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Integrated classification and assessment of lakes in Wales: Phase 1

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Final Report to the CCW under Contract No: FC 73-01-71

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Executive Summary

1. This is the final report to the Countryside Council for Wales under contract FC 73-01-71: 'Integrated Classification and Assessment of Lakes: Phase 1'.

2. Data is presented from the first phase of the study. The lakes assessed are Llynnau Coron, Penrhyn and Dinam on Anglesey and Llynnau Idwal and Cwellyn in Snowdonia.

3. A brief literature review on lake classification is presented, emphasising schemes designed for nature conservation.

4. The data collected from the study sites include some physical data derived from secondary sources. However, the focus of the programme has been the development of a survey methodology for collecting field data suitable for an integrated lake classification scheme.

5. The field survey and analytical methodology adopted incorporates the characterisation of lake-water chemistry and the following biological groups: epilithic diatoms, surface sediment diatom assemblages, aquatic macrophytes, littoral zooplankton, open water zooplankton and littoral macroinvertebrates.

6. All data collected from the study sites are stored in a relational database at the Environmental Change Research Centre. The database allows flexible data retrieval, suitable both for this research programme and for other potential uses and users.

7. A critique of the survey methodologies is presented on the basis of the first phase of the study. Although the current protocols provide an effective basis for lake classification and assessment, some changes should be made for future surveys. In particular it is recommended that macroinvertebrates are sampled once per year and that water chemistry samples are obtained from lake outflows.

8. The survey data is used to classify the five lake systems on the basis of the most commonly employed existing schemes. Some preliminary evaluation is made of the value of such schemes for classifying Welsh lakes.

9. Multivariate data analyses are performed on selected individual data types in order to generate preliminary lake classification schemes. These analyses are intended only as examples of methodologies which might be adopted in later stages of the research programme.

10. The data analytical methodology for the development of an integrated classification scheme, incorporating both physio-chemical and biological data, is outlined. The methodology is exemplified using a sub-set of the survey data. The preliminary integrated classification categorises the five sites into two classes; the lowland, high-alkalinity, nutrient-rich sites in Anglesey and the upland, low-alkalinity, nutrient-poor sites in Snowdonia.

11. The preliminary classifications presented are dominated by the significant chemical and biological differences between the three Anglesey lakes and the two Snowdonia sites. Inspection of the data reveals significant physio-chemical and biological variation within these two broad site types, and more refined classifications can be expected with the addition of further lakes to the data-set.

12. Clearly, many more than five sites (*c*.30+) will be required for the development of a robust, widely applicable, integrated classification scheme. Once a larger lake data-set is available a more complete assessment of the value of different data types can be made. Additionally, the final data-set will allow the effective evaluation of existing classification schemes and analyses of the relationships between individual biological groups and environmental variables.

13. Data collected during the field surveys provide a contemporary 'baseline' against which future ecosystem change at these sites can be assessed. Palaeolimnological techniques, not included within the current programme, could allow the definition of historical 'baseline' or pre-anthropogenic impact conditions to be established quantitatively, forming the basis for a classification scheme based on ecosystem change.

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1 Introduction

Site selection and evaluation are key aspects of UK conservation practice. Criteria for evaluating sites of nature conservation interest include factors such as the diversity of species and habitats, the area of the site, rarity of species or habitats, naturalness and representivity of the site (Usher 1986). It is increasingly recognised that the series of sites selected for conservation should contain adequate representation of the total range of variation in ecosystem types (NCC 1989). Effective site evaluation is therefore dependent on two key factors:

i) The availability of classifications to allow each site to be placed in the context of regional site variation.

ii) The collection of field survey data which adequately represent the environment, flora and fauna of each site of interest.

In the UK classifications have provided an important framework for the selection of key conservation sites, including standing waters. The Nature Conservation Review (NCR) selected key standing water sites using a classification of six site types; dystrophic, oligotrophic, mesotrophic, eutrophic, marl and brackish (Ratcliffe 1977). More recently Palmer (1992) has classified standing waters throughout Great Britain using aquatic macrophytes. Ten site types are defined based on the occurrence of individual macrophyte species. The site types broadly correspond to a gradient from low > high alkalinity, conductivity and pH values. These approaches are based on the assumption that broad environmental gradients or individual vegetation communities can be used as surrogates for ecosystem variation.

However, it is increasingly being suggested that classification should be based on all the relevant biologically and environmental attributes of an ecosystem. The conservation ethic is moving away from the consideration of single species and towards approaches based on the full range of site resources (Usher 1986). There is therefore a clear requirement for the development of integrated site classifications that take into account a fuller range of environmental and biological variation exhibited by standing water sites.

Effective integrated classification requires the collection or collation of field survey data for relevant environmental and biological attributes. It also requires effective analysis of the survey data to provide a robust, objective and widely-applicable classification.

This study has two primary aims:

i) To develop and critically assess a methodology of field survey for the key physical, chemical and biologically variables necessary for integrated classification of lakes.

ii) To develop and evaluate an integrated classification for lakes in Wales suitable for nature conservation practice.

For the first phase of this programme five lakes were chosen by the Countryside Council for Wales for the survey and assessment. Data have been collected from these lakes on key variables of biological importance including the physio-chemical environment, algal, aquatic macrophyte, zooplankton and macroinvertebrate communities.

This report outlines the sampling methodology adopted, and presents data collected from the first five study sites. The survey methodology is critically reviewed with a view to improving it for later phases of the programme. The report also contains a literature review of lake classification, emphasising schemes developed specifically for nature conservation. The most commonly used and relevant of these schemes are applied to the five study lakes. The survey data collected is used to produce classifications based on both individual data types and an integrated data-set. These classifications are preliminary and unsuitable for wider application. As such they are presented merely as an exemplification of the relevant data analytical techniques. Full utilisation of the ecological statistics which would allow the various chemical, biological and physical characteristics of the sites to be interrelated, classified and potentially modelled will require many more than five sites (*c.* 30+).

2 Lake classification: a literature review

2.1 Introduction

Throughout this century limnologists have sought to classify lake systems. Lake classification schemes have been developed largely as attempts to simplify a growing amount of descriptive information, and have been based on a diverse range of lake and drainage basin characteristics (see Elster 1974, Leach & Herron 1992, Johnes *et al.* 1994). This brief review summarises the origins of lake classification before describing the principal schemes in common use and discussing schemes specifically designed for conservation purposes.

The earliest attempts to classify lake systems were made by Thienemann and Naumann. Thienemann (1909, 1915) studied Alpine lakes and observed a relationship between deoxygenation of the hypolimnion and the nature of the bottom fauna. Naumann (1917, 1932) recognised an association between lake phytoplankton and the geological nature of the catchment. Using such observations these two workers recognised that many characteristics of lake systems are inter-related, and developed the concept of lake types. They initially recognised two types of lakes based on trophic state; nutrient-poor, oligotrophic lakes in the Alpine regions and nutrient-rich, eutrophic lakes in the lowlands. As further studies were carried out more lake types emerged (e.g. dystrophic).

It was soon recognised that lake systems do not conform to a set of readily definable types, but demonstrate a continuous range of variation in their characteristics. For instance, Pearsall (1921) worked on lakes in the English Lake District. These showed a clear series or continuum in trophic state, from high transparency/small algal crops/low productivity to low transparency/high algal crops/high productivity. Any classification of such a continuum of variation would by necessity require arbitrary distinctions. Pearsall suggested that this series reflects the evolution or maturity of the lakes, from "immature" lakes (e.g. Wastwater) to "mature" lakes (e.g. Esthwaite Water), and used the terms oligotrophic and eutrophic to describe the extremes of the series. However, the importance of Pearsall's work was to demonstrate the difficulties in imposing a classification of lake types onto a continuum of variation (Johnes *et al.* 1994).

This consideration has not prevented a profusion of classification schemes being developed for lake ecosystems (see Leach and Herron 1992). The majority of these schemes have been based on trophic state due to the growing interest in quantifying the problem of eutrophication (e.g. Premazzi & Chiaudani 1992). The most frequently used of these trophic state schemes are those based on studies by the Organisation for Economic and Co-operative Development (Vollenweider 1968, OECD 1982). However, several schemes in general use are not based on trophic state, most notably the Hutchinson and Loffler (1956) scheme based on thermal mixing.

2.2 Lake classification schemes

The variables used in lake classifications schemes are numerous (Busch and Sly 1992). Additionally the approaches adopted vary from simple, single parameter schemes to those based on multi-variate analyses of complex data-sets. This section outlines the range of lake classification schemes adopted and the approached taken, indicating the variables most commonly utilized. A more complete review is provided by Leach and Herron (1992).

a. Schemes based on lake origin, morphology and location

Hutchinson (1957) summarised 11 processes leading to the formation of lakes (e.g. tectonic, glacial, volcanic), and suggested that lakes could therefore be classified by origin. This scheme is applicable on large spatial scales, but is of less use on a more restricted regional level when most lakes may have a common origin. The majority of lakes in Wales, for example, are of glacial origin.

The influence lake morphology exerts on the chemistry and biology has long been recognised by limnologists (e.g. Thienemann 1915). Accordingly, several classification schemes have been based on morphometric parameters (e.g. Hutchinson 1957, Herdendorf 1982). The most commonly used parameters of lake morphometry are lake area, catchment area, volume, maximum depth, mean depth, and shoreline development.

Several authors have classified lakes according to geographical location (e.g. Zafar 1959, Herdendorf 1982). Such schemes are relevant to lake variation on a global scale, when lake types can be related to broad climatic factors, but are of less relevance on a regional basis unless combined with data on other lake characteristics.

b. Schemes based on thermal properties

Seasonal variations in temperature and water column stratification strongly influence the oxygen regime, chemistry and biology of lake systems (Wetzel 1983). Limnologists therefore commonly classify lakes on the basis of characteristics of thermal mixing. The scheme presented by Hutchinson and Loffler (1956), and revised by Lewis (1983), classifies lakes into eight types on the basis of ice cover, mixing and direct stratification (see Table 2.1). Lewis (1983) also produced a chart allowing lake type to be predicted from maximum depth and latitude (after adjustment for altitude).

c. Schemes based on transparency

Lake transparency is strongly correlated with algal density, and has therefore been used by several authors to provide a simple index of trophic state (e.g. Forsberg and Ryding 1980). Transparency can be measured simply using a secchi disc, and there is a clear relationship in many lake systems between chlorophyll *a* concentrations, often used as a measure of algal biomass, and secchi disc depth (e.g. Vallentyne *et al.* 1969). However, these relationships do not apply to all systems, particularly those lakes where dissolved organic carbon levels are high.

d. Schemes based on water chemistry

Most classification schemes based on water chemistry have been developed with relation to specific environmental problems, and have been intended as management tools. As eutrophication has become a dominant theme in applied limnology, the majority of classification systems relate to the trophic state of standing waters.

Table 2.1 Classification of lakes based on thermal mixing (from Lewis 1983)

Lake Type	Description
Amictic	Always ice covered
Cold monomictic	Ice covered most of the year, ice free during the warm season but not above 4°C.
Continuous cold polymictic	Ice covered part of the year, ice-free and above 4°C during the warm season, and stratified at most on a daily Basis during the warm season.
Discontinuous cold polymictic	Ice covered part of the year, ice free and above 4°C and stratified during the warm season for periods of several days to weeks, but with irregular interruption by mixing.
Dimictic	Ice covered part of the year and stably stratified part of the year with mixing at the transitions between these two states.
Warm monomictic	No seasonal ice cover, stably stratified part of the year, and mixing once each year.
Discontinuous warm polymictic	No seasonal ice cover, stratifying for days or weeks at a time, but mixing more than once per year.
Continuous warm polymictic	No seasonal ice cover, stratifying at most for a few hours at a time.

Various authors have developed trophic classification systems based on single chemical parameters. Hutchinson (1938) developed a scheme which linked trophic state to dissolved oxygen. He set limits of hypolimnetic oxygen loss for lakes considered oligotrophic (<0.5 mg cm^{-2} month^{-1}) and eutrophic (>1.0 mg cm^{-2} month^{-1}). Although oxygen regime is an important variable in lake systems, having a considerable influence on biological communities, this scheme is rather limited in scope being suitable only for large, deep, stratified lakes.

Rodhe (1958) argued that primary production could be used as a basis of lake classification as it reflects the overall productivity of a lake system. He related trophic state to the rate of primary production in gC m^{-2} yr^{-1}. However, this scheme is of limited use due to the problems of measuring primary productivity or photosynthesis (Leach and Herron 1992). Vollenweider (1968) proposed that total nitrogen (TN) could be used as a simple indicator of trophic state, and defined levels of TN for oligotrophic, mesotrophic and eutrophic waters. However, the chemical parameters most commonly employed in trophic classifications have been total phosphorus (TP) and chlorophyll *a* concentrations. Numerous authors have defined trophic states for standing waters using these two parameters (see Leach and Herron 1992). These variables have been popular due to their clear relationship with trophic conditions. TP is important in plant nutrition and influences algal biomass. Chlorophyll *a* provides a surrogate for algal biomass and its concentration in the water column reflects trophic state. Both parameters are relatively easy to measure and data availability is therefore high.

The Dillon and Rigler (1975) system uses summer chlorophyll *a* levels to divide lakes on the basis of their potential uses (see Table 2.2), a scheme also expanded to relate the classes to secchi disc depths and TP levels. The system was originally proposed for lakes in Southern Ontario, but has been widely used by water managers concerned with fishery development and other recreational uses of water bodies. With the emphasis on resource exploitation, it is of course inappropriate as a tool for a conservation based classification and is included in this section solely as a further example of the current range of existing classification schemes.

Table 2.2 Dillon and Rigler (1975) lake classification scheme

Category	**Summer Chl_a ($mg\ m^{-3}$)**	**Lake use**
Class I	2	Lake for recreational use maintaining a salmonid fishery
Class II	5	Lake for recreational use in which maintenance of a salmonid fishery is not of importance
Class III	10	Lakes with little or no recreational use destined mainly to be fished, excluding salmonids
Class IV	25	Lakes only to be utilised for Cyprinid species.

The Organisation for Economic and Co-operative Development (OECD) cooperative programme attempted to relate classical trophic terminology (oligotrophic, mesotrophic, eutrophic) to specific levels of water quality variables to provide a widely applicable trophic classification scheme (OECD 1982). The boundaries for the five classes of standing waters described are shown in Table 2.3. This scheme has become very widely used, and now provides the standard trophic classification scheme for lakes.

Table 2.3 OECD trophic classification scheme (OECD 1982)

Trophic Category	TP (mg m^{-3})	Chl_a (mg m^{-3})	Secchi Depth (m)
Ultra-oligotrophic	<4	<1	>12
Oligotrophic	<10	<2.5	>6
Mesotrophic	10-35	2.5-8	6-3
Eutrophic	35-100	8-25	3-1.5
Hyper-eutrophic	>100	>25	<1.5

This scheme uses fixed boundaries to categorise lakes, although the OECD also provided an open boundary system detailing the ranges and standard deviations of each parameter within each class (Premazzi and Chiaudani 1992). The open system recognizes the inherent uncertainty in classifying a lake to a single trophic category, but has not been widely applied.

