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Work Package 2

Ecological Resource Characterisation

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by

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1. AIMS OF THE REPORT

This report discusses the characterisation of lakes and rivers through consideration of measures of their ecology. A great deal of ecological monitoring of surface waters occurs through out Europe using a number of metrics which have usually been developed locally or are local adaptations of methods developed elsewhere. The Water Frame Work Directive (WFD) (European Union, 2000) has focussed attention on the biological status of water bodies as the means for assessing their quality, defining monitoring schemes and assessing the impacts of programmes of measures. Given the importance of the WFD for the management of river basins particular emphasis is placed on those characterisations of these river basins in the context of the Directive. One aspect of characterisation is the ability to attribute the ecological status of a water body to some external pressure, which then allows a programme of measures to be put in place to alleviate that pressure. Within this report an attempt has been made to identify characterisation methods that are attributable to specific pressures. This proved possible for rivers but was less successful for lakes where a more general approach has been taken.

The concept of reference conditions against which ecological status is assessed is an important feature of the WFD. This report, therefore, also describes the use of palaeoecology which can be used as a method of defining reference conditions through the reconstruction of past ecological and water quality conditions.

2. CONTEXT: DRIVERS OF CHANGE, PRESSURES, IMPACTS / CRITICAL ISSUES

2.1 Background and Drivers of Change

Biological assessment and classification of rivers and lakes has been a routine part of the work of the Environment Agency in England and Wales and the Scottish Environment Protection Agency in Scotland, and their fore runners for many years. In the past, this characterisation has been used mainly to assess the impacts of point source pollution on water quality, with the emphasis on monitoring changes in the state of the water body over time. More recently the situation has changed. Now the WFD has become a major driver for ecological charaterisation with its goal of achieving “good ecological status” for all water bodies (expect those that are defined as heavily modified) by 2015. The WFD defines good ecological status is in very general terms indicating that to achieve this status a water body must be only slightly changed from the reference condition for that water body as a result of human activities (Environmental Quality Standards (EQS) must also be achieved for relevant physico-chemical quality elements- see below). A consequence of this definition is that reference conditions must be established for water bodies and that ecological characterisation must be able to indicate change from this reference condition.

The WFD requires that monitoring schemes are put in place for rivers, lakes, transitional waters, coastal waters and artificial and heavily modified surface water bodies. These monitoring schemes should be suitable for the monitoring of water status in order to establish a coherent and comprehensive overview of water status within each river basin district and to assess the impact of any programme of measures implemented within that river basin. The monitoring programme should contain a number of “Quality Elements”, which include biology, hydromorphology, specific synthetic pollutants, specific non-synthetic pollutants and physico-chemical measures.

An assessment of the current status of fresh waters is important for describing the state of the resource. The need for a state-changed approach, however, whereby the current status is compared with a baseline state in the past to successfully manage surface waters is now encompassed in the WFD. The WFD requires water quality assessments (including biological, hydromorphological and chemical elements) to be based on the degree to which present day conditions deviate from those expected in the absence of significant anthropogenic influence, termed reference conditions.

2.2 Links with other Work Packages

Under the WFD catchment management has the objective of restoring good ecological status. This means that it is important that the current ecological status and also good ecological status are well defined and that a management route (programmes of measures) from one to the other can be determined. This is essentially a technical matter and assumes that the knowledge either exists or can be developed within the timescale of the Directive for scientists and catchment managers to deliver the required outcomes. However, catchments are complicated systems in which cause and effect are not necessarily intuitive or proportionate when relating the activities of the people who live and work there to an ecological response. Each catchment is different and the water resources and economic activities within each one will also influence the measures that are necessary to reach good ecological status (see WP1 and WP3 respectively for means of characterising these resources).

One approach to determining appropriate measures is to distil scientific knowledge into a mathematical representation of the way a catchment behaves in terms of water movement and chemical fluxes (a model) and how this might impact on the ecological status (see WP4 for a full discussion of models and their use in catchment management). To use such models requires that the ecological characteristics that are deemed to represent good ecological status are consistent with the types of biological response that the models can predict.

Maps are a good way of communicating spatial data and would provide a means of showing the extent of the different types of ecological status present in all parts of a river system in a single diagram. This gives a clear indication of the extent and locations of any problems, which may allow associations to be drawn with land use or point discharges. WP7 provides a summary of the uses of Geographical Information systems which can be used to generate and display such maps.

There is a further question: What does good ecological status look like? It is possible to define the concept technically, but this may not represent the types of environment that the stakeholders with the catchment might expect or desire! For example one result of reducing the nutrient status of rivers is that high coarse fish populations maybe replaced by high-ecological-value, low density salmonid (so called game fish, such as trout and salmon) fisheries; fine for fly fishermen but not for the majority of course fishermen who populate the river banks at most weekends. To gain public acceptance of good ecological status will require engagement a very early stage (see WP8 for a fuller discussion of this process).

3. REVIEW OF CURRENT THEORY AND PRACTICE

Monitoring schemes based on the use of biological indicators of aquatic ecosystem biointegrity should in general aim to meet six criteria (Murphy et al, 2002, quoting Norris & Hawkins 2000). Effective methods will:

- quantify and simplify complex ecological phenomena;
- provide easily interpretable outputs;
- respond predictably to damage caused by humans, while being insensitive to natural spatial/ temporal variation;
- relate to an appropriate scale;
- relate to management goals;
- be scientifically defensible.

The WFD gives five biological groups which should be included within monitoring schemes for river and lakes and specifies characteristics of these groups that should be assessed (Table 1). However, the guidance[1] that accompanies the legislation does not specify any particular method of characterisation, but expects that, *"Member States should use their own discretion based on local knowledge and expertise as to what specific*

[1] Water Framework Directive Common Implementation Strategy, Working Group 2.7 – Monitoring. Guidance on Monitoring for the Water Framework Directive, Final Version, 23 January 2003

sub-element or parameter will provide the best representation of catchment pressures for each quality element."

Table 2.1 Specified characteristics of the five biological groups to be used in monitoring schemes for the Water Framework Directive.

