_{LEAFPACS} - 0.20}{0.35 - 0.20} \times 0.20$

< 0.20	= 0

The standardised $EQR_{LEAFPACS}$ is calculated as follows;

(0.712 – 0.66) ÷ (0.80 – 0.66) x 0.2 + 0.6
= 0.371 x 0.2 + 0.6
= 0.674

This value equates to **Good** status.

$^{s}EQR_{LEAFPACS}$	Status
≥ 0.80 < 1.00	High
≥ 0.60 < 0.80	Good
≥ 0.40 < 0.60	Moderate
≥ 0.20 < 0.40	Poor
≥ 0 < 0.20	Bad