Vollenweider (1975) adopted a rather different approach to defining trophic state. He observed a clear relationship between trophic conditions, hydraulic flushing rate and nutrient loadings. He therefore produced a model of trophic state, presented graphically as a double logarithmic plot relating the annual phosphorus load to the hydraulic residence time. This plot can be used to classify lakes as oligotrophic, mesotrophic or eutrophic, and also allows the prediction of trophic state under different nutrient loading scenarios.

Several classification schemes have been used which are based on a multivariate approach. Shannon and Brezonik (1972) developed a trophic state index (TSI) using seven variables; primary productivity, Chlorophyll *a*, total organic nitrogen, TP, secchi disc depth, conductivity and Pearsall's cation ratio ((Na+K)/(Ca+Mg)). The index was generated using principal components analyses (PCA), the TSI being the first principal component summarising total variation within the data-set. They used lakes in Florida to calibrate the index against traditional trophic classes (oligotrophic, mesotrophic, eutrophic). Although the index was designed for use only within Florida, the approach demonstrated the value of ordination techniques such as PCA for summarising variation within lake systems. Carlson (1977) also adopted an approach to lake classification based on trophic state indices. He proposed a system using the parameters secchi disc transparency, TP and chlorophyll *a*, assuming each of these correlated to algal biomass and therefore represent trophic conditions. The scheme is useful for describing trophic change within a lake system and can potentially be used to classify surface waters on a regional basis, although this would again introduce problems of defining boundaries between categories.

Although the majority of classification schemes using water chemistry have been based on trophic state, the debate over acid deposition over the last two decades has created interest in classifying lakes at risk from lake acidification. In Ontario, for instance, Pitblado *et al.* (1980) categorised lakes impacted by acid deposition. They grouped the lakes according to the degree of impact, and related these groups to nutrients, buffering, sodium-chloride and atmospheric deposition. In the UK the Acid Waters Review Group (UKAWRG 1989) used three broad categories of surface water to help define the vulnerability of surface waters to acid deposition (Table 2.4). This scheme has been used to assess the acidification status of surface waters (e.g. Juggins 1991). More recently Battarbee *et al.* (1992) have characterised the variation in physio-chemical parameters of upland lakes in the UK using a data-set collected as part of the Critical Loads Advisory Group's (CLAG) research programme.

Table 2.4 UK Acid Waters Review Group surface water classification

Category	Description
i	Waters which are permanently acid. pH <5.6, alkalinity close or equal to zero, low conductivity.
ii	Waters which are occasionally acid. pH occasionally drops below 5.6, low alkalinity (<5 mg l^{-1} $CaCO_3$).
iii	Waters which are never acid. High alkalinity (>5 mg l^{-1} $CaCO_3$), pH never drops below 5.6.

e. Biological classifications

Many biological classification schemes have been developed to provide biotic indices for water quality assessment. Most of these use biological indicators to provide a prediction of physio-chemical conditions. These kinds of classifications have been most widely applied to running waters, although similar schemes have also been developed for standing waters. Biological communities have the advantage of being representative of average physio-chemical conditions, and therefore biological indices have often been used to avoid the problem of variation in water chemistry which can influence purely chemical classifications.

The potential of algae for lake classification, particularly the diatoms, has long been recognised (e.g. Round 1958). Numerous studies have demonstrated the strong relationships between diatom assemblages and physio-chemical variables in lake systems such as pH, organic carbon, nutrients, and salinity. Diatom-lake water chemistry data-sets have been used extensively to develop robust quantitative relationships allowing the prediction of lake water chemistry from diatom assemblage (e.g. Birks *et al.* 1990a, 1990b, Fritz *et al.* 1991, Bennion 1994). However, so far few of these data-sets have been used to provide systematic lake classifications. An exception is provided by Stevenson *et al.* (1991), who provided a detailed description of the variation of soft-water lakes in north-west Europe based on surface sediment diatom assemblages.

Zooplankton also have potential for lake classification purposes, although there are a number of associated problems (Leach and Herron 1992). The relationships between zooplankton communities and physio-chemical parameters are complex, as are the interactions between zooplankton and other biological communities within lakes. Sprules (1980) suggested that three lake types could be distinguished on the basis of zooplankton size and feeding behaviour, although clearly more sophisticated systems could be developed based on zooplankton communities.

Aquatic macrophytes have also been used to classify lake systems. Such schemes have mostly been rather general, using indicator species to assign surface waters into a restricted number of classes related to the chemical characteristics of the water. An example is provided by Premazzi and Chiaudani (1992) who give indicator species for three classes of surface waters; soft waters, hard waters and alkaline waters. A more sophisticated classification scheme based on macrophytes with direct significance to conservation is that developed by Palmer *et al.* (1992), and is described below.

Macroinvertebrates have been used to classify lake systems (Brinkhurst 1974) and were probably the first biological group to be widely used as water quality indicators (e.g. Kolkwitz and Marsson 1908, 1909). However, most schemes based on invertebrates have been developed for the biomonitoring of running waters and provide indices of water quality, usually linked to the degree of pollution or the trophic state (Hellawell 1986). Nevertheless, some schemes have been developed for lakes based mainly on benthic invertebrates dwelling in the sediments. Saether (1979) used Chironomid communities from the bottom of lakes to delineate 15 lake types. Although he then related these to trophic state, he emphasised that the types represented recognisable chironomid communities and that the scheme was essentially independent of chemical state. Other schemes have provided systems for assessing trophic state used Oligochaetes (e.g. Lang 1984). Such schemes are generally calibrated for lakes within a limited geographical region, and this restricts their application to other lake systems (Premazzi and Chiaudani 1992).

Lake classification systems have also been developed based on fish populations. Fish are often an important component of lake ecosystems from a management perspectives, and several classification schemes have been designed around the need to provide data appropriate to fisheries managers (e.g. Busch and Sly 1992). Johnson *et al.* (1977) defined fourteen associations of fish species which could be used to classify lakes in Ontario. They then related these association to seven limnological variables using PCA to demonstrate the correlations between fish associations and lake types.

f. State-change classification schemes

Lakes are dynamic ecosystems and show changes through time. These changes can be natural, occurring over hundreds or thousands of years (e.g. Atkinson and Haworth 1990, Renberg *et al.* 1993). Change can also take place over much shorter time-scales due to anthropogenic activities. With the growing interest in environmental change over the past few decades it has been recognised that many lake ecosystems have been significantly impacted by human activities, principally as a result of aquatic pollution. In the UK, for instance, there is clear evidence from palaeolimnological studies of the impacts on lake ecosystems of organic pollution, nutrient enrichment, acidification, trace metal contamination, and afforestation (e.g. Anderson *et al.* 1986, Battarbee *et al.* 1988, Bennion 1993, Rippey 1990). These impacts can affect both water chemistry and biological communities, and therefore have a profound influence on the characteristics of the lake ecosystem. Moreover such impacts are dynamic, and at any point in time a lake ecosystem may be adjusting to perturbation. Existing lake conditions do not necessarily always provide an adequate basis for assessing the current status of a lake, or the potential for change.

These considerations have lead to criticism of spatial state classification schemes, which disregard the notion that individual lake systems may be changing (Johnes *et al.* 1994). The schemes described above fall into this category (e.g. OECD trophic classification). A major criticism is that such schemes do not differentiate between, say, a naturally eutrophic lake and one which has become eutrophic because of anthropogenic impact. They are also generally based on arbitrary boundaries between categories of lakes, and therefore do not recognise the continuous nature of variation between lake ecosystems.

This has led to the suggestion that state-change classification schemes should be more widely adopted. State-change schemes are designed to take into account the history of the lake ecosystem and are based on the reconstruction or prediction of a pre-anthropogenic impact baseline or reference state. The present state can then be compared to this baseline to evaluate the degree of change in the ecosystem, and the lakes can be classified on the basis of both the baseline state and the degree of change. Johnes *et al.* (1994) have proposed such a scheme based on predicting baseline state from land use within the lake catchment. An alternative approach has already been established using palaeolimnological techniques which can provide robust, accurate reconstructions of historical lake-water pH, organic carbon, TP and salinity levels (e.g. Birks *et al.* 1990a, 1990b, Fritz *et al.* 1991, Bennion 1994). Macro- and micro-fossil remains within lake sediments can also provide an indication of the biological communities present at different periods in a lake's history (see Berglund 1986).

A good example of a state-change classification system employing palaleolimnological techniques is given by Cumming *et al.* (1992) from lakes in the Adirondack Mountains of the USA. Using diatom analysis of sediment core tops and bottoms they classified lakes on the basis of post-1850 changes in diatom and chrysophyte assemblages and reconstructed pH, aluminium and dissolved organic carbon levels. This approach provides an accurate, efficient and relatively rapid means of categorising lakes on the basis of ecosystem change.

In Europe a state-change scheme based on the concept of critical loads has been adopted to evaluate the extent of lake acidification and to explore the environmental value of emissions abatement strategies. A critical load can be defined as "the highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on ecosystem structure and function" (Nilsson and Grennfelt 1988). Critical loads for freshwaters can be defined in a number of ways. Battarbee *et al.* (1993) presented the diatom critical loads model, calibrated using palaeolimnological data. This allows the base critical load for a site to be calculated, the point of first ecological response to acidification. The Henriksen model is also widely used to provide critical loads relating to Acid Neutralising Capacity (ANC), a parameter strongly correlated to the biological status of soft-water bodies. In the UK Henriksen critical loads are calculated for zero ANC, a level at which there is a 50% chance of brown trout being present (Harriman and Christie 1993).

Surface waters can be classified using a combination of their critical load and the amount of sulphur deposition to predict acidification status. If the sulphur loading exceeds the critical load, the site is predicted to have acidified. The level of critical load exceedance can also be related to the ecological damage caused by acidification.

2.3 Lake classification schemes for conservation

Although many of the schemes described above have been widely employed, most were developed by limnologists for reasons not directly related to nature conservation. However, there have been a series of classification schemes developed in the UK specifically for conservation purposes.

The Nature Conservation Review (NCR) (Ratcliffe 1977) developed criteria for the assessment and selection of standing waters of conservation value. These criteria included such attributes as size, diversity, naturalness, rarity, fragility, research value and typicalness. The review aimed to identify key sites of national conservation importance requiring statutory protection. In order to adequately assess the representivity of any site, and to set the sites in both a regional and national context, a classification scheme was developed. This scheme identified six lake types. The classes adopted were the traditional trophic categories of oligotrophic, mesotrophic, and eutrophic, with the addition of dystrophic lakes (dominated by dissolved humic acids derived for peat), marl (calcareous) lakes (where precipitated $CaCO_3$ coats the lake bed), and brackish water lakes. The review then summarised the general chemical conditions and range of ecological variation found within each lake type. Key sites were selected to adequately represent the range of site variation, with particular attention being given to representing the range of site size, nutrient status and altitude, as well as selecting similar sites from widely ranging localities of the UK.

The NCR scheme was based on existing knowledge, using very broad categories of site type as the basis for conservation evaluation. The scheme is essentially based on variation in water chemistry, assessing ecological variation only after the classification has been made.

Guidelines for the selection of sites for conservation were updated in 1989 by the Nature Conservancy Council (1989). This study emphasised the need to select sites on the basis of ecological variation, and stressed the importance of habitat in determining biological communities and therefore conservation value. The importance of site classification as a tool for site evaluation and selection was re-affirmed, and for standing waters a classification scheme based on the use of aquatic macrophytes was introduced. This scheme, essentially based on the work of Margaret Palmer, identified ten standing water types on the basis of floating and submerged macrophyte species (Palmer *et al.* 1992) (see Table 2.5). The approach is based on indicator species analysis of 1124 fresh and brackish water sites. The ten classes were then related to variation in the alkalinity, pH and conductivity of the water to help categorize the chemistry of each site type.

The system allows the description of whole sites, summarises the floral characteristics of a lake, and allows the distribution of communities to be related to physio-chemical variables (NCC 1989, Palmer *et al.* 1992). It is simple, and additional sites can normally be classified on the basis of a single visit. The scheme also has the advantage of being based on aquatic macrophytes, which are of considerable conservation importance. The classification is essentially independent of physio-chemical variation, although the site types generally correspond to a chemical gradient and can also be used to provide Trophic Ranking Scores (TRS) for each site (Palmer *et al.* 1992).

Table 2.5 Summary of aquatic macrophyte classification for standing waters (from Palmer *et al.* 1992)

Site type	Characteristic species	Category
1	Submerged *Sphagnum* and *Juncus bulbosus.*	Dystrophic
2	*Juncus bulbosus* and *Potamogeton polygonifolius*, with *Littorella uniflora*, *Lobelia dortmanna*, and *Potamogeton natans.*	Oligotrophic
3	Similar to type 2, but with higher incidence of *Myriophyllum alterniflorum*, *Isoetes lacustris* and *Fontinalis antipyretica.*	Oligotrophic
4	Elements of type 3 but with *Potamogeton filiformis*, *Potamogeton praelongus*, *Myriophyllum spicatum* and *Chara* species also common.	Oligotrophic with eutrophic influence.
5A	*Littorella uniflora*, *Myriophyllum alterniflorum*, *Nitella* species, *Potamogeton* species, *Elodea canadensis.*	Mesotrophic
5B	Dominated by *Potamogeton natans* and *Nymphaea alba.*	Mesotrophic
6	Few species apart from *Potamogeton pectinatus*, *Ruppia* species and seaweeds such as *Fucus ceranoides.*	Brackish
7	Similar to type 4, but lacking *Myriophyllum alterniflorum* and *Juncus bulbosus.*	Eutrophic, often marl.
8	*Lemna minor*, *Callitriche stagnalis*, *Polygonum amphibium.*	Eutrophic, often marl.
9	*Nuphar lutea* and *Nymphaea alba.*	Eutrophic, sometimes marl.
10A	*Myriophyllum spicatum*, *Potamogeton pectinatus*, *Elodea canadensis* and *Lemna minor.*	Eutrophic, sometimes marl.
10B	*Myriophyllum spicatum*, *Potamogeton pectinatus*, and *Chara* species.	Eutrophic, sometimes marl.

Of growing importance to nature conservation in Britain is the National Vegetation Classification (NVC) (e.g. Rodwell 1991, Rodwell in preparation). The NVC covers aquatic, swamp, fen and mire vegetation throughout Britain, and includes 24 aquatic communities. Although the NVC does not provide a site classification, it can be used to identify which and how many communities are present at a site, information of significant importance to nature conservation.