Invertebrate Fauna	Fish	Phytobenthos	Macrophytes	Phytoplankton
Abundance	Abundance	Abundance	Abundance	Abundance
Diversity	Diversity	Diversity	Diversity	Diversity
Presence of sensitive Taxa	Presence of sensitive Taxa	Presence of sensitive Taxa	Presence of sensitive Taxa	Biomass
Composition	Life cycle/age structure			Bloom frequency/intensity

The biological monitoring scheme needs to be set up so that it can provide appropriate information for an assessment of the current state of the ecosystem but also so that the signals in the biological data can be related to specific pressures and the reduction in these pressures. The biological effects of selected pressures for rivers have been reviewed for the Rebecca Project[1] (Table 2.2).

Table 2.2 Examples of pressure affecting the biology of water bodies

Pressure effecting biology	Source of the Pressure
River morphological changes	Dams and weirs
	Weed cutting
	Abstraction and diversion
	Drainage
	Urbanization
	Forestation/deforestation
Acidification	Burning fossil fuels
	Car emissions
Organic Matter	Domestic water water
	Food processing
	Pulp and paper processing
	Discharges from agricultural production
	Fish farming
Eutrophication	Domestic Effluent
	Food production (dairy plants)
	Agricultural production (arable and livestock)

3.1.1 Examples of biological characterisation methods directed to detecting the effects of specific pressures for Rivers

Biological characterisation methods have been developed to identify the effects of each of these pressures and these are discussed in the following text.

River Morphological Changes

The Lotic Invertebrate index for Flow Evaluation index (LIFE, Extence et al., 1999) was formulated to test whether it is possible to link changes in benthic invertebrate community structure with indices of historical river flow at a gauge close to the sample site. The LIFE index can be calculated from species or family-level bio-monitoring data. Every taxon is assigned a velocity preference from I to VI (based on

[1] http://www.environment.fi/syke/rebecca

literature data), and five abundance categories are used. Implicit in the 'velocity' preference is preference or avoidance of silty substrates. A matrix is then used to give a combined score for each taxon in the sample of between 1 and 12. The scores for all taxa are added together, and the average score is the LIFE index.). LIFE is currently being used in England and Wales as part of the implementation of Catchment Abstraction Management Strategies and the Water Framework Directive (Soley et al., 2002; Dunbar et al., 2004).

The Mean flow rank index (**MFR**) is an unpublished (in refereed literature) method to relate flows to macrophyte communities developed by the Environment Agency of England and Wales, but is based on similar principles to the LIFE index (Soley et al, 2002)..

The Habitat Suitability Index (HSI) relates flows to habitat (physical variables) via a hydraulic model and habitat to ecology via habitat suitability indices. Physical HSIs allow relation of habitat preferences for a given species and life stage to hydraulic parameters such as velocity, depth and substrate. Most HSIs have been defined as univariate response functions but more complex multivariate relationships also exist (Parasiewcz & Dunbar, 2001). Habitat preferences take into account the available habitat at the time the data are collected.

The Instream Flow Incremental Methodology (IFIM) and other methodologies have been developed as a framework for river management, which are used throughout the world to identify flow regimes for ecological protection (Dunbar et al., 1998; Acreman & Dunbar, in press). Most habitat models use preference indices, which determine how suitable a given quality element (commonly hydraulic parameters: velocity, depth, substrate) is for certain species and their individual developmental / life history stages. These models then combine the results from hydraulic models with the preference indices to produce values of river area weighted by habitat quality (weighted usable area) as a function of flow for a given species and life stage. Current software include PHABSIM (Physical Habitat Simulation; Bovee, 1982; Milhous et al., 1989) and RHABSIM (River Habitat Simulation) used in the United States, RHYHABSIM (River Hydraulics and Habitat Simulation; Jowett, 1989) used in New Zealand, EVHA (Evaluation of Habitat; Pouilly et al., 1995) in France, CASIMIR in Germany (Jorde, 1997), RSS (River Simulation System; Killingtviet & Harby, 1994) in Norway and HABITAT in the Netherlands (Duel et al., 2003).

The River Invertebrate Prediction and Classification System (RIVPACS) was developed by the Centre for Ecology and Hydrology[1] in order to enable the estimation of the macroinvertebrate community to expect at high quality sites from information on their environmental and physical features. Further, by measuring these environmental features for a new site, the macroinvertebrate fauna expected to be found at the site can be predicted if it was also of high quality. The expected fauna for a site is referred to as its "biological Reference Condition" within the WFD. In order to develop a RIVPACS type model a series of high quality sites are required. These are short river stretches which are carefully selected to try to encompass the full range of running water sites within the region of interest. Care must also be taken to encompass individual reference sites at a sequence of locations from headwaters to downstream sampling sites. At each reference site, macroinvertebrates and environmental data are collected using agreed standard protocols. Each site may be sampled on a number of occasions over the year to ensure a complete picture of the macroinvertebrate fauna is acquired e.g. in the UK, reference sites were sampled in each of spring, summer and autumn. The macroinvertebrate fauna is identified to the lowest practical taxonomic level e.g. species or genus level. The environmental data collated for each site should focus on features which would be unaffected by environmental stresses. Statistical models are then developed to summarise the inter-relationships between the observed macroinvertebrate fauna of the reference sites and their environmental characteristics. If a macroinvertebrate sample is then taken at the new site using the same standardised protocols as for the reference sites, the observed fauna can be compared with the expected fauna and discrepancies between the two used to assess the biological condition or 'ecological status' for that stretch of river.

The River Habitat Survey (RHS) is a system for assessing the character and quality of rivers based on their physical structure. The survey consists of two components, namely data collected in the field and map based attributes. The field survey takes place over a 500m length of river, with spot-check data gathered at 50m intervals Data on a variety of variables are recorded, including bank and channel materials/substrates,

[1] http://www.dorset.ceh.ac.uk/River_Ecology/River_Communities/Rivpacs_2003/rivpacs_introduction.htm

modifications, natural features, channel vegetation, surrounding land use, channel dimensions and artificial features. The map-based attributes include altitude, slope, distance from source, and underlying geology. One of the main outputs of RHS is the development of indices that express the habitat quality and the degree of modification of a site. These are scores based systems based on the extent and variety of natural features (Habitat Quality Assessment) and the type and extent of artificial features (Habitat Modification Score). RHS is now a standard method and is widely used for the description and assessment of the physical character and habitat quality of rivers. RHS is frequently used as part of Local Environment Agency Plans and Environmental Impact Assessments.