Although so far not widely applied, state-change schemes have particular relevance to conservation, which as well as being concerned with ecosystem representivity is concerned with naturalness and stability (Usher 1986). The critical loads approach, for example, has been used to help assess the acidification status of freshwater SSSIs throughout Great Britain (e.g. Allott and Juggins 1992, Rimes 1992). There is considerable potential in developing schemes to consider other changes that have taken place in lake ecosystems, such as nutrient enrichment, change in algal communities and macrophyte loss.

Conservation is increasingly concerned with the full range of physio-chemical variation and biological communities present at a site (Usher 1986). However, the majority of existing schemes are based on a restricted range of variables and assume that ecosystem variation can be summarised by the use of broad environmental gradients or individual biological communities. To date the potential of such an integrated approach has not been explored, although there has been some use of integrated schemes in conservation practice in the Netherlands (van der Ploeg 1986). Additionally, the UK Action Plan on Biodiversity (Anon. 1994) has stressed the current inadequate understanding of the interrelationships between various animal and plant groups and recognises the need for further research. In this project we seek to address these issues by providing the structure for an integrated classification scheme which takes into account the full range of environmental and biological variation demonstrated by standing waters and allows the investigation of correlations between various biological and physio-chemical parameters. Intensive biological surveys will allow the the current biological diversity of standing waters in Wales to be catalogued. The project will thus address the remit of CCW to audit the biological composition of the Welsh countryside and, in the spirit of the Action Plan, will provide a coordinated data collection system for subsequent quantification of the lacustrine biodiversity resource in Wales.

3 Site Descriptions

Llyn Idwal

Llyn Idwal lies in the Snowdonia National Park at 370 m altitude, above Llyn Ogwen at the head of the Nant Ffrancon Valley (Figure 3.1). The lake and its immediate catchment are within the Cwm Idwal SSSI and in 1991 it was designated a Ramsar site (e.g. a special site for conserving wetlands deemed to have international significance in terms of their ecology and wildlife). The conservation value of the lake was also recognised by the Nature Conservation Review (Ratcliffe 1977).

The lake covers an area of approximately 0.14 km^2 and is relatively shallow for an upland corrie lake of this size (mean depth 3.4 m, maximum depth 13 m). The deeper, broad northern basin of the lake is quite different in character from the shallow, macrophyte-filled southern arm which in limnological terms may almost be considered a separate system.

A precipitous catchment of 3.05 km^2 drains to the lake via a series of steep streams and falls. Three small upland 'tarns' lie high above Llyn Idwal. One of these, Llyn Clyd, has been the subject of palaeolimnological and chemical study in the past (Walker 1977, Patrick 1989).

Catchment geology is a complex combination of granite and Ordovician sedimentary rock of the Caradoc Series. The lower catchment supports a Gramineae-dominated moorland vegetation which is grazed by sheep. Soils in the lower catchment are humic brown podzolic soils of the Moor Gate association. These are well drained humose, gritty, loamy soils, occasionally with a thin ironpan. Soils in the upper catchment are humic rankers of the Bangor association. These are shallow, loamy upland soils on steep slopes, with peaty topsoils. Scree and bare rock occur locally.

There is a significant recreational pressure on the catchment of Llyn Idwal, hill walkers climbers and visitors to the lake pass through in great numbers and paths, stream and lake margins suffer from erosion.

Llyn Cwellyn

Llyn Cwellyn (Figure 3.2) is the largest lake in this study, covering some 0.85 km^2. It lies at an altitude of 150 m in the Nant y Betws valley within the Snowdonia National Park. Llyn Cwellyn is designated as an SSSI primarily on the basis of its Arctic char population, and was included in the Nature Conservation Review (Ratcliffe 1977).

The lake comprises a simple deep basin (mean depth 22.6 m) which attains a maximum depth of 36 m. A large upland catchment drains to the lake via a series of upland streams and two larger influents, the Afon Treweundydd and Afon Gwyrfai. The outflow from the lake has been regulated but there is little evidence of significant fluctuations in water level.

The Llyn Cwellyn catchment is extensive. It covers some 19.88 km^2 and reaches a maximum altitude of 1085 m at Snowdon (Figure 3.2). One other significant lake, Llyn y Gadair, a dammed reservoir and other smaller upland tarns lie in the upper catchment. Ward (1931) states that although Llyn Dywarchen now connects with Llyn Cwellyn by Llyn y Gadair, the connection is artificial, and previous to the middle of the nineteenth century the outflow was down the Pass of Drws-y-

Coed only. The uppermost of these tarns, Llyn Glas, has been the subject of past palaeolimnological and chemical study (Walker 1977, Patrick 1989) as has Llyn y Gadair (Flower *et al.* 1989).

Table 3.1 Llyn Idwal: site characteristics

Grid Reference	SH 646 595
Lake altitude	370 m
Maximum depth	13.0 m
Mean depth	3.4 m
Volume	c.0.48 $\times 10^6$ m^3
Lake area	14 ha
Shoreline development index	1.55
Estimated hydraulic residence time	c.20 days
Catchment area (excluding lake)	305 ha
Catchment:lake ratio	21.8
Net relief	625 m
Mean annual rainfall (1988)	c.2900 mm
Total S deposition	2.21 keq H^+ ha^{-1} yr^{-1}
Total N deposition	1.63 keq H^+ ha^{-1} yr^{-1}

Table 3.2 Llyn Cwellyn: site characteristics

Grid Reference	SH 560 550
Lake altitude	150 m
Maximum depth	36 m
Mean depth	22.6 m
Volume	c.19.21 $\times 10^6$ m^3
Lake area	85 ha
Shoreline development index	1.43
Estimated hydraulic residence time	c.220 days
Catchment area (excluding lake)	1988 ha
Catchment:lake ratio	23.4
Net relief	935 m
Mean annual rainfall (1988)	c.1950 mm
Total S deposition	1.36 keq H^+ ha^{-1} yr^{-1}
Total N deposition	0.99 keq H^+ ha^{-1} yr^{-1}

The slopes immediately to the west of the lake and parts of the southern, upper catchment have been afforested with conifers. Some of this area has been thinned and felled and secondary planting instigated. There are a few scattered houses, a youth hostel, a hotel and one hamlet (Rhyd-Ddu) in the catchment. A minor but ancient Roman road - the A4085 traverses the eastern shore of the lake. In the vicinity of Llyn y Gadair and more sporadically on the slopes adjacent to Llyn Cwellyn, there is evidence of past quarrying activity.

The geology of the catchment is complicated and includes Ordovician and Cambrian sedimentary rocks together with outcrops of granite, tuffs and basalt. Away from the forested area the catchment supports moorland vegetation, which has been marginally improved on the lower slopes, and which throughout, is utilised for rough grazing for sheep and cattle.

The catchment also contains a rather complex pattern of soil types. The high ground to the north-west of the catchment includes humic rankers of the Bangor association and brown podzolic soils of the Malvern association. The former are shallow, loamy soils on steep slopes with peaty topsoils. Scree and bare rock occur locally. The brown podzolic soils are well drained loamy soils on moderate to steep bouldery slopes. Again, crags and scree are common in areas. Soils on the high ground on the southern part of the catchment watershed are ferric stagnopodzols of the Hafren series. These soils, occurring in areas of relatively low relief, contain a wet peaty surface horizon and often have an ironpan. Peat formation is also common.

The intermediate catchment slopes contain raw oligo-amorphous peat soils of the Crowdy 2 association (thick, very acid raw peat soils; perennially wet; hagged and eroded in places) and iron stagnopodzols of the Hexworthy association (loamy, acid soils, with a wet peaty surface horizon; thin ironpan often present; bare rock and boulders occurring locally). The area around Llyn y Gadair is dominated by typical humic gley soils of the Laployd association. These are permeable gritty, course loamy soils with a wet or peaty surface horizon strongly influenced by groundwater. Some peat soils and bare rock are also present.

The slopes immediately to the north of the lake are dominated by brown podzolic soils of the Manod association. These are well drained, fine loamy or silty soils over rock which are often shallow in places. These slopes have been marginally improved, and on 4 September 1994 were being limed.

Llyn Coron

Llyn Coron lies at 10 m above sea level just 2 km from the coast in south-west Anglesey. The lake covers an area of approximately 0.26 km^2 and drains a catchment of 17.17 km^2 (Figure 3.3). Llyn Coron and its outflow the Afon Ffraw form the Tywyn Aberffraw SSSI. The lake was recognised in the Nature Conservation Review (Ratcliffe 1977).

The lake is shallow and comprises a simple broad basin (mean depth 1.8 m) which reaches a maximum depth of 2.8 m. A significant wildfowl population, whose numbers vary seasonally, is supported by the lake and its immediate surrounds and a recreational fishery is maintained.

The catchment is of low relief with a maximum altitude of only 65 m. Drainage is by one principal stream, the Afon Gwna and is supplemented in places by minor artificial drainage ditches.

Catchment soils are dominated by cambric stagnogley soils of the Brickfield 2 association. These are slowly permeable, seasonally waterlogged fine loamy soils. To the south and east of the catchment typical brown earths of the East Keswick 2 association are also present. These are deep, fine loamy soils with slowly permeable subsoils which again experience slight seasonal waterlogging The extremely ancient Pre-Cambrian sedimentary geology which dominates the catchment outcrops in places and gives rise to poor agricultural land which is utilised for rough grazing for sheep and cattle. Isolated farms and a diffuse rural population are present and domestic drainage to septic tanks and production and storage of silage may represent relevant land-uses in terms of their impact on lake water quality. A pig farm is also present within the catchment.

Table 3.3 Llyn Coron: site characteristics

Grid Reference	SH 378 380
Lake altitude	10 m
Maximum depth	2.8 m
Mean depth	1.8 m
Volume	c.0.47 x10^6 m^3
Lake area	26 ha
Shoreline development index	1.46
Estimated hydraulic residence time	c.18 days
Catchment area (excluding lake)	1717 ha
Catchment:lake ratio	66.0
Net relief	55 m
Mean annual rainfall (1988)	c.1020 mm
Total S deposition	1.58 keq H^+ ha^{-1} yr^{-1}
Total N deposition	0.46 keq H^+ ha^{-1} yr^{-1}

Llyn Penrhyn and Llyn Dinam

These two lakes lie only 0.5 km apart some 1.5 km from the coast of western Anglesey and are both within the Llynnau y Fali: Valley Lakes SSSI. The two lakes are low lying (< 10 m altitude) and the catchment of Llyn Penrhyn is rather difficult to distinguish topographically. The two sites are portrayed together in Figure 3.4.

Llyn Penrhyn has an area of approximately 0.19 km^2 and is shallow (mean depth 2.2 m) with a maximum depth of 3.0 m occurring in a minor basin at the northern end of the lake. The lake is part of a RSPB reserve and is an important wildfowl sanctuary. The catchment area is approximately 0.43 km^2.

Llyn Dinam is also shallow (mean depth 1.4 m, maximum depth 1.8 m) and supports a significant wildfowl population. The lake is smaller than Llyn Dinam, covering approximately 0.09 km^2. Llyn Dinam drains a catchment of approximately 6.48 km^2 through which flows one minor stream and a series of small artificial drainage channels. The A5 trunk road passes through the middle of the catchment and the small village of Caergeiliog lies only 0.5 km to the north of the lake.

The overall catchment of both lakes catchment is of very low relief with a maximum altitude of about 25 m. Ordovician sedimentary rocks underlie most of the catchment, but sedimentary rocks of the Pre-Cambrian occur at the extreme western edge. Soils are exclusively cambric stagnogley soils of the Brickfield 2 association, slowly permeable, seasonally waterlogged, fine loamy soils. The geology and soils give rise to agricultural land, managed in places for arable and better quality rough grazing which is utilised for sheep and cattle. Apart from the village of Caergeiliog, drainage from individual farms and rural dwellings together with that from silage stores, may constitute relevant land-use impacts in the catchment.

Llyn Penrhyn is separated from Llyn Dinam by a low lying marshy area and receives no discrete drainage from its poorly distinguished, small catchment. However, immediately adjacent to the north and east of the lake are residential and operational facilities for the Valley air base (Dowyn), and a further 0.5 km to the north, the village of Llanfihangel yn Nhowyn. These settlements house a significant population and a sewage treatment plant serving this community lies within the catchment. At the time of the current survey, effluent from this plant was discharged directly into Llyn Penrhyn, but from May 9th 1994 a phosphate stripping facility has become operational. Non built-up land in the catchment is dominated by scrub vegetation and some rough grazing.

A further potential impact on these lakes may come from the extreme low altitude with which incoming and outgoing aircraft fly over the lake and its catchment and the exhaust plumes from aircraft readying for take-off on the main runway just at the southern proximity of the catchment.

Table 3.4 Llyn Dinam: site characteristics

Grid Reference	SH 311 775
Lake altitude	4 m
Maximum depth	1.8 m
Mean depth	1.4 m
Volume	c.0.13 x10^6 m^3
Lake area	9 ha
Shoreline development index	2.09
Estimated hydraulic residence time	c.20 days
Catchment area (excluding lake)	648 ha
Catchment:lake ratio	72.0
Net relief	21 m
Mean annual rainfall (1988)	c.880 mm
Total S deposition	0.57 keq H^+ ha^{-1} yr^{-1}
Total N deposition	0.47 keq H^+ ha^{-1} yr^{-1}

Table 3.5 Llyn Penrhyn: site characteristics

Grid Reference	SH 315 770
Lake altitude	4 m
Maximum depth	3.0 m
Mean depth	2.2 m
Volume	c.0.42 x10^6 m^3
Lake area	19 ha
Shoreline development index	2.08
Estimated hydraulic residence time	c.690 days
Catchment area (excluding lake)	43 ha
Catchment:lake ratio	2.3
Net relief	21 m
Mean annual rainfall (1988)	c.880 mm
Total S deposition	0.57 keq H^+ ha^{-1} yr^{-1}
Total N deposition	0.47 keq H^+ ha^{-1} yr^{-1}

Figure 3.1 Catchment of Llyn Idwal

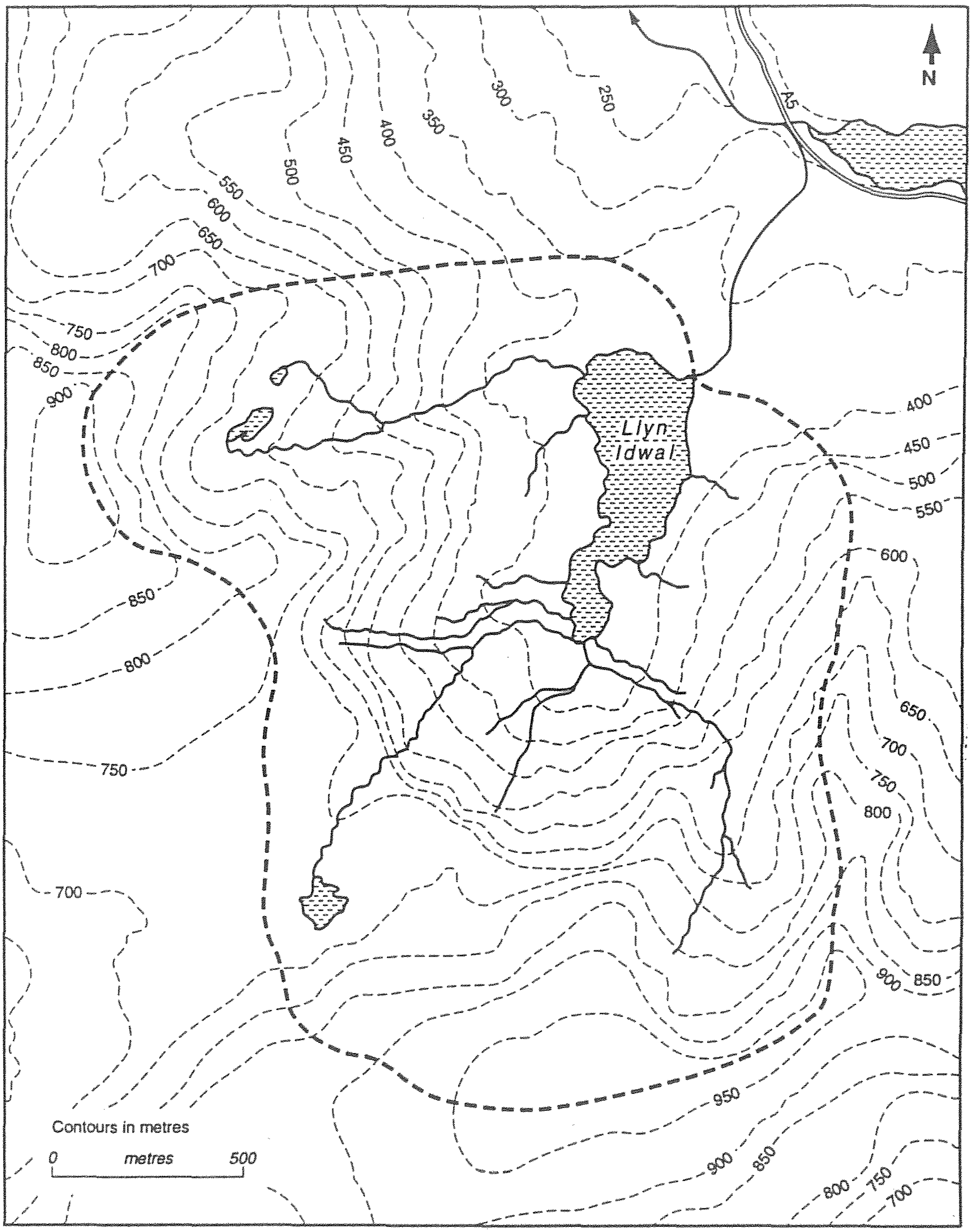


Figure 3.2 Catchment of Llyn Cwellyn

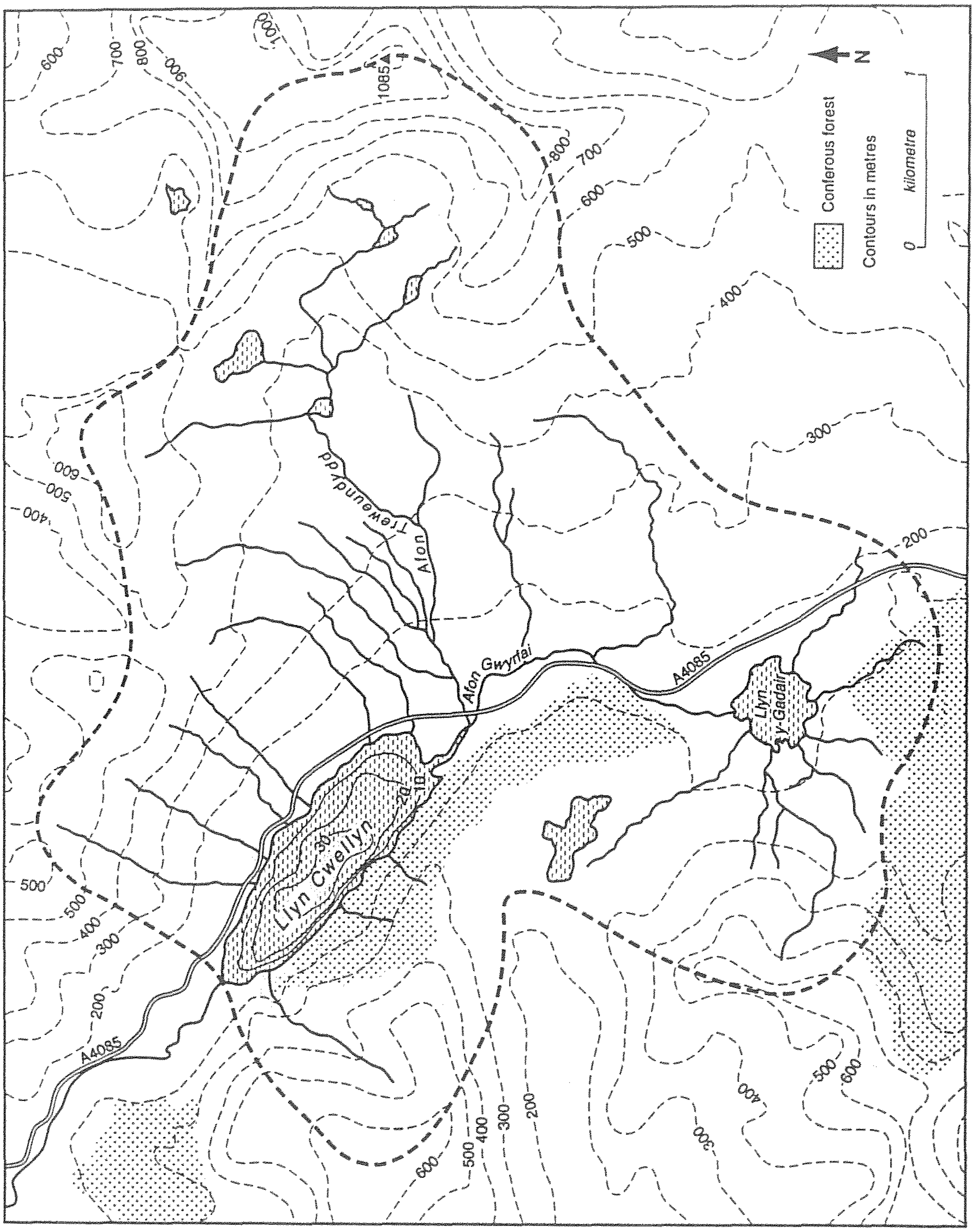


Figure 3.3 Catchment of Llyn Coron

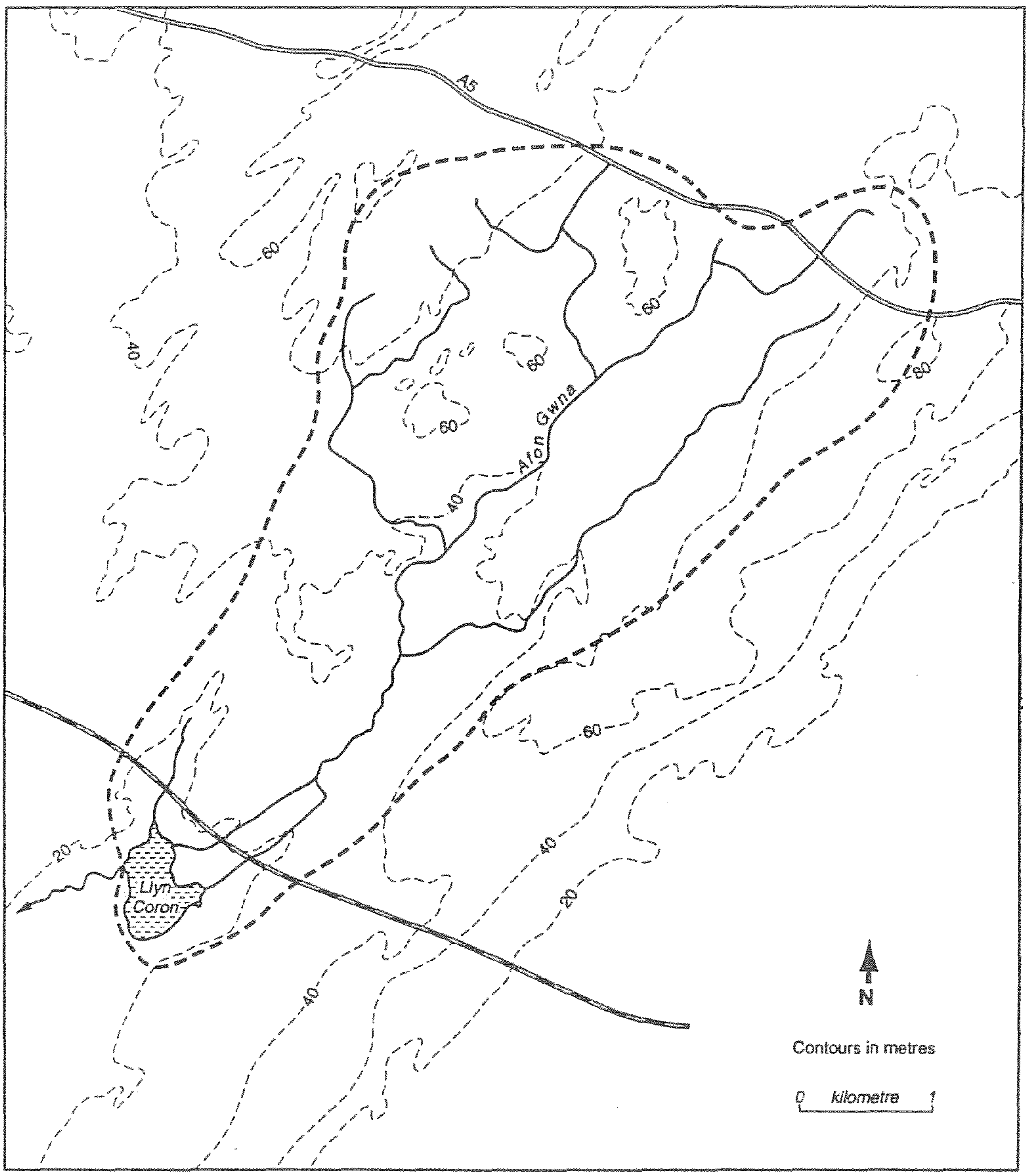
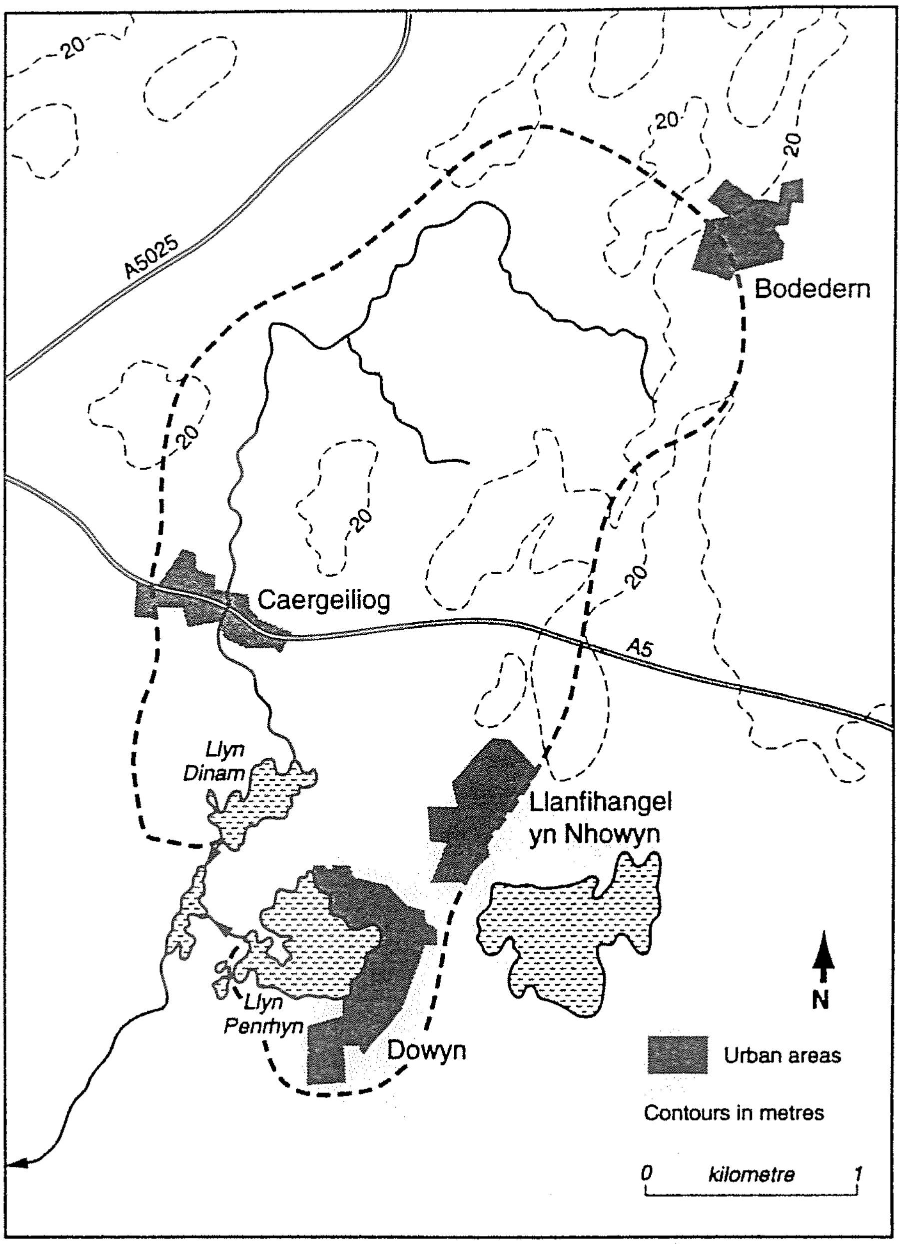


Figure 3.4 Catchments of Llyn Dinam and Llyn Penrhyn



4 Methods

The variables recorded and measured were determined by the Countryside Council for Wales in their original tender document for this programme. The sampling methodologies have been adopted after consultation with relevant specialists, and where possible recognised standard field and analytical methods have been used. All methods are kept under review and their applicability was re-assessed at the end of the first survey period (see section 6.1).

4.1 Site and catchment data

Catchment and lake areas were determined using Ordnance Survey 1:25,000 scale maps. Catchment geology was taken from British Geological Survey maps and catchment soils data from the Soil Survey of England and Wales 1:250,000 soil map (SSEW 1983) . Land-use was determined by field survey. The cost-effectiveness of utilising 1 km^2 resolution data of land cover from the GIS database at the Institute of Terrestrial Ecology are being investigated for possible use in future reports. Data on total sulphur deposition and total nitrogen deposition were taken from the United Kingdom Review Group of Acid Rain (UKRGAR) (1990).