Acidification

The Biotic index of acidification (BIA) has been proposed as a useful tool to access acidification on the Vosges Mountains in France (Guerold et al., 1997, 1999). The method uses a multimetric approach applying data on both taxa richness as well as the macroinvertebrate tolerance to acid water. The index has 10 classes that vary from 0 (unaffected) to 9 (strongly acidified). The index has shown to have a highly significant relation to the mean pH and ANC of the stream water.

The Medins acidification index has been developed for Sweden and is based on a substantial set of macroinvertebrate data from that country (Henrikson & Medin 1986). The tolerance list is mainly based on macroinvertebrate data from humus rich rivers in Sweden. The index is a multimetric one using more than one criterion to make a total assessment of the final acidification status. Besides the presence /absence evaluation of indicator taxa, it also uses the relation between numbers of individuals of the species richness in the assessment . The outcome of this index is put in one of five classes.

The Raddums index is based on a set of data primarily from clear water rivers with low conductivity in the southern and western Norway. From these, an acidification tolerance list has been produced. Each taxon is given a score corresponding to a pH interval and to an acidification class in the index system (Raddum & Fjellheim 1984, Lien et al 1996). This index has four classes. In addition there is an option to make an assessment within the intolerant class (Raddum index 2) based on the relation between the number of individuals of the mayfly genus *Baetis* and the total number of tolerant stonefly individuals. The Raddum index has been used also on a European scale in e.g. the ICP-Water monitoring programme (Raddum 1999, Raddum & Skjelkvåle 1995).

The **AWIC (Acid Waters Indicator Community)** scoring system is a new acidification metric based on scoring systems at family (or species) level. The AWIC model allocates scores to the invertebrate families found in streams, based on their known acidity tolerance. The scores are then used to calculate the AWIC index that shows the biological impact of the stream's acidity. The system was developed for the Environment Agency as a tool for evaluating the acidity of watercourses (Davy-Bowker *et al.*, 2003). AWIC will be included in the next version of RIVPACS.

Organic Matter

The Saprobic Index focuses on organic pollution and the associated decrease in dissolved oxygen and was first developed by Kolkwitz & Marsson (1908) and subsequently changed and improved (Rolauffs et al., 2003). According to the Saprobic System, waterbodies are characterised by the degree of heterotrophy (ratio between heterotrophic and autotrophic processes). A determination of the saprobic value is based on the sampling and the identification of species of fauna and flora and a comparison with the Saprobic characteristics established for each species (see Sládecek, 1973). No single species is representative of a single saprobic zone.

The Biological Monitoring Working Party (BMWP) protocol is the principal system used in the UK (Armitage et al., 1983). The method involves taking a "kick" sample from the stream bed and the macroinvertebrates captured are identified and listed, each one having a score according to its perceived tolerance to pollution; no account is taken of abundance. The scores for each family identified are totalled to give the BMWP score. This figure is then divided by the number of taxa, to give the **Average Score Per Taxon (ASPT)**. The ASPT is independent of sample size and it provides an additional more consistent index. It should be noted that within environmental protection agencies in the UK, it is usual to carry out BMWP assessments within the RIVPACS protocol (see above).

The EPT index is based on the abundance of macroinvertebrates belonging to the orders *Ephemeroptera*, *Plecoptera*, and *Trichoptera*. Since these orders of macroinvertebrates are highly sensitive to pollution, they are often used as water quality indicators. Their presence indicates a high quality of water, while their absence suggests water may be polluted. The EPT Index is calculated as the sum of the number of *Ephemeroptera*, *Plecoptera*, and *Trichoptera* divided by the total number of midges. Midges (*Diptera*: *Chironomidae*), a species of fly that is present in large numbers in nearly all streams.

Eutrophication

The Mean Trophic Rank has been developed for England and Wales to implement the EC Urban Waste Water Directive: it is used to assess the impact of point sources on the river (Kelly, 1998). It is based on the combination of species at a site and, for each species, its indicator value and its abundance (Holmes et al., 1998, Holmes et al., 1999). 128 species have been identified for this index. They can be split in 4 broad groups and in 10 River Community Types (Holmes et al., 1998). These River Community Types are physically described and the mean MTR value for each of these groups can be used as a reference for physically similar sites. The lower the MTR score the more the site is impacted by eutrophication.

The Trophic Index of Macrophytes (Trophie-Index Macrophyten, TIM) has been developed for Bavaria (Germany) to indicate the trophic state of rivers. It is based on a trophic value (determined with Soluble Reactive Phosphorus in the water column and phosphorus in sediments) and a sensitivity index and number of sites where the species occur (Schneider et al., 2003). This index can take values between 1 (oligotrophic) and 4 (Polytrophic).

The Trophic Diatom Index (TDI) has been used as the basis for a eutrophication classification of rivers for the UK (Kelly, 1998). The TDI values range from 0 (indicating very low nutrient concentrations) to 100 (indicating very high nutrient concentrations). It is combined with an indicator of pollution tolerant to estimate the relative influence of organic pollution to eutrophication.

$$TDI = 25 \times \left(\frac{\sum a_j . s_j . v_j}{\sum a_j . v_j} - 1\right)$$

Where:

a_j the abundance of species *j*
s_j the pollution sensitivity of the species *j* (1-5)
v_j the indicator value of the species *j* (1-3)

3.1.2 Characterisation of Lakes

A classification system for Scottish Lakes

In order to develop an ecologically based characterisation of lakes for Scotland, SNIFFER (Scotland and Northern Ireland Forum for Environmental Research) and the Environment Agency of England and Wales, commissioned a review of the systems that were in routine use both within the EU and internationally (Murphy et al, 2002). The report contains a list of schemes (50 in total) used for bio-monitoring that utilise one or more of the target groups (macroinvertebrates, macrophytes and phytoplankton) specified by the EA/SNIFFER. The report recommended three assessment protocols that were currently in use or close to final development that could be adapted to the needs of the WFD and its application in the UK (see Table 2.3 for further details). There were:

- the USEPA Bioassessment Protocols (LRBB) for lakes and reservoirs;
- the Swedish Environmental Quality Criteria (SEQC) scheme for freshwater assessment
- the UK-led European shallow lake assessment scheme currently under development (ECOFRAME);

Table 2.3 Summary of the three schemes judged most appropriate for ecological classification of lakes in Scotland by Murphy et al, 2002.