A shoreline development index was calculated for each lake according to Wetzel (1983). This index represents the ratio of the length of shoreline to the circumference of a circle of area equal to that of the lake. Shoreline development is of interest because it reflects the potential for the development of littoral communities in proportion to the area of the lake (Wetzel 1983). An approximate bathymetry for lake each was obtained using existing data sources and point echo soundings (see Figures A.1 - E.1).

4.2 Physio-chemical analyses

Oxygen and temperature profiles were determined for each of the lakes during summer 1993. Profiles were taken during the period 10-11 July 1993 and again during the period 1-5 September 1993. Measurements were made from the deepest point using an EIL oxygen and temperature meter. Secchi disc transparency was also recorded at the deepest point.

Water chemistry has been sampled at quarterly intervals using the standard sampling and analytical methodology adopted by the Acid Waters Monitoring Network (Patrick *et al.* 1991). Water samples were taken from the middle of the lake from elbow depth and measured on site immediately for pH (using a Beckmann Φ10 pH meter with Beckmann electrodes) and conductivity (using a PHOX 52E conductivity meter).

The following determinands were measured at the Freshwater Fisheries Laboratory, Pitlochry using standard methods (Harriman *et al.* 1987); pH, H^+, alkalinity, conductivity, Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-} Cl^-, soluble monomeric Al, non-labile monomeric Al, soluble labile Al, total organic carbon (TOC) and absorbtion at 250nm. Alkalinity was measured using two techniques; a standard titration to pH 5.0 (alkalinity 1) and a Gran titration (alkalinity 2). This latter technique is normally recognised as the standard procedure.

The following determinands were measured at the Institute of Freshwater Ecology, Penicuick according to the methodology of Wolfe-Murphy *et al.* (1991); total silica, soluble reactive silica, chlorophyll *a*, total phosphorus, total soluble phosphorus, soluble reactive phosphorus, and nitrate.

Both the laboratories used for chemical determinations meet the necessary criteria required for BS quality assurance, and participate in ongoing inter- and intra-laboratory AQC programmes.

4.3 Epilithic diatoms

Epilithic diatoms were sampled during 1-5 September 1993. Ten cobble size stones were selected from the permanently submerged littoral at three or four locations around the shore, with areas close to inflow or outflow streams being avoided (Figures A.1 - E.1). The diatoms are removed by brushing into a tray, decanting into plastic vials and preserved with Lugols Iodine.

Samples are prepared using standard techniques (e.g. Battarbee 1986) and examined by light microscopy at x1000. A minimum of 300 valves are counted from each site and the abundance of each taxon is expressed as a percentage of the total count. Identification and nomenclature follows that developed by the Royal Society SWAP programme (Munro *et al.* 1990) and the ENSIS eutrophic lake survey (Anderson and Bennion, pers. comm.). Slides and diatom solutions are archived for quality control.

All diatom counts are stored on the central database, coded using ECRC diatcodes. For the purposes of this report a list of taxa comprising >1% of the total count is presented.

4.4 Surface sediment diatoms

Surface sediments were sampled during the period 1-5 September 1993. A short core was extracted from the deepest point in each of the sites (Figures A.1 - E.1) using a Glew gravity corer (Glew 1989). The surface sediment samples (0-0.5 cm or 0-1 cm) from each core were sub-sampled in the field and subsequently analysed in the laboratory.

Samples are prepared using standard techniques (e.g. Battarbee 1986), with a minimum count of 500 valves, then archived, computed and reported in the same way as the epilithon (section 4.3).

4.5 Open water phytoplankton

Although not included in the full survey programme, open water phytoplankton samples were taken from the five study sites using standard methods (Wetzel and Likens 1979), preserved with Lugol's iodine and stored at 4°C. These samples are available for possible future analysis, although if a detailed phytoplankton survey is required it may be more appropriate to re-sample the study lakes.

4.6 Aquatic macrophytes

Aquatic macrophyte surveys were conducted during the period 1-5 September 1993. A methodology was adopted, broadly following that of the Northern Ireland Lake Survey and the NCC survey of

Sutherland lochs. The aim was to maximise species detection and best summarise the abundance and location of individual species and communities, within the time constraint of one lake per day. The survey concentrated on those species which are regarded as strictly aquatic. Owing to the difficulty of defining the extent of adjacent wetland habitats, the time required to record the species therein and the limited usefulness of non open water vegetation in deriving classifications of lakes (Palmer 1992), it was decided to only record wet marginal vegetation that was easily visible from the open water.

Two techniques were applied to establish the presence and estimate the abundance of all submerged, floating and emergent aquatic macrophyte taxa.

Firstly the perimeter of the lake was inspected in a shoreline walk. Where shoreline morphology or the presence of deep growing emergent vegetation (eg. *Phragmites* or *Scirpus* beds) made access to the perimeter difficult, a small rubber dingy was employed. The littoral zone was searched thoroughly by wading out to a depth of approximately 1 metre. At frequent intervals during the shoreline walk, a double headed rake grapnel was cast perpendicularly from the lake shore to retrieve vegetation floating in the water column or attached to substrate beyond wadeable depth. The dingy was then employed in longitudinal and transverse transects of the lake, the grapnel being dragged frequently over approximately 2m lengths of the lake bed; all recovered species were recorded and mapped.

For each site, a list was compiled of all aquatic taxa, under the categories of emergent, floating or submergent. Using information gathered from the two survey techniques the abundance of each taxon was given a score according to the DAFOR scale as used in NCC lake surveys; dominant (D), abundant (A), frequent (F), occasional (O), rare (R). The classification of "dominant" was applied to taxa with a cover of 80% or more of the shoreline or open water. The occurrence of macrophyte stands, associations and isolated "rare" specimens was recorded on a map outline, photocopied on to an A4 sheet of waterproof paper. Notes were also made of the type of substrate, the location of inflows and outflows, potential pollutant inputs and other catchment details. In addition, photographs were taken of the most notable features of each site.

Voucher specimens of the more difficult plant groups were collected and subsequently dried, pressed and archived. *Potamogeton* specimens were sent to Chris Preston, of the Biological Records Office, for verification. Charophytes were preserved in alcohol and samples of filamentous green and blue-green algae in Lugol's iodine.

Species lists were used to type each site according to Palmer (1992) and in addition Palmer's DOME index was applied to provide the Trophic Ranking Score.

Macrophyte data are stored on the central database using the standard codes of Holmes *et al.* (1978).

4.7 Littoral Cladocera

The littoral Cladoceran populations of the five study sites were sampled during the period 1-5 September 1993. Six or seven sampling sites were chosen around the lake shores (Figures A.1 - E.1) in a range of vegetation communities and substrate types (Appendix F). The samples were taken using a hand-held net (0.2 mm mesh; 17 cm diameter) which was moved for one minute over the substrate and through any submerged vegetation present at each sampling site, from the edge of the lake down to a depth of one metre where possible. The substrate type at each sampling site was classified as mud-vegetation (MV), sand-rock (S) or a combination (C) of both these substrates (Appendix F). Replicates were taken at a number of sites to investigate the degree of variation between samples. All the material collected was preserved in the field in (approximately) 4% formalin. In the laboratory successive aliquots of each sample were examined in a scored petri dish using a binocular microscope.

A species list for each sample was compiled following the examination of all the material. Taxonomic monographs by Scourfield and Harding (1966), Flössner (1972) and Smirnov (1971) were used for the identifications.

All the individuals were counted in samples Coron 1, 2, 3, 5, 6, 7, Cwellyn 3, Idwal 1, 2A, 2B, 3, 4, 5, 6, 7 and Penrhyn 3, 4, 5. Concentrations were significantly higher in the remaining samples and in order to determine relative species concentration five aliquots were removed from each sample in suspension. The frequency of occurrence of the component species in each sample was estimated by counting the individuals of each species in each aliquot. Each sub-sample was returned to the sample before the next aliquot was withdrawn. These data were converted to percentages when all the samples had been analysed. Species reported as "+" indicate that they were present but not in sufficiently high concentrations to be recorded in the aliquots. Those recorded as "s" infers that only shell remains were found.

4.8 Open water zooplankton

Open water zooplankton were sampled during the period 1-5 September 1993 using an Apstein plankton net (diameter 20 cm, mesh size 200 μm) using vertical hauls from bottom to surface. Sample locations are given in Figures A.1- E.1. At least two hauls were combined in each sample. The sample was divided into three size fractions using sieves with mesh 0.71 mm and 0.42 mm respectively. The larger size fraction retained on the 0.71 mm sieve was composed entirely of Cladoceran species. The two smaller fractions were separated into Cladocera, Copepoda and algae using the narcotic- floatation technique of Straškraba (1964). The biomass of all fractions was measured as dry weight after 14 days storage in bottles with 4% formaldehyde. All dry weights reported take into account a correction factor for formaldehyde fixed dry weight. The sample from the deepest point of the lake was used for analyses of zooplankton structure.

To estimate the heterogeneity of lake zooplankton three vertical hauls at three different stations (A, B, C) were taken. The material from each haul was individually preserved and the total dry weight per single haul was estimated. Samples for determining the species composition of zooplankton were taken from two stations, at the deepest point (station A) and central part of the lake (station B) respectively. A species list was generated, and in this report species abundance is divided into three classes; common (>5% abundance), rare (species found in both samples analysed) and very rare (species found in one of samples analysed).

4.9 Littoral macroinvertebrates

The sampling protocol followed for littoral macroinvertebrates is that used in the annual survey of lakes of the UK Acid Waters Monitoring Network (Patrick *et al.* 1991). However, in this programme the lakes were sampled during two periods, autumn and spring, to obtain the fullest range of species. Macroinvertebrates in the five study lakes were sampled during the period 9-10 October 1993 to represent autumn populations, and on 4 April 1994 for spring populations. Five one minute kick/sweep samples were collected using a standard pond net (300 μm mesh) from the littoral zone of each lake. Sampling was carried out in the dominant habitat type for which it is feasible to collect replicate kick/sweep samples. All material is preserved in 4% formalin. The substrate type at each sampling site was noted and is described in Appendix G.

In the lab, all macroinvertebrates in each sample were separated from organic and inorganic material using a magnifying lamp, identified to the lowest possible taxonomic grouping, and counted.

Macroinvertebrate data are stored on the central database using the standard codes of Maitland (1977).

4.10 Sediment cores

Quantitative reconstructions of lake water quality derived from palaeolimnological analyses comprise a powerful technique for determining 'pre-pollution', 'background' levels. Such information might well be considered central to any classification and assessment of the conservation status of lakes. Although these techniques have not been funded as part of the current programme, sediment cores were retrieved and archived as a contingency measure.

Short sediment cores (*c.* 25-30 cm) were extracted from the deepest point in each lake using a gravity corer (Glew 1989) and extruded at 0.5 cm intervals down to 5 cm, and then 1 cm intervals to the base of the core. The sub-samples were returned to the laboratory and archived.

4.11 Data storage and analyses

All physical, chemical and biological data collected from the five lakes are stored within a central PARADOX data-base at the ECRC. The data-base structure allows flexible retrieval of the different data types, or combinations of data types, both for this project and for other potential users. Multivariate data analyses were performed using the computer programmes CANOCO 3.0 (ter Braak 1987, 1990) and MVSP Plus v.2.0 (Kovach 1990).

5 Results

Comprehensive results of the field surveys are presented as data tables and figures in appendices A-G. In the following section the main chemical and biological attributes of the sites are briefly discussed.

5.1 Physio-chemical Data

Llyn Idwal

The water chemistry of Llyn Idwal is indicative of a nutrient-poor, upland water body (Table A.1), although the lake shows relatively high alkalinity and pH compared to similar sites in north Wales (cf. Flower *et al.* 1989). Winter alkalinity levels are significantly lower than those recorded during the summer. Levels of phosphorus are low throughout the year, although there is a winter peak in nitrate levels (231 µg l^{-1}). Secchi disc transparency is relatively high (6-7 m) and total organic carbon (TOC) concentrations are low, demonstrating the clear water nature of the site. The oxygen and temperature data (Figures A.3 and A.4). indicate that during the summer sampling periods the lake was isothermic and oxygen saturation was high.

Llyn Cwellyn

The water chemistry of this site is also indicative of nutrient-poor conditions (Table B.1). The high secchi disc transparency (7-9 m) and low TOC concentrations emphasise the clear water nature of the site. Alkalinity is low throughout the year, typically below 40 µeq l^{-1}. Phosphorus levels are low throughout the year (<10 µg l^{-1}), although nitrate values exceed 200 µg l^{-1} over the winter period. The oxygen and temperature data indicate that the lake stratifies during the summer period with a thermocline developing at a depth of 10-15 m (Figures B.3 and B.4). However, oxygen levels remain high within the hypolimnion, and it is unlikely that the water column ever becomes deoxygenated.

Llyn Coron

The water chemistry of Llyn Coron is indicative of a highly alkaline, nutrient-rich lake (Table C.1). Alkalinity values exceed 2000 µeq l^{-1} over the summer period and mean total phosphorus >150 µg l^{-1}. Nitrate values show significant seasonal variation ranging from 14 µg l^{-1} in late summer to exceptionally high levels of >1400 µg l^{-1} in the late winter period. Chlorophyll *a* values are high in the September 1993 sample (56 µg l^{-1}), emphasising the productive nature of this site. The considerable fluctuation in nutrient and pH levels indicates the importance of biological processes in determining annual variation in water chemistry. Chloride levels are elevated throughout the year (>900 µeq l^{-1}), suggesting some marine influence on the chemistry. The oxygen and temperature data indicate relatively isothermal conditions, although there is some evidence of limited stratification in September 1993 (Figures C.3 and C.4). However, there is no evidence of significant water column deoxygenation from the data collected. The shallow, exposed nature of the lake almost certainly means that the water column will be regularly mixed.

Llyn Dinam

The water chemistry of Llyn Dinam is indicative of an alkaline, nutrient-rich lake (Table D.1). Total phosphorus concentrations are consistently above 110 μg l^{-1} and alkalinity above 1500 μeq l^{-1}, although significant seasonal variation is apparent in both alkalinity and nutrient levels. Values of TOC are generally high (>8 mg l^{-1}). Chloride values are very high throughout the year (>1400 μeq l^{-1}) suggesting a significant marine influence on water chemistry. There is no evidence of water column stratification from the oxygen and temperature data collected (Figures D.3 and D.4). The water column was isothermal during both sample periods and it is likely that the exposed, shallow nature of the site allows regular mixing of the water column.