Name	LRBB	SEQC	ECOFRAM
Water Body	Lakes and reservoirs	Lakes and rivers	Lakes (<3 m deep)
Organisms used	Macrophytes/ phytoplankton/ benthic macroinvertebrates/ zooplankton/ fish	Phytoplankton/ macrophytes/ periphyton/ benthic macroinvertbrates	Phytoplankton/ zooplankton/ macrophytes/ fish/ macroinvertbrates
Brief Description	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 bioassessment and biocriteria programs	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.	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.
Utility	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. It appears to be well tested and uses robust analyses	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	This scheme has been built around the requirements of the WFD and sampling protocols are relatively routine, but at present the scheme is still under development. Only shallow water lakes are considered, and development has not used the minimum lake size required by SEPA/EA. The authors consider that minor adjustments may allow the scheme to be used in deeper lakes.
Reference	USEPA.,1998 http://www.epa.gov/owow/monitoring/tech/lakes.html	Swedish Environmental Protection Agency, 2000.	

3.1.3 Methods and protocols developed for the Water Framework Directive

Rivers

AQEM

The European Union Framework 5 project[1] AQEM has produced a software system that enables water managers in European countries to assess the Ecological Quality of streams with benthic macroinvertebrates using a system which fulfils the demands of the Water Framework Directive. Presently AQEM covers 28 European stream types, future updates will further extend its applicability.

Aims of the AQEM system are:

[1] 5th Framework Programme Energy, Environment and Sustain-able Development; Key Action 1: Sustainable Management and Quality of Water - Contract No: EVK1-CT1999-00027 (www.aquem.de)

- to classify a stream reach into an Ecological Quality Class from 5 (high) to 1 (bad) based on a macroinvertebrate taxa list, which has been obtained using a harmonised sampling method

- to give information about the cause of a possible degradation to help direct future management practices.

In order to apply the method, managers need access to the software and user manual, both of which can be downloaded from the AQEM website. The methods coded into the software can be used with both newly collected data and historical data. In both cases the method provides check lists to ensure that the data collected are sufficient and of good enough quality to be used within the AQEM system. Further development of this method is taking place under a follow-up EU funded project – STAR (see below).

STAR

Standardisation of River Classifications (STAR): This EU funded project[1] aims to produce a framework method for calibrating different biological survey results against ecological quality classifications for the Water Framework Directive. The variety of assessment methods for streams and rivers in Europe provides good opportunities for implementing the Water Framework Directive but their diversity may also result in serious strategic problems. The number of organism groups that will be used to assess Ecological Status, and the number of methods available for doing so are so diverse that inter-calibration and standardisation of methods is crucial. Similarly, protocols need to be devised to integrate the information gathered on the different taxonomic groups. The project aims to derive a detailed picture of which methods are best suited for which circumstances as a basis for standardisation. The project also proposes to develop a standard for determining class boundaries of Ecological Status and another for inter-calibrating existing methods.

One of the work package outputs was to compile an overview of data on reference conditions and existing assessment methods using benthic invertebrates, fish, phytobenthos, macrophytes and river habitat surveys, national standards on sampling, analysis and quality evaluation, related national projects and existing databases. This information has been collated into a data base ("waterview"), which contains a comprehensive compilation of assessment methods for rivers and streams in Europe using the 'biotic elements' macroinvertebrates, macrophytes and phytobenthos.

FAME

The FAME project (the development of a Fish-based Assessment Method for the Ecological status of European rivers – a tool to support the implementation of the European Water Framework Directive[2]) has developed the European Fish Index (EFI). The principle of the site-specific European Fish Index is to measure, for any observed site, the deviation of observed metrics from predicted reference metrics, and then to compute the probability that the site represents reference conditions. Based on the degree of deviation, the final ecological status class is identified within a 5-tiered assessment scheme. The European Fish Index is independent from the environmental conditions of any independent site. The EFI also shows a strong response to chemical (nutrients/organic input, toxic substances/acidification) pressures as well as a weaker but significant response for sites only exposed to physical pressures (hydrology, morphology). A user-friendly PC-software was developed to implement the European Fish Index and the European Fish Types in routine monitoring. It performs all calculations necessary for the European Fish Index, such as (1) observed metrics, (2) theoretical (reference) metrics, (3) probability metrics, (4) the final index, and (5) the ecological status class. Input data are the13 abiotic, location and sampling variables as the basis for calculating the reference metrics, and the number of fish caught. The corresponding European Fish Type is also identified in an automated routine. The FAME system is designed to be used for both rivers and lakes.

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[1] Fifth Framework Programme, Key Action 1:Sustainable Management and Quality of Water - Contract No: EVK1-CT 2001-00089 (http://www.eu-star.at/frameset.htm)

[2] Supported by the European Commission under FP 5, EESD – Sustainable Management and Quality of Water; Contract EVK1-CT-2001-00094 (http://fame.boku.ac.at).

Lakes

In order to meet the requirements of the WFD, the EA and SEPA have commissioned various scoping studies in recent years to review ecological assessment schemes for lakes. In one such study, Carvalho et al. (2002a) reviewed the literature to identify the physico-chemical conditions associated with high and good ecological status classes in UK lakes and rivers for the following parameters: acidity, transparency, oxygen and temperature. These parameters were considered in relation to the biological quality elements: phytoplankton, phytobenthos, macrophytes, benthic invertebrates and fish. Nutrient conditions were considered in a separate review (Carvalho *et al.* 2002b). The reviews focussed on (a) approaches to establishing the relationship between the physico-chemical conditions and biological quality using field and laboratory studies, and (b) procedures and methods for establishing reference levels of these physico-chemical conditions.The reviews highlight the lack of well developed methodologies for establishing reference conditions for oxygen, temperature and transparency, with acidity and nutrients being the only supporting physico-chemical elements which have a number of well established approaches for assessing background levels for lakes.

The most established biological indicator schemes for nutrient conditions are those developed for chlorophyll *a*, diatoms and macrophytes (see Carvalho et al., 2002b for details). All have established significant relationships with nutrient conditions but require further development in terms of the WFD and standardised methodologies. There is also a need to develop measures for phytoplankton (specifically bloom-forming species) and value in developing indicators from invertebrate (particularly chironomids) and fish communities to provide a more holistic ecosystem response to nutrient conditions over a range of spatial and temporal scales. In a second phase of the work to review nutrient impacts on freshwater ecosystems, Carvalho et al. (2003) summarised methodologies required for carrying out a risk assessment for lakes, specifically in relation to nutrient pressures. The study provides a number of approaches of increasing sophistication for assessing the magnitude of diffuse and point-source nutrient pressures and develops a nutrient classification for different lake types that can be applied to assess the impact of these pressures. Approaches to ecological classification for phytoplankton composition and abundance in lakes and slow-moving rivers are also outlined, as phytoplankton is considered the biological quality element most sensitive to nutrient pressures.

The reviews cited above showed that whilst a number of systems existed for ecological characterisation of lakes, none were suitable for WFD purposes in their current form. Therefore, over the last few years, a number of new projects have been funded to develop ecological classification tools specifically for the WFD. For UK lakes, schemes for phytoplankton, phytobenthos, aquatic macrophytes, invertebrates and fish are currently in development. In order to support these projects, lake monitoring programmes have been established to collect the necessary biological and associated environmental data from a network of over 200 lakes covering a range of types across the UK. At this time the projects are in a major data colle ction and analysis phase and are aiming for completion in 2006.

The Chironomid (non-biting midge) pupal exuvaie (skins) survey method (Ruse, 2002) is being is being developed as a classification scheme by The Environment Agency of England and Wales for potential use in implementing the WFD. It involves netting floating debris from the leeward shores of lakes and then filtering out the exuvaie, which have been shed on the surface during adult emergence, and using these to identify the chironomid species present within the lake. This method has been shown to sample both deep and shallow dwelling species while requiring little effort or expensive sampling equipment. The abundance and composition of the chironomid species has been shown to be correlated with alkalinity and with mean trophic rank.

3.2 Using biology to reconstruct past water quality conditions and reference conditions

3.2.1 The role of palaeoecology in ecological characterisation and the assessment of impacts

The WFD states that, in the absence of long-term data, reference conditions based on modelling may be derived using hindcasting methods, and palaeolimnology (the study of the lake sediment record) is given as one such technique (Pollard & Huxham, 1998). The sediment accumulated in a water body can provide a good historical record of its past floral, faunal and chemical changes (e.g. Smol, 1992). Interpretation of these sediments allows scientists to quantify and evaluate environmental change, assess its causes, and determine baseline or reference values for ecosystem status that can guide the setting of restoration targets (Battarbee, 1999). The techniques are valuable, therefore, in ecological characterisation of catchments and assessment of impacts from, for example, agriculture and other land uses, air pollution and climate change.

Diatoms (*Bacillariophyceae*: unicellular, siliceous algae) are the most commonly used biological indicators in palaeolimnological studies. Their glass (silica) cell walls are generally well preserved in most lake sediments, they are very sensitive to changes in water quality and are, therefore, good indicators of past lake conditions such as lake pH (Battarbee *et al.*, 1999; 2001a) and total phosphorus (TP) concentrations (Hall & Smol, 1999). Of the biological elements relevant to the WFD, diatoms represent components of both the phytoplankton and phytobenthos, but importantly shifts in the diatom community often correspond closely to changes in other biological groups (e.g. Kingston *et al.*, 1992). The diatom record is a potentially useful tool, therefore, for assessing water quality and defining ecological reference conditions (e.g. Kauppila *et al.*, 2002; Bennion *et al.*, 2004).

In recent years, transfer functions have been developed to model the relationship between diatom assemblage composition and water chemistry in a training set of lakes. Once calibrated, such models are then applied to fossil diatom assemblages in sediment cores to infer past water chemistry. Weighted averaging (WA) regression and calibration (ter Braak & van Dam, 1989) and its extension WA partial least squares (WA-PLS) (ter Braak & Juggins, 1993) are the most widely used techniques for reconstructing past environmental variables in this way (Birks, 1998). A large European diatom database for palaeolimnological reconstruction has been developed as part of an EU funded project, EDDI (Battarbee *et al.*, 2001b), enabling the generation of tailor-made transfer functions for the reconstruction of environmental conditions at individual sites. This approach can provide not only estimates of baseline (reference) conditions in lakes but also the timing, rates and possible causes of change at a particular site if the sediment cores are dated. For this reason, it has become a standard tool in lake management for setting chemical targets for restoration (e.g. Battarbee, 1999). There are a range of potential error sources in transfer functions including poor estimates of species optima for some taxa, inherent bias in some of the statistical techniques, sediment sampling and representativity problems, differential diatom dissolution, and natural high variability in TP concentrations. Nevertheless, comparisons of diatom TP reconstructions with long-term monitoring data have shown that the models can reliably track changes in trophic status (e.g. Bennion *et al.* 1995, Rippey *et al.* 1997, Bennion *et al.* 2000).

There are a number of other biological groups that preserve in the lake sediments, representing a range of biological elements relevant to the WFD. Chironomids (Diptera) are non-biting midges whose larval head capsules are preserved in lake sediments and they are good indicators of oxygen and nutrient conditions. Chironomid transfer functions have recently been developed for inferring past lake oxygen conditions (e.g. Little *et al.*, 2000; Ruiz *et al.* 2001) and TP concentrations (Lotter *et al.*, 1998; Brooks *et al.*, 2001). Cladocera are microscopic crustaceans (zooplankton) that are represented in the sediments by a variety of body parts. They are good indicators of temperature, pH and alkalinity, and can also be used to reconstruct ecological structure because their composition and abundance are influenced by macrophytes and fish (Jeppesen *et al.*, 1996). Aquatic pollen and plant macrofossil remains are commonly found in sediments and can be used to assess vegetation change (Birks, 2001). The analysis of this broader range of fossil remains is particularly valuable for ecological characterisation of small, shallow waterbodies where, in addition to nutrient effects, top down factors such as predation influence the ecological structure and functioning of the system. Such complexities reduce the ability of hydrochemical transfer functions to reconstruct the nutrient history of these waters (Bennion *et al.*, 2001a; Sayer, 2001).