Llyn Penrhyn

The water chemistry of Llyn Penrhyn is indicative of a highly alkaline, highly nutrient-rich lake (Table E.1). Alkalinity is consistently above 2000 μeq l^{-1} and shows relatively little seasonal variation. Phosphorus concentrations are particularly high, with total phosphorus only falling below 1000 μeq l^{-1} in the March sample. Nitrate levels are also very high, reaching a marked peak of 413 μeq l^{-1} in winter 1993. Chloride levels are consistently high (>1700 μeq l^{-1}), indicating a significant marine influence on water chemistry. There is no evidence of water column stratification from the oxygen and temperature data collected (Figures E.3 and E.4), and the water column was isothermal during both sample periods. It is likely that the exposed, shallow nature of the site allows regular mixing of the water column.

5.2 Epilithic Diatoms

Llyn Idwal

The epilithic diatom flora of Llyn Idwal is typical of nutrient-poor, circumneutral to slightly acid upland water bodies (Table A.2). The dominant taxon is *Achnanthes minutissima*, a cosmopolitan species very common in circumneutral waters. Other common species include *Brachysira vitrea* and *Nitzschia* [cf. *perminuta*]. Species diversity is relatively low with the three most common species accounting for nearly 70% of the total count.

Llyn Cwellyn

The epilithic diatom flora is acidophilous and indicative of oligotrophic waters (Table B.2). The flora is dominated by *Achnanthes minutissima*, a widely tolerant species common in circumneutral conditions. Other common species include *Tabellaria flocculosa*, characteristic of slightly acid water bodies with pH between 5 and 5.5, and *Fragilaria vaucheriae* which is indicative of more circumneutral waters. Species diversity is low with the three most common taxa accounting for over 80% of the total count.

Llyn Coron

The epilithic flora is dominated by *Fragilaria vaucheriae*, here split into two major types; fine (i.e. >12 striae in 10 µm) and coarse (i.e. <12 striae in 10 µm). Other common species include *Nitzschia fonticola* and *Navicula tripunctata* (Table C.2). The overall flora is alkaliphilous and indicative of nutrient-rich waters. Species diversity is relatively high.

Llyn Dinam

The epilithic diatom assemblages are dominated by *Nitzschia* species, particularly *Nitzschia inconspicua* and *Nitzschia palea* var. *debilis* (Table D.2). Other abundant species are *Rhoicosphenia curvata* and *Amphora pediculus*. These taxa are all associated with the littoral zones of alkaliphilous waters with intermediate nutrient levels.

Llyn Penrhyn

The epilithic diatom flora is dominated by *Rhoicosphenia curvata* with *Navicula radiosa* var. *tenella*, *Nitzschia amphibia* and *Navicula tripunctata* also common (Table E.2). The flora is indicative of high alkalinity, nutrient-rich waters.

5.3 Surface Sediment Diatoms

Llyn Idwal

The surface sediment diatom assemblage is indicative of a nutrient-poor, circumneutral, upland lake with relatively high alkalinity (Table A.3). The dominant species is *Achnanthes minutissima*, which has a pH optima of 6.3 (Stevenson *et al.* 1991). Other common species include *Brachysira vitrea*, *Nitzschia* [cf. *perminuta*] and *Fragilaria virescens* var. *exigua*. The similarity of the surface sediment assemblages to the epilithic assemblages suggests that the epilithic habitat is the dominant source of diatoms to the sediments and the extent of other habitat types is restricted. Planktonic diatoms are poorly represented in the sediment, although *Cyclotella* [*kuetzingiana* var. *minor*] and *Synedra acus* are present in abundances >2%.

Llyn Cwellyn

The surface sediment diatom assemblages are dominated by *Achnanthes minutissima*, with *Tabellaria flocculosa*, *Brachysira vitrea*, *Eunotia incisa* and *Fragilaria vaucheriae* also common (Table B.3). These species are typical of low alkalinity, nutrient-poor, soft-water lakes, and have pH optima around 6.0 (Stevenson *et al.* 1991). *Eunotia incisa*, however, is typical of more acid waters and has a pH optima of 5.1 (Stevenson *et al.* 1991). The assemblages are compositionally similar to the epilithic diatom flora, suggesting that the other habitat types are relatively unimportant sources of diatoms for the sediments. Planktonic diatoms are particularly poorly represented, with only *Cyclotella rossii* achieving an abundance >1%.

Llyn Coron

The surface sediment diatom assemblage is dominated by the planktonic taxa *Stephanodiscus parvus*, *Aulacoseira granulata* var. *angustissima* and *Cyclostephanos* [cf. *tholiformis*] (Table C.3). The flora is typical of strongly nutrient-rich, alkaline waters.

Llyn Dinam

The surface sediment diatom assemblage are dominated by the planktonic diatom *Stephanodiscus parvus* and the periphytic *Fragilaria construens* var. *venter* (Table D.3). High abundances of *Cyclostephanos* [cf. *tholiformis*] and *Fragilaria pinnata* are also recorded. There is a balance between the abundance of planktonic and periphytic forms. The assemblage is typical of alkaline, nutrient-rich, shallow waters. The high abundance of *Fragilaria* species could be due to these taxa growing *in situ* on the surface sediment. This is consistent with data on secchi disc transparency (Figure D.3), which indicate that the lake bottom is periodically within the photic zone.

Llyn Penrhyn

The surface sediment diatom assemblages are dominated by the planktonic *Stephanodiscus parvus* with the periphytic *Navicula menisculus* and non-planktonic *Fragilaria* species and *Cocconeis* species also common (Table E.3). The high proportions of *Cocconeis* types indicates the importance of epiphytic habitats at this site. The assemblages are indicative of alkaline, nutrient-rich, shallow waters.

5.4 Aquatic Macrophytes

Llyn Idwal

The main bay of Llyn Idwal is largely dominated by the isoetids *Isoetes lacustris*, *Lobelia dortmanna* and *Littorella uniflora* and *Juncus bulbosus* var. *fluitans* (Figure A.2 and Table A.4). The maximum depth of *Isoetes lacustris* is restricted to approximately 2.5 m although bryophytes occur below this. The charophyte *Nitella* is locally abundant and is particularly evident in shallow water in the north-west. *Potamogeton berchtoldii* is locally frequent in deeper water in the north. *Subularia aquatica*, *Myriophyllum alterniflorum* and *Callitriche hamulata* occur frequently throughout. Emergent and floating vegetation is mainly confined to the relatively sheltered, shallow sub-basin at the south end, where *Sparganium angustifolium* forms extensive mats alongside stands of *Phragmites australis*, *Equisetum fluviatile* and *Carex rostrata*.

The aquatic macrophytes can also be described in terms of the communities present, using the National Vegetation Classification (NVC) (Rodwell 1991, Rodwell in preparation). The *Littorella uniflora - Lobelia dortmanna* community (A22) is most apparent in shallow water up to approximately 1m water depth, particularly on the east and west shores and often includes *Subularia aquatica*, *Myriophyllum alterniflorum*, *Juncus bulbosus* var. *fluitans* and a short prostrate form of *Isoetes lacustris*. The *Myriophyllum alterniflorum* community (A14) including *Callitriche hamulata* and *Juncus bulbosus* var. *fluitans* interrupts the *Littorella-Lobelia* dominance in patches in shallow water in the north and more clearly in parts of the southern bay.

In deeper water the *Isoetes lacustris* community (A23) including *Lobelia dortmanna*, *Juncus bulbosus* var. *fluitans*, *Myriophyllum alterniflorum* and *Callitriche hamulata* occurs to a depth of approximately 2.0 m, below which the community becomes a more homogenous stand of *Isoetes lacustris* only, to a depth of 2.5m.

The sheltered southern bay contains several stands of *Sparganium angustifolium* alongside species-poor communities of *Carex rostrata* (S9), *Equisetum fluviatile* (S10), *Potamogeton natans* (A9), *Phragmites australis* (S4) and *Juncus bulbosus* (A24).

Notable aquatic species, recorded in CCW archives following previous surveys at this site, which were not found during this project survey include the following: *Callitriche brutia* (1972, 1976, 1976), *Elatine hexandra* (1972, 1976, 1976), *Pilularia globulifera* (1979), *Scirpus lacustris* (1976, 1976), *Sparganium erectum* (1976, 1976), *Sparganium minimum* (1980). See Appendix H for a complete list of species and survey dates. *Scirpus lacustris* and *Sparganium minimum* are considered rare for the NRA Welsh region (Palmer and Newbold 1983).

Llyn Cwellyn

The macrophyte flora of Llyn Cwellyn is typical for a nutrient-poor system, characterised by the abundance of the isoetids *Isoetes lacustris*, *Lobelia dortmanna* and *Littorella uniflora* and *Juncus bulbosus* var. *fluitans* (Figure B.2 and Table B.4). *Isoetes lacustris* grows to a depth of 5.5 m which is considerable, even for a clear water lake. *Myriophyllum alterniflorum* occurs frequently, and the rare species *Subularia aquatica* is also abundant in places. The acidophilous moss *Sphagnum auriculatum* occurs occasionally and the moss *Fontinalis antipyretica* is locally abundant in the south where *Juncus bulbosus* grows most prolifically. Surprisingly, a small number of individuals of *Elatine hexandra* were detected in shallow water off the north shore. There is little growth on the north-west shore littoral zone above approximately 40 cm depth, presumably as a result of wave action and the resulting instability of the shoreline environment. The shoreline is generally boulder strewn with a predominance of slates in the north-west.

The macrophyte communities present at Llyn Cwellyn can be described with reference to the NVC (Rodwell 1991, Rodwell in preparation). The *Littorella - Lobelia* community (A22) is dominant in shallow water around most of the perimeter and includes *Subularia aquatica*, *Callitriche hamulata*, *Juncus bulbosus* var. *fluitans*, *Myriophyllum alterniflorum* and *Littorella uniflora*. It is interrupted in places, particularly on the south-western shore, by what can better be described as the *Myriophyllum alterniflorum* community (A14) which again includes *Callitriche hamulata*, *Juncus bulbosus* var. *fluitans* and *Littorella uniflora*.

Below approximately 1m there is a transition to the *Isoetes lacustris* community (A23) which includes the shallow water species mentioned above down to a depth of 2m. *Callitriche hamulata* remains associated to about 3m below which the community becomes an almost homogenous stand of *Isoetes lacustris* (apart from occasional mosses including *Sphagnum auriculatum*) to a depth of 5.5m.

A single small *Potamogeton natans* community (A9) occurs off the north-west shore.

Notable aquatic species, recorded in CCW archives following previous surveys at this site, which were not found during this project survey include the following: *Callitriche brutia* (1972), *Callitriche stagnalis* (1980), *Luronium natans* (1895, 1972, 1980), *Phragmites australis* (1895, 1972). See Appendix I for a complete list of species and survey dates. *Luronium natans*, which is considered rare for the NRA Welsh Region (Palmer and Newbold 1983), has been previously recorded at the lake inflow (Wade pers comm.) and was observed on the north shore of the lake in summer 1994 (Jones pers comm.).

Llyn Coron

The macrophyte distribution within Llyn Coron is shown in Figure C.2 and a species list is presented in Table C.4. The littoral zone of the lake is dominated by sand and gravel. During the survey the lake was covered by a bloom of the alga *Microcystis aeruginosa* which severely limited the transparency of the water and made the detection of some littoral species difficult. The alga *Enteromorpha* sp. was present throughout and appeared to be growing profusely in places often in association with *Callitriche stagnalis*. The western shoreline is dominated by several stands of *Scirpus lacustris* ssp. *tabernaemontani* fringed occasionally on the open water side by *Polyganum amphibium*. *Elatine hydropiper* is locally abundant in shallow water on both the northern and southern shoreline. The eastern margin of the lake is largely open and free of emergent vegetation, *Callitriche stagnalis* forming only sparse cover over the stony littoral. A single large stand of *Phragmites australis* exists in a silty bay in the south east. Despite the largely nutrient-rich characteristics of the site *Littorella uniflora* is present on the northern shoreline and a single specimen of *Myriophyllum alterniflorum* was found close to a nearby inflow. Occasional specimens of *Potamogeton perfoliatus* were found close to the southern and northern shorelines. A single specimen only of *Potamogeton trichoides* was recovered from a rake trawl. The alien aquatic *Elodea canadensis* was found in small amounts at three isolated locations.

The macrophyte communities present can also be described with reference to the NVC (Rodwell 1991, Rodwell in preparation). The *Scirpus lacustris* spp. *tabernaemontani* community (S20), which most commonly occurs in brackish sites, is represented in large stands along the western shore-line. It is occasionally adjoined by smaller patches of the *Polyganum amphibium* community (A10) which is able to exploit the relatively coarse substrate. The species-poor *Callitriche stagnalis* (A16) community is present in patches along much of the shoreline and in deeper water. The *Phragmites australis* community (S4) is represented as a single stand in a sheltered bay in the south-east.

Notable aquatic species, recorded in CCW archives following previous surveys at this site, which were not found during this project survey include the following: *Apium nodiflorum* (1983), *Elatine hexandra* (1982), *Equisetum palustre* (1895), *Juncus bulbosus* (1983), *Mentha aquatica* (1983), *Myriophyllum spicatum* (1982, 1983), *Polyganum amphibium* (1983), *Potamogeton pectinatus* (1895), *Ranunculus flammula* (1895, 1983), *Apium inundatum* (1982), *Baldellia ranunculoides* (1895, 1957, 1983), *Callitriche hermaphroditica* (1982, 1983), *Ceratophyllum demersum* (1895, 1982), *Lemna trisulca* (1982),*Luronium natans* (1895, 1982), *Oenanthe fistulosa* (1895, 1982), *Potamogeton crispus* (1983),*Potamogeton pusillus* (1895, 1957, 1982) and *Rumex hydrolapathum* (1982). The latter ten species are considered rare for the NRA Welsh region (Palmer and Newbold

1983). See Appendix J for a complete list of species and survey dates.

Llyn Dinam

Llyn Dinam is extremely shallow with a shoreline dominated by *Phragmites australis* and to a lesser extent *Scirpus lacustris* ssp. *lacustris* (Figure D.2 and Table D.4). In the north there is a limited stretch of open shoreline, maintained by cattle grazing, and the open water here contains abundant *Elatine hydropiper*, *Callitriche hermaphroditica* and *Littorella uniflora*. *Ceratophyllum demersum* occurs in abundance in much of the open water habitat often in association with *Callitriche hermaphroditica* and *Lemna trisulca*. The charophyte *Nitella* sp. and the moss *Fontinalis antipyretica* thrive at the far eastern end. A second charophyte species *Chara* sp. (to be verified) was found close to the shore at the western end. *Nymphaea alba* and *Nuphar lutea* dominate a sheltered arm of the lake in the west. Three species of *Potamogeton*, *P.pectinatus*, *P.perfoliatus* and *P. pusillus* were found, the latter being the most frequent and occurring mainly close to the shore in the eastern half of the lake.