Another method that can be used for ecological characterisation is analogue matching which is a form of space-for-time substitution modelling. It is a statistical technique that compares degree of floristic or faunistic similarity between a fossil sample (in a sediment core) taken from an impacted lake and a range of modern (surface sediment) samples. The best modern analogues for the pre-disturbance assemblages are identified. These analogue lakes are then assumed to have similar community composition to those present in the pre-disturbance period of the impacted lake in biological groups other than those analysed in the palaeo-record (e.g. fish, benthic macroinvertebrates). The technique has been developed for identifying restoration targets for acidified lakes based on diatom analogues (Flower *et al.*, 1997) and more recently based on both diatoms and cladocera in 83 upland surface waters in the UK (Simpson, 2001). The technique is proving a powerful one for identifying site specific ecological reference conditions in these waters but requires further development to be applicable to a wider range of UK lake types. In order to establish pre-disturbance communities in enriched lakes, the analogue matching approach must be extended to lowland waters spanning the full trophic gradient from oligotrophic to hypertrophic conditions. Bennion (2004) generated a 30 lake training set of diatom and cladocera data for demonstrating the application of the analogue matching technique to nutrient stressed systems. The study showed that the technique has potential for identifying appropriate reference sites to formulate restoration targets for lakes impacted by eutrophication. The methods will be further developed and tested in a recently initiated EU funded integrated project, Euro-limpacs[1] .

3.2.2 Case studies

The use of palaeoecological techniques for establishing reference conditions for lakes is well established with many examples of their application to aquatic management and conservation (e.g. Battarbee, 1999, Stoermer & Smol, 1999). However, such investigations have tended to focus on detailed studies of a limited number of sites (e.g. Sayer *et al.* 1999, Bennion *et al.* 2000, 2004). A different approach has been taken in recent years whereby palaeoecological techniques have been adapted to enable the study of large numbers of lakes and thus to aid implementation of legislation and management of water resources at the national level. Two examples follow:

Palaeolimnological techniques have played an important role in establishing nutrient reference conditions and characterising ecological conditions of lakes in the United States. In 1989, the United States Environmental Protection Agency (USEPA) began the Environmental Monitoring and Assessment Program for Surface Waters (EMAP-SW). This aimed to:

- Catalogue the present geographical distribution and current ecological conditions of the nation's lakes and rivers,
- Determine the proportion of sites that are degrading or recovering,
- Determine where, and at what rates, these changes are occurring
- Identify the likely causes of these changes (Larsen *et al.*, 1991; Dixit *et al.*, 1999).

The objectives of EMAP-SW have many parallels with those of the WFD. A 'top and bottom' sediment sampling approach involving the analysis of only two samples per site from a single sediment core was adopted as it can be applied easily to a large number of lakes (Cumming *et al.*, 1992; USEPA, 1998). Biological assemblages in the top (0-1 cm) sediment sample are taken to represent present-day conditions, while those of the bottom sample (from > 30 cm deep in the core) are generally taken to represent pre-disturbance conditions. The latter can be analysed for ^{210}Pb activity to confirm the chronology. Hydrochemical transfer functions were then applied to infer the lake water parameters of interest, with the bottom samples identifying the reference conditions. EMAP employed a probability-based sampling design that would allow lake-specific data to be scaled up to the entire population of lakes in a country or geographical region. 'Top and bottom' diatom data were generated from 257 lakes distributed across three broad eco-regions of northeastern USA and representative of the target population of over 10,000 lakes. Diatom inference models were successfully applied to reconstruct lake pH, TP and chloride concentrations and the study demonstrated that a sample of a few hundred sites is sufficient to infer current and past conditions of thousands of lakes (Dixit *et al.*, 1999).

As part of the UK strategy for the implementation of the WFD, the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER) funded project '*Identification of reference lakes and evaluation of palaeoecological approaches to define reference conditions for UK (England, Wales, Scotland & Northern Ireland) ecotypes*' has recently been completed (Bennion, 2004). This study employed palaeoecological techniques to identify reference lakes, describe reference conditions and assess ecological status for a set of UK lakes. The project builds on ideas derived from the existing body of work on the palaeolimnology of UK lakes including the SNIFFER funded *Palaeolimnological Investigation of Scottish Freshwater Lochs* (SR(00)02 F) (Bennion *et al.*, 2001b). The project involved the collation of existing data from large numbers of lakes in the UK and analysis of new sediment cores from lakes thought to be relatively unimpacted. A top and bottom approach was taken whereby diatoms were analysed in the bottoms (reference condition) and the

[1] http://www.eurolimpacs.ucl.ac.uk

surface samples (present day conditions) of sediment cores from 219 lakes covering the range of types found in the ecoregion. Two Way Indicator Species Analysis (TWINSPAN) was employed to classify the reference samples according to their diatom assemblages, and thereby characterise the reference floras of the different lake types. The diatom groups were compared with the GB Lake Typology (see WP1) to assess the ecological relevance of the typology scheme. The degree of floristic change between the reference and surface sample of each core was assessed in order to assist in determination of ecological status. More detailed, higher resolution analysis was carried out at selected sites.

3.2.3 Summary

In summary, sediment records allow timescales to be extended beyond those of most long-term datasets and, importantly, provide temporally integrated datasets that are more suitable than shorter instrumental data-sets for the detection of cyclic, aperiodic and irreversible phenomena that contribute to ecosystem variability. A long time perspective is of value to catchment management in a number of ways:

- To define reference conditions that can be used for restoration target setting.
- To identify specific chemical and biological responses to management (e.g. nutrient reduction).
- To identify inter-annual and decadal scale processes, natural or anthropogenic, that confound expected recovery trajectories.
- To provide information on the full range of natural variability that is critical for planning, management and numerical modelling .
- To determine the timing and the progressive impact of human activity.
- To evaluate the rate of ecosystem state change and can help to identify the mechanisms responsible for change.

In the context of ecological characterisation, assessment of impacts and management of rural catchments, palaeolimnological approaches can be employed to:

- Establish the link between *pressures* such as increased nutrient and sediment loads and their *impacts* in aquatic systems over timescales of years, decades, and centuries.
- Assess ecological *reference conditions*, past nutrient concentrations and sediment accumulation rates in a range of catchment-landscape types based on existing datasets for UK lakes, and use the outputs to define achievable management targets.
- Assess *rates of change* in sediment and phosphorus loading (link to other modelling techniques such as export-coefficient models and compare with instrumental / documentary records where available) in a range of catchment-landscape types.
- Look ahead and feed into catchment management plans for the next few decades and beyond (under various land use, pollution, climate change scenarios) using the information on land use history and ecosystem change over the last ~100 years.
- Determine role of *natural versus anthropogenic* processes.
- Assess impacts at a spatial scale by applying techniques to a range of sites at various locations within selected river basins. Suitable lakes are likely to be located in most river catchments.

3.3 Gaps/problems

There are a whole range of specific gaps in our knowledge that relate to individual methods of characterising water bodies through measures of ecology (e.g. phytoplankton, phytobethos, macrophytes). These would be too numerous to list here and so an attempt has been made to select the generic issues that recur when considering characterisation methods.

3.3.1 Quantitative assessments of responses to changes in pressures

There are a number of metrics, some of which have been described above, that can be related to particular pressures but only in an essentially qualitative way. Thus, for example, the degree of eutrophication of a river or lake can be assessed through determining the mean trophic rank from the macrophyte abundance and composition. However, it is not possible at the present time to determine how the current state would respond to a change in the phosphorus or nitrate loading. In particular there is a lack of data on recovery from pressures. The new state that a river or lake will achieve if a pressure is removed cannot be predicted, although such information is essential if an effective programme of measures is to be put in place to alleviate a pressure.

3.3.2 Characterising the effects of multiple pressures

Despite the linkage between bioassessment and water quality, there are surprisingly few examples of bioassessment used explicitly to support the development of numerical water-quality criteria. One of the primary reasons for this is that traditional bioassessments are intentionally developed to capture the effect of a wide range of stressors on biological integrity. This lack of specificity results in ambiguity about the potential cause of impairment and, consequently, the levels of a stressor that may result in a threshold response.

3.3.3 Accounting for seasonal changes

All aspects of ecology change seasonally as the ecosystems respond to different levels of light, heat and changing flow regimes and chemical concentrations. The question here is how to incorporate this variability into a characterisation that needs to be compared with a single reference condition? Some methods (e.g. RIVPACS) seek to get around this problem by taking samples at different times of year and pooling the results, but there is still a need for more generic methods. Furthermore, where the output of the characterisation method is to put a water body into a class within a classification scheme, there is the need to consider the confidence in that classification given the uncertainties within the sampling and processing methods employed.

3.3.4 Hydromorpholgy

In contrast to say organic pollution of rivers, or eutrophication of lakes, there are currently very few biological indicators that are sensitive to hydromorphology. This is, in part, due to the difficulties in assembling the required datasets to develop and test the indices.

3.3.5 Natural variations in communities versus those arising from external pressures

As stated above, the scientific knowledge about quantitative relationships between biotic indices and the concentrations and/or qualities of organic matter should be improved. It is not possible at present to establish dose-response relationships between particular pressures and the biota. These relationships are likely to change with ecoregions and to be affected by the other possible pressures affecting freshwater ecosystems. Therefore, there is a need to better distinguish the variations in communities caused by natural fluctuations (ecoregional factors) from those caused by pressures.

3.3.6 Classification methods applicable to River and Lakes

Although, here are many ecological assessment methods that are used on lakes or rivers that use members of different phyla, there are no good, standardized methods which use a classification method based on members of a single phylum.

3.3.7 Linking catchment water quality models and ecology

A number of water quality models exist for rivers and lakes and some of these models include a biological response (mainly in lakes), however, biology modelled is usually very limited and is not necessarily compatible with the methods used to characterise good ecological status.

3.3.8 Public participation in Ecological classification

The concept of good ecological status is very much defined technically by natural scientists by reference to the study of pristine or low impacted sites. There has been very little scope for public participation in this process. Equally there has been little effort made to develop methods of characterisation that could be amenable to public participation. There is certainly scope for some interdisciplinary thinking about how stakeholders can be involved in the characterisation process.

4. FUTURE RESEARCH

4.1. Research questions in biological characterisation

4.1.1 Monitoring

There is a clear need for continued monitoring of lakes using standard methodologies. For some key parameters, data are extremely limited and this prevents robust ecological characterisation at present. For instance, transparency or turbidity are not regularly monitored in UK lakes, and thus further work is necessary to establish reference conditions for transparency in relation to biological quality, particularly submerged macrophytes. Lake invertebrate classification schemes, similar to RIVPACS, have the potential to be developed for WFD purposes, but lake data are relatively scarce for calibrating such schemes. Continuous oxygen monitoring in a number of lake sites should be considered in order to provide empirical data on minimum oxygen conditions. Monitoring is required not only to gather sufficient data for ecological classification and characterisation but in order to assess degree of recovery and sustainability of any management measures that are implemented.

4.1.2 Integrated ecological classification

A number of ecological classification tools, each concentrating on a single biological element, are currently in development. Future research will be needed to produce a method for integrated ecological classification based on the combined results from each of these tools. The final tool will be expected to produce an overall assessment of ecological status for a given site.

4.1.3 Impacts of climate change on management targets

Further research is required to assess the impacts of future climate change on aquatic ecosystems. For instance will changes in climate exacerbate catchment based pressures such as eutrophication? An EU funded Sixth Framework Programme, *Integrated Project to Evaluate the Impacts of Global Change on European Freshwater Ecosystems (Euro-limpacs)* (2004-2008), aims to address such issues.

4.1.4 What are we aiming to conserve/restore?

Given that catchments in the 21st century are under very different land use and management regimes than they were in the past, it may not be feasible to restore impacted systems to their former state. Further work is needed on achievable restoration and on setting feasible targets for management. For instance, we may not be able to restore former biological structure but we can aim for something less perfectionist such as healthy ecosystem functioning.

4.2. Cross-cutting research questions

4.2.1 What are we aiming to conserve/restore – Stakeholder input

The same research need as indicated above in 4.1.4 but with particular reference to how to include stakeholder opinion in what the river or lake eco-system should look like.

4.2.2 The value of ecological states

This research need is liked to 4.2.1 and centres on the need to include some assessment of the values (economic/social) of the ecological status that currently exists or might exist under various management scenarios. Although the WFD requires that good ecological status is a requirement in time, the costs to achieve this could be incommensurate with the added value of this ecological state over the present one or intermediate states that could be more readily achieved.