The NVC communities present at Llyn Dinam are as follows. Most of the perimeter is occupied by the *Phragmites australis* sub-community of the *Phragmites australis* community (S4), with *Typha latifolia* and *Scirpus lacustris* var. *lacustris* being locally prominent. *Typha lacustris* grows particularly well on the open water side of *Phragmites* around the outflow. The *Nymphaea alba* community (A7) occurs in patches, mainly in sheltered western bays. Much of the open water contains *Ceratophyllum demersum* which appears to grow in association with *Callitriche hermaphroditica* and *Lemna trisulca*, but there is no evidence of *Elodea canadensis* or other species which are usually important members of the NVC *Ceratophyllum demersum* community. The *Potamogeton pectinatus* - *Myriophyllum spicatum* community (A11) occurs out from the *Phragmites* fringe in the north-east and includes occasional *Potamogeton pusillus*.

Notable aquatic species, recorded in CCW archives following previous surveys at this site, which were not found during this project survey include the following: *Alisma plantago aquatica* (1977, 1983, 1988), *Apium nodiflorum* (1982), *Elatine hexandra* (1983), *Elodea canadensis* (1978, 1983, 1988), *Equisetum fluviatile* (1983), *Limosella aquatica* (1910), *Lobelia dortmanna* (1813), *Apium inundatum* (1895, 1957, 1972, 1982), *Baldellia ranunculoides* (1972, 1983) and *Potamogeton crispus* (1988); the latter three species are considered regionally rare for the NRA Welsh region. See Appendix K for a complete list of species and survey dates.

Llyn Penrhyn

Slightly deeper than Llyn Dinam with a maximum depth of approximately 3 m, Llyn Penrhyn includes a significant deeper water zone where submerged vegetation is either sparse or absent. However, like the neighbouring site, the margin is dominated by *Phragmites australis* often fringed on the open water side by *Scirpus lacustris* ssp. *lacustris* (Figure E.2 and Table E.4). A few large stands of *Nymphaea alba*, with associated *Nuphar lutea*, occur in sheltered bays in the west.

Ceratophyllum demersum dominates some submerged areas and often occurs with *Callitriche hermaphroditica* and the alien aquatic species *Elodea canadensis*. Of the three *Potamogeton* species found *P. crispus* and *P. pectinatus* are most frequent, occurring mainly on the western margins. The alga *Enteromorpha* sp. is locally abundant, particularly in the east. No charophyte or bryophyte species were found.

The NVC communities present are as follows. As is the case at Llyn Dinam much of the perimeter of Llyn Penrhyn is occupied by the *Phragmites australis* community (S4). In the west however it is often succeeded on the open water side by the *Scirpus lacustris* var. *lacustris* swamp community (S8). Extensive *Nymphaea alba* communities (A7), occasionally bordered on the deep water side by *Nuphar lutea* occur in sheltered western bays. Much of the open water is occupied by the *Ceratophyllum demersum* community (A5) including *Elodea canadensis* and some *Callitriche hermaphroditica*. The *Potamogeton pectinatus* community (A12) occurs in patches in open water off stands of *Scirpus lacustris*.

Notable aquatic species, recorded in CCW archives following previous surveys at this site, which were not found during this project survey include the following: *Apium nodiflorum* (1983), *Callitriche brutia* (1972), *Lobelia dortmanna* (1895), *Mentha aquatica* (1978, 1983), *Potamogeton berchtoldii* (1983), *Potamogeton obtusifolius* (1895, 1983), *Ranunculus circinatus* (1895, 1957, 1972), *Ranunculus flammula* (1983), *Sparganium emersum* (1972) *Utricularia australis* (1895, 1982), *Hippuris vulgaris* (1983), *Hottonia palustris* (1895), *Myriophyllum spicatum* (1972, 1978, 1982), *Oenanthe fistulosa* (1983), *Potamogeton lucens* (1972), and *Potamogeton perfoliatus* (1895). The latter six species are considered rare for the NRA Welsh region. See Appendix L for a complete list of species and survey dates.

5.5 Littoral Cladocera

A total of 34 Cladocera species have been recorded from the ten samples examined from the five study sites (Figures A-E.1, Appendix F). Results are given in Tables A-E.5 and Tables A-E.6. Unfortunately the *Argulus* specimen from Llyn Dinam was without its abdominal lobes and could not be identified to species level. The number of Cladocera species was in the range 3-11 for each sample and 11-16 for each lake.

With the exception of Llyn Idwal, it was noted that >70% of the total species number was recorded following the examination of three samples covering the range of substrate types recorded for each lake (Tables A-E.6). Only one additional species was recorded at sampling sites where replicate samples were taken.

Idwal had the highest species diversity with a total of sixteen species being recorded (Table A.5). Coron had the lowest species diversity with eleven species being recorded. Although Idwal had high species diversity there was a relatively small number of specimens in each sample. *Chydorus sphaericus*, *Eurycercus lamellatus* and *Pleuroxus aduncus* were found in all lakes. However, the latter species was noticeably less abundant in the Snowdonia lakes.

It is evident that there is little species overlap between the Anglesey and Snowdonia sites. *Acroperus harpae*, *Alona affinis*, *Alona rustica*, *Bosmina coregoni*, *Diaphanosoma brachyurum*, *Eubosmina longispina*, *Pleuroxus trigonellus* and *Scapholeberis mucronata* are the only additional species which occurred in both an Anglesey and Snowdonia lake.

The differences in cladoceran species composition between the Anglesey and Snowdonia lakes is amplified when the ecology of the rarer component species is examined. For example, *Alona rustica*, *Alonopsis elongata*, *Alonella excisa*, *Chydorus piger*, *Diaphanosoma brachyurum*, *Drepanothrix dentata* and *Polyphemus pediculus* are confined to the Snowdonia sites and all are known to favour waters with low productivity (Fryer and Forshaw, 1979; Duigan 1992). Scourfield (1895) remarked that *Alonopsis elongata* was one of the most abundant and widely distributed Cladocera of North Wales. He also frequently found *Polyphemus pediculus* in the Snowdon district. In contrast, *Daphnia longispina*, *Daphnia pulex*, *Pseudochydorus globosus* and *Simocephalus vetulus* are confined to the Anglesey lakes. Other studies have shown that they are most frequently found in lowland, relatively alkaline sites with abundant macrophyte growth (Fryer 1993). The ubiquitous nature of species such as *Eurycercus lamellatus*, *Alona affinis* and *Chydorus sphaericus* is supported by investigations in other regions (Duigan 1992, Fryer 1993).

A relationship between pH and cladoceran species distribution is supported by a number of independent investigations. This research has lead to the identification of a pattern of decreasing faunal diversity with increasing alkalinity, with the most diverse assemblages at low pH values (Whiteside 1970, Synerholm, 1979, Crisman 1980, Chengalath 1982). This trend is supported by the results of this study as the most acidic sites (Idwal and Cwellyn) have the highest species diversity.

Only two previous investigations have focussed on the Cladocera of North Wales (Scourfield 1895; Galliford 1953). As a result of the general paucity of knowledge on the distribution of Cladocera in Wales, a complete assessment of the conservation importance of communities reported here is dependent on further investigations.

Taxonomic Note

Taxonomic monographs by Scourfield and Harding (1966), Flössner (1972) and Smirnov (1971) were used for the identification of the littoral Cladocera species. After production of the preliminary data report efforts were made to standardise the taxonomy used to report the open water and littoral zooplankton communities. For example *Biapertura affinis* is now reported as *Alona affinis* and *Daphnia hyalina* var. *galeata* was substituted for *Daphnia galeata*. The identification of *Daphnia longispina* from Llyn Coron has been revised to *Daphnia hyalina*. In the preliminary data report the analysis of Llyn Dinam littoral Cladocera sample 2 was reported in error as sample 7.

5.6 Open Water Zooplankton

Results of the open water zooplankton survey are given in Tables A-E.7 and A-E.8. There were considerable differences in the zooplankton species composition of the study lakes. Of the 31 planktonic taxons identified in the five lakes no single taxon was common to all five lakes. This is possibly because of the wide gradient of trophic conditions covered in the study.

Species common in Llyn Idwal included *Cyclops abyssorum*, *Eubosmina longispina*, *Daphnia longispina* and *Arctodiaptomus laticeps*. However, diversity at this site was low with only five species identified (Table A.7). Llyn Cwellyn had a comparatively diverse zooplankton fauna, with nine species identified from the samples (Table B.7). Common species included *Cyclops abyssorum*, *Sida crystalina*, *Diaphanosoma brachyurum* and *Eudiaptomus gracilis*.

Llyn Coron also had a relatively diverse fauna with a total of 10 species identified from the samples. Common species included *Cyclops strenuus*, *Cyclops vicinus* and *Daphnia hyalina* var. *galeata* (Table C.7). The most similar sites in terms of zooplankton species composition were Llyn Dinam and Llyn Penrhyn; out of 13 planktonic crustacean species identified in the study seven were common in both these lakes (Tables D.7 and E.7). Llyn Dinam was characterised by *Eudiaptomus gracilis*, *Eucyclops serrulatus*, *Ceriodaphnia dubia*, *Macrocyclops albidus* and *Bosmina longirostris*. Llyn Penrhyn was characterised by high abundances of *Daphnia pulicaria*, *Daphnia hyalina* var. *galeata*, *Cyclops strenuus* and *Eudiaptomus gracilis*.

5.7 Macroinvertebrates

Macroinvertebrates were abundant in the littoral zones of all the lakes studied (see Tables A-E.9), however, the following should be noted in reading these data tables:

i. It is not possible to identify triclads to species level from preserved specimens.
ii. Individuals of Baetidae, *Leptophlebia* sp., Corixidae - immatures and *Limnephilus* sp. are all very small and cannot be identified to species level.
iii. There are no identification keys to the groups Haliplidae sp. - larvea; Dytiscidae - larvea; *Hydroptila* sp.; and *Oxyethira* sp.
iv. More detailed identification of the *Haliplus ruficollis* group rely on male genetalia and are beyond the scope of this project.
v. More detailed descriptions of Diptera are extremely difficult and beyond the scope of this project.
vi. To avoid duplication, the measure of species richness does not include unidentified immatures where more mature specimens in the same group were present (e.g. for Llyn Coron, immature Corixidae were not included in the count as adults of the same group were present).

The most marked division among the lakes based on the macroinvertebrate fauna was between the upland, nutrient-poor lakes (Llynnau Idwal and Cwellyn) and the lowland, nutrient-rich lakes of Anglesey. The upland lakes have fewer species, but by no means a particularly impoverished fauna, whereas the lowland lakes are more species rich and have higher invertebrate densities.

The macroinvertebrate fauna of both nutrient-poor lakes is dominated by insect taxa typical of stony lake shores. The littoral food webs are probably based in attached algae and fine detritus on the lake bottom. Species of leptophlebiid and caenid mayflies that typically occur in the silt/mud between stones, feeding on periphyton and detritus, were common. Similar habitats are characteristic of both larvae and adults of the abundant elmid beetle *Oulimnius troglodytes*. Other abundant taxa such as the net-spinning polycentropodid caddis flies and Corixidae are primarily predatory in their feeding habits. The Plecoptera found in Llyn Cwellyn are perhaps more usually associated with running waters, but are characteristic of wave lashed lake shores - a dominant feature of this lake. Neither lake showed a marked change in species composition between autumn and spring, bearing in mind the heterogeneity inherent to these habitats and the sampling methods used. The apparent spring boom in the number of plectopteran species in Llyn Cwellyn is attributable, at least in part, to life stages of these species. For example , *Capnia bifrons* was probably in diapause, buried deep in the substrates during the autumn sampling, but active again in time for spring sampling.

The three lowland lakes (Llynnau Coron, Dinam and Penrhyn) are all characterised by abundant and diverse assemblages of molluscs, leaches, amphipods, isopods and various insects, all typical of highly productive, nutrient-rich conditions. The macroinvertebrate food web is dominated by the well developed macrophyte beds found in all these lakes. The molluscs graze periphyton growing on plant stems and leaves, whereas the super-abundant *Asellus* and *Gammarus* shred decomposing plant parts and other detritus. The leaches are all predatory on invertebrates, and primarily those living on macrophyte surfaces, with the exception of *Theromyzon tessusatum* which is parasitic on water birds. The Corixidae and Odonata are also important predators within macrophyte beds where they escape the predation pressures of fish restricted to the more open water. Llynnau Penrhyn and Dinam have very similar species assemblages. Differences between them probably reflect small-scale variations among local micro-habitats rather than whole-basin differences. The most distinguishing feature of Llyn Coron is the dominance of *Asellus meridianus*, whereas the other two Anglesey lakes are dominated by the more common *A. aquaticus*. *A. aquaticus* is widely distributed throughout the British Isles; *A. meridianus* tends to be restricted to western and island areas, although the ecological differences between these two species are unclear. The most marked seasonal change in species composition in these three lakes was a decline in the abundance of *Asellus* spp. and an increase in numbers of Chironomidae. These is some suggestion of a decline in numbers of Hirudinea from autumn to spring and this may reflect a shift in their microdistribution from the shallow littoral zone to deeper water for the winter period, rather than any population cycles.

5.8 Site Comparison

The data consistently indicate a profound difference between the physical, chemical and biological characteristics of the Anglesey lakes (Llynnau Coron, Dinam and Penrhyn) and the Snowdonia lakes (Llynnau Idwal and Cwellyn). The former are shallow and nutrient-rich, the latter nutrient-poor and relatively deep. Classification using almost any of the chemical or biological data collected will emphasise the dichotomy between these two principal lake types. There are few similarities in the overall biological communities of the two lake types, and few species are common to both the nutrient-poor and nutrient-rich sites.

Closer examination of the data, however, reveals important differences within the two broad site types. Several important distinctions can be made between Llynnau Idwal and Cwellyn, even though both lakes are nutrient-poor. There are obvious differences in topographic and bathymetric factors such as altitude, lake and catchment size, mean depth, and extent of shallow water. Llyn Idwal is a high altitude, relatively shallow lake whereas Llyn Cwellyn is much deeper, larger and at lower altitude. In addition, the alkalinity of Llyn Idwal is considerably higher than Llyn Cwellyn. There are also differences in the biological communities of the two lakes. For instance, Llyn Idwal includes taxa indicative of relatively high alkalinity conditions such as the diatom *Nitzschia* [cf. *perminuta*], and the charophyte *Nitella*. The open water zooplankton communities recorded are also rather different, with only *Cyclops abyssorum* being common between the two lakes.

Although the characteristics of the three nutrient-rich lakes in Anglesey are broadly similar, there are some profound differences in both physio-chemical variables and biological communities. Llyn Penrhyn, for example has a much higher estimated hydraulic residence time than the other sites, and Llyn Dinam has a relatively low alkalinity. All three sites have high concentrations of phosphorus and nitrate, but Llyn Penrhyn is outstanding in experiencing phosphorus concentrations an order of magnitude higher than the other two sites. Llyn Coron is distinguished by exceptionally high winter nitrate values. There are also considerable differences in biological communities. For instance, the diatom assemblages of Llyn Penrhyn and Llyn Coron are dominated by the planktonic *Stephanodiscus parvus*, indicative of highly nutrient-rich conditions. This taxon is less abundant in Llyn Dinam. Similar contrasts can be noted in other biological communities of the lakes. The zooplankton communities of the three lakes share some common species, but are essentially distinctive. The macroinvertebrate data emphasises the dominance of *Asellus meridianus* at Llyn Coron, whereas the other two sites are dominated by *A. aquaticus*.