5. CONCLUSIONS

Ecological classification methods have been widely used for many decades within catchment management as a means of following the evolution of the quality of rivers and lakes.

- There is a wide diversity of methods that can be used to detect the effect of different pressures (changing flow regimes, organic mater pollution) on ecological status.
- Different methods of assessment have been developed for rivers and lakes.
- The Water framework directive has put ecological status at the centre of catchment management and requires that methods of ecological survey are sufficient to demonstrate good ecological status and that programmes of measures to achieve this are sufficient.
- Reconstruction of past biologies through the study of the flora and fauna of lake sediments demonstrates one approach to determining reference conditions for good ecological status.
- Most classification methods developed to date are specific to either rivers or lakes and it is desirable to develop methods applicable to both.
- Although the ecological response of certain species to particular pressures is known, it is not clear how the ecosystem as a whole will respond to a change in that pressure or whether changes in ecological state are reversible in a predictable way.
- None of the ecological classification methods described in this report is designed to allow publis participation in their calculation or interpretation.
- Given that catchments in the 21st century are under very different pressures thatn in the past, it may not be feasible to restore impacted systems to their former state. In which case, we might need to aim for healthy ecosystem functioning.

6. GLOSSARY OF TERMS

Aerobic respiration - respiration that requires oxygen
Algae - microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. They are food for fish and small aquatic animals. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. Their biological activities appreciably affect the pH and dissolved oxygen of the water.
Algal bloom - sudden, massive growths of microscopic and macroscopic plant life, algae, and cyanobacteria, which develop in lakes, reservoirs, and marine waters
Anaerobic respiration - respiration that occurs in the absence of oxygen
Autotroph - an organism that can produce its own food from inorganic molecules and sunlight. All photosynthetic plants are autotrophs.
Bacteria - single-celled micro-organisms, some of which are pathogenic in humans, animals and plants. Singular is bacterium
Benthic - Of or pertaining to a benthon**.**
Benthon - The aggregate of organisms that live on or in the benthos.
Benthos - The biogeographic region that includes the bottom of a lake, sea, or ocean, and the littoral and supralittoral zones of the shore.
Biomass - The amount of living matter in a given habitat, expressed either as the weight of organisms per unit area or as the volume of organisms per unit volume of habitat.
Biota - The animals, plants, fungi, etc., of a region or period.
Chlorophyll - the green chemical inside the chloroplasts of plant cells. It enables photosynthesis to take place.
Community - An integrated group of species inhabiting a given area; the organisms within a community influence one another's distribution, abundance, and evolution.
Conservation - The management of human use of the biosphere so that it may yield the greatest sustainable benefit to current generations while maintaining its potential to meet the needs and aspirations of future generations: Thus conservation is positive, embracing preservation, maintenance, sustainable utilization, restoration, *and* enhancement of the natural environment.

Diatom - unicellular algae capable of photosynthesis and characterized by producing a thin outer shell made of silica (glass)
Dominant - Any of one or more types of plants, or sometimes animals, that by virtue of abundance, size, or habits exert so important an influence on the conditions of an area as to determine, to a great extent, what other organisms can live there.
Ecosystem - A system formed by the interaction of a community of organisms with their environment.
Ecotone - the transition zone between two different plant communities, as that between forest and prairie.
Eukaryotic cell - A cell containing a membrane bound nucleus and organelles.
Eutrophication – the process by which an excess of nutrients stimulates the growth of plants, depleting the water of oxygen.
Evaporation - the process in which a liquid turns into a gas
Fauna - All of the animals found in a given area.
Flora - All of the plants found in a given area.
Food chain - A series of organisms interrelated in their feeding habits, the smallest being fed upon by a larger one, which in turn feeds a still larger one, etc.
Habitat - The environment in which an organism lives. Habitat can also refer to the organisms and physical environment in a particular place.
Heterotroph - an organism requiring organic compounds for its principal source of food..
Heterotrophic - Capable of utilizing only organic materials as a source of food.
Indicator - A plant or animal that indicates, by its presence in a given area, the existence of certain environmental conditions.
Larvae - Refers to the juvenile stage of most invertebrates, amphibians, and fish, which all hatch from eggs. It is unlike the adult in form and is usually incapable of sexual reproduction. It develops into the adult by undergoing metamorphosis. Examples are the tadpoles of frogs, caterpillars of butterflies, or larvae to hornets
Membrane - A flexible layer surrounding a cell, organelle (such as the nucleus), or other bodily structure. The movement of molecules across a membrane is strictly regulated in both directions.
Niche - The position or function of an organism in a community of plants and animals.
Oligotrophic – Water body characterized by a low accumulation of dissolved nutrient salts, supporting but a sparse growth of algae and other organisms, and having a high oxygen content owing to the low organic content.
Organelle - a subcellular structure having a specialized function.
Paleolimnology - the study of ancient lakes from their sediments and fossils.
Phylum - In taxonomy, a high-level category just beneath the kingdom and above the class; a group of related, similar classes.
Pollutant - any substance, as certain chemicals or waste products, that renders the air, soil, water, or other natural resource harmful or unsuitable for a specific purpose.
Polytrophic - deriving nourishment from many organic substances.
Population - A group of individuals with common ancestry that are much more likely to mate with one another than with individuals from another such group
Respiration - chemical change that takes place inside living cells, which uses glucose and oxygen to produce the energy organisms need to live. Carbon dioxide is a by-product of respiration
Species - A group of organisms capable of interbreeding freely with each other but not with members of other species.
Species diversity - A function of the distribution and abundance of species. Approximately synonymous with species richness. In more technical literature, includes considerations of the evenness of species abundances. An ecosystem is said to be more diverse, according to the more technical definition, if species present have equal population sizes and less diverse if many species are rare and some are very common.
Species richness - The number of species within a region. A term commonly used as a measure of species diversity, but technically only one aspect of diversity
Supralittoral - Of or pertaining to the biogeographic region of a shore of a lake, sea, or ocean permanently above water but made damp by spray from waves or by capillarity of the substrate..
Taxon (pl. taxa) - The named classification unit (e.g. Homo sapiens, Hominidae, or Mammalia) to which individuals, or sets of species, are assigned. Higher taxa are those above the species level.
Taxonomy - The naming and assignment of organisms to taxa**.**
Trophic level - Position in the food chain, determined by the number of energy-transfer steps to that level.

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