These considerations suggest that although preliminary classifications will probably be dominated by the differences between the two broad site types, there is considerable scope for producing useful schemes which will characterise sites on a finer resolution (e.g. within nutrient-rich or nutrient-poor site types).

6 Discussion

6.1 Critique of survey methodologies

The survey has adopted recognised sampling protocols and analytical quality control procedures wherever possible. At this stage, however, some evaluation can be made of the suitability of these protocols in order that appropriate changes can be made for later stages of the programme.

The scheduling and methodologies of sampling are designed to maximise species/community detection, or in the case of physio-chemistry useful data-generation, within the budgetary constraints of the project. A clear compromise must therefore be established between sampling intensity on the one hand and resource availability on the other. The sampling regime for this project was adopted following consultation with the various specialists involved, and is felt to provide suitable physio-chemical and biological data for lake classification purposes. Most sampling exercises can be achieved for a particular site by one or two individuals over the course of one day, the most obvious exception being water chemistry where four samples through a year are required. Clearly other factors, particularly laboratory analysis, must also be taken into account.

Whether or not a particular biological species is detected or adequately recorded at a site will depend to some extent on the timing of its life cycle and whether its habitat is sufficiently sampled. Of all the biological groups the aquatic macrophytes are probably simplest to record comprehensively, owing to their longevity, size and because (with the exception of some free floating species) they are static. Diatom floras are also straightforward to sample and can be comprehensively quantified, although specialist laboratory analysis is required. The faunal groups, which are generally more ephemeral and free moving, can be more problematic. Although the sampling methodologies adopted certainly allow adequate characterisation of community types, how representative the faunal samples are of the total faunal populations of the five study sites has not been investigated in this project. Such detailed evaluation of sample representivity would require considerable resources. Representivity studies have been carried out in other projects, such as that on invertebrates in the Acid Waters Monitoring Network. Such information will be important in evaluating the power of the survey data for classification purposes, as well as the potential as an environmental monitoring resource.

Value of survey data for integrated classification

Although the parameters measured in this survey were selected to provide as comprehensive coverage of physio-chemical variables and biological communities as possible, an important issue is the extent to which the various components of the survey data provide a useful basis for an integrated classification scheme. Effective integrated classification requires data on as many aspects of lake ecosystem variation as possible. By definition, the parameters which best summarise total ecosystem variation will remain unknown until a complete data-set of lakes is available, and at this point the value of each of the data-types collected can be fully evaluated. However, it is important to note that several biological communities have not been surveyed, including benthic macro-invertebrates and fisheries. Phytoplankton communities are another important component of lake ecosystems which have not so far been characterised.

Two data types included within the survey require further consideration; water chemistry and littoral macroinvertebrates.

Water chemistry

Three aspects of the water chemistry methodologies need to be considered; choice of determinands, representivity of the sampling regime, and location of sampling site.

A total of 29 types of chemical determination have been made from each of the lake site. Although all help to characterise the lake systems, if significant co-variance exists some may have limited value for lake classification. However, the extent to which the chemistry collected from the five sites is representative of the full range of conditions in Welsh lakes is unknown, and a complete evaluation will only be possible once the full data-set has been assembled.

An effective water chemical sampling regime will both provide sufficient information on seasonal variation and allow mean conditions to be assessed with accuracy. Clearly the greater the number of samples obtained through the year, the better represented the chemical conditions will be. These considerations must be balanced against the costs of sampling and analysing each sample. The protocol adopted (four samples per annum) has been extensively used in nutrient-poor soft-water systems (e.g Patrick *et al.* 1991). Nutrient-rich systems, however, can experience more significant variation in water chemistry (e.g. Bennion 1993) and require more than four samples per year. The chemistry presented for the three nutrient-rich sites may therefore not represent the full range of seasonal variation. Despite this consideration, however, it is recommended that a sampling regime of four samples a year is retained for all sites. Costs preclude more frequent sampling, and four samples provide adequate data for site classification and some useful data on seasonal variation.

In the site surveys conducted so far water samples were taken from the middle of each lake. This has provided a major logistical constraint as a boat is required for each visit to the lakes. A more practical method would be to sample at the lake outflow, a methodology widely adopted for soft-water systems (e.g. Kreiser *et al.* 1993). At nutrient-rich sites, however, some variation might be expected between water chemistry in the middle of a lake and at the outflow, and if such a change in sample protocol is adopted it will require some further evaluation.

Macroinvertebrates

The sampling protocol adapted from the UK Acid Waters Monitoring Network was appropriate for the nutrient-poor, soft-water lakes (Llynnau Idwal and Cwellyn). However, it was probably not the best strategy for the more productive sites. The mechanics of collecting samples was not particularly difficult, although extensive macrophyte beds can make access difficult. Processing littoral macroinvertebrate samples is time consuming and labour intensive, and the huge numbers of organisms associated with the vegetative material recovered from the productive lakes resulted in exorbitant laboratory effort. The very nature of the vegetative material precluded sub-sampling.

In future surveys of productive sites it should be possible to make the sampling process much more efficient and effective by reducing sample kick/sweeps to 30 or even 20 seconds, yet still maintain the same degree of replication. Because the number of organisms collected is so large, it should also be possible to characterize the fauna adequately with five smaller samples, even for the upland lakes.

Invertebrate sampling is relatively labour and cost intesive, as it requires both field sampling and specialist laboratory analysis. An measure that would improve the labour/cost effectiveness of the invertebrate sampling would be to reduce the sampling programme to one per year, the protocol adopted for the other biological groups. Invertebrate communities can show considerable annual variability, so by definition this measure would reduce the representivity of the samples. Comparison of the invertebrate data, however, indicates the overall similarity between invertebrate samples taken in autumn and spring (Table A-E.9). There are differences between the sets of samples, but these reflect the detection of rare species rather than the dominant community types. At the nutrient-poor sites, for example, slightly higher species numbers are recorded in the spring period. There are no major changes in the invertebrate assemblages recorded between the two periods. Future surveys could therefore adopt a single site visit as the invertebrate sampling protocol.

6.2 Strategy for data analyses and integrated classification

A range of ordination and classification techniques may be applied to the different individual data types or data formats presented in this report. For example, Palmer (1992) used the ordination programme DECORANA (Hill 1979a) and the classification programme TWINSPAN (Hill 1979a) to produce the classification based on aquatic macrophyte communities. Classifications based on individual biological groups and physical and chemical data will comprise an ongoing component of this programme. However, the field survey data provide an excellent basis for the assessment and integrated classification of lake ecosystems and a wide variety of powerful techniques are available for analysing the types of multi-variate chemical and ecological data presented in this report (e.g. Jongman *et al.* 1987, ter Braak 1987).

Data analyses within this study programme will focus on four areas;

i) Application of existing classification systems to the study lakes. These systems include chemical classifications (e.g. OECD 1982) and biological classification (e.g. Palmer *et al.* 1992). The data on water chemistry and selected biological groups can also be assessed with respect to existing data-sets of lake chemistry and biology (e.g. Flower *et al.* 1989, Stevenson *et al.* 1991, Anderson & Bennion unpublished).

ii) Development of lake classifications based on individual biological groups, physical and chemical data. These classifications will be generated using ordination and classification techniques appropriate to the individual data types. Seperate analysis of the various biological components will also allow the relationships between species occurrence and environmental parameters to be established.

iii) Development of data analytical methodology for an integrated classification system.

iv) Comparison of integrated classification with results of existing lake classifications and classifications generated from individual biological groups, physical and chemical data.

i) can be addressed as each new lake is added to the database but a major weakness of the current study is the need to utilise many more than five sites in any widely applicable classification scheme. The five sites studied to date clearly do not adequately represent the full range of standing water types in the region of interest and therefore ii) and iii) will develop only when the database of sites reaches a size appropriate for the relevant statistical techniques (*c.* 30+). Until such a time the classifications generated will be preliminary, useful for exemplification only, and will need to be progressively refined by the addition of data from a wider range of sites. The ultimate objective of this work must be to survey a sufficient number of sites of diverse nature to permit a full comparative evaluation of both the individual and integrated classification schemes generated (i.e. iv) above).

The classification schemes produced as a result of this programme will be defined by the data-set used to generate them, but also by the weighting given to each variable in this data. It is proposed to base the integrated classification scheme on the dominant gradients in lake ecosystem characteristics revealed in the final data-set. These might be gradients in certain water chemical parameters or biological communities. Such an approach is designed to maximise the overall ecosystem variation in Welsh lakes represented by the classification. Site assessment and selection in conservation is increasingly concerned with representivity (e.g. Usher 1986), but there are always certain individual species of particular conservation interest (e.g. Boon *et al.* 1992). It is therefore intended that a seperate site classification will be generated based on the presence/absence of rare species, or those of particular conservation interest. Comparison with the overall integrated scheme will allow the relationship between ecosystem variation and the presence of important species to be addressed.

6.3 Application of existing classification schemes

The data presented within this report can be used to classify the five lakes according to the most relevant of the existing classification schemes described earlier (Table 6.1). These schemes include the thermal mixing classification of Lewis (1983), the OECD (1982) trophic state scheme, the Dillon and Rigler (1975) classification for lake use, the UKAWRG scheme for acid waters (UKAWRG 1989), the two critical loads schemes for predicting lake acidification (Battarbee *et al.* 1993, Harriman and Christie 1993), and the schemes designed for nature conservation use of Ratcliffe (1977), Palmer *et al.* (1992) and the National Vegetation Classification.

On the basis of thermal mixing the five sites can be divided into warm monomictic lakes (the two Snowdonia sites) and continuous warm polymictic (Anglesey sites). This division is based on the limited data on thermal conditions collected during the survey period. It is possible that the considerable altitude of Llyn Idwal leads to significant annual winter ice cover, in which case this site may be classified as cold polymictic. Indeed, complete ice cover was observed on 27 November 1993. Similarly it is possible that during warm, calm summer periods the Anglesey lakes stratify for days or weeks at a time. In this case they would be classed as discontinuous warm polymictic.

According to the Dillon and Rigler (1975) classification, Llynnau Idwal, Cwellyn and Dinam are class I sites (suitable for recreational use maintaining a salmonid fishery), Llyn Penrhyn falls into class II (suitable for recreational use where a salmonid fishery is not of importance), and Llyn Coron class IV (suitable only for Cyprinid species). The classification of Llyn Dinam together with the Snowdonia lakes seems anomalous, but is due to the low chlorophyll *a* levels measured at this site. A major weakness of this classification is its failure to take into account the presence or absence of suitable spawning habitats. It is very unlikely that Llynau Dinam or Penrhyn could support self sustaining salmonid populations due to the physical nature of the environment alone. The classification for Llyn Coron is in conflict with the fact that it is currently run as a stocked brown trout fishery

The OECD (1982) trophic state scheme divides the lakes into three categories. The two Snowdonia lakes are classed as oligotrophic, Llyn Dinam as eutrophic and Llynnau Coron and Penryn as hyper-eutrophic. However, the data demonstrates the difficulty in applying categories based on fixed variable boundaries. Llyn Idwal, for instance, could be classified as ultra-oligotrophic on the basis of chlorophyll *a* and secchi disc measurements. This site would more correctly be described as transitional between ultra-oligotrophic and oligotrophic. Similarly, Llyn Dinam is transitional between eutrophic and hyper-eutrophic. Of particular interest is Llyn Penrhyn, which does not fit into the scheme easily. On the basis of TP alone the lake is certainly hyper-eutrophic, with levels an order of magnitude higher than would be expected in a eutrophic system. However the site would be classified as mesotrophic on the basis of chlorophyll *a* and secchi disc measurements.

Although it is impossible to infer long-term changes in nutrient chemistry from the data presented here, the relatively high nutrient levels recorded from the three sites suggest that cultural eutrophication may have taken place. This could be confirmed by employing palaeolimnological techniques. The sites are certainly vulnerable to the effects of increased nutrient loadings.

The UK Acid Waters Review Group scheme was designed to help identify surface waters susceptible to acidification. It classes the three Anglesey lakes as category iii (never acid), and these sites are therefore not vulnerable to acid precipitation. Llynnau Idwal and Cwellyn are classed as category ii (occasionally acid) on the basis of low winter alkalinities in the former, and annually low alkalinity in the latter. These sites may therefore be susceptible to acidification.

Acidification status is clarified further by classifications based on the critical loads approach (Table 6.1). The three Anglesey lakes have very high critical loads in both the diatom and Henriksen models, and these critical loads have not been exceeded. The sites have not acidified and are not at threat from acidification. Llyn Cwellyn has low critical loads, and these are predicted to have been exceeded on the basis of both models. It is therefore likely that Llyn Cwellyn has acidified, with associated chemical and biological effects. The lake is certainly susceptible to acid deposition. Llyn Idwal also has low critical loads and is vulnerable to the effects of acid deposition. However, for this site an exceedance is predicted from the diatom model, yet no exceedance is predicted if the Henriksen model is used. This implies that some acidification has occurred, with ecological change occurring to sensitive communities, but that an Acid Neutralising Capacity (ANC) above zero has been maintained. This conclusion is supported by the high levels of acid deposition at the site (Table 3.1), and the relatively high alkalinity levels measured throughout the survey period. The impact of acidification at the two Snowdonia sites could be comprehensively evaluated using palaeolimnological techniques such as diatom-based pH reconstruction (e.g. Battarbee 1986, Birks *et al.* 1990).

In the Nature Conservation Review (NCR) (Ratcliffe 1977) Llynnau Idwal and Cwellyn are classified as oligotrophic and Llyn Coron as eutrophic. Although not specifically mentioned in the review the scheme would class Llynnau Dinam and Penrhyn as eutrophic.

According to Palmer *et al.* (1992) Llynnau Idwal and Cwellyn are both type 3 lakes (oligotrophic) with very similar Trophic Ranking Scores (TRS) of 5.57 and 5.32 respectively. Due to the occurrence of *Littorella uniflora* and a single specimen of *Myriophyllum alterniflorum* Llyn Coron is typed as 5A (mesotrophic) with a TRS of 8.59. Without the presence of the *Myriophyllum* the site would have been typed as 8 (eutrophic). Llyn Dinam is typed as 10B (eutrophic) with a TRS of 8.59. Llyn Penrhyn is typed as 10A (eutrophic), and differs from the typing of Llyn Dinam due to the presence of *Elodea canadensis* and *Potamogeton crispus* and the absence of *Chara* species. The TRS for Llyn Penrhyn is 8.68.

Although not providing a site classification, it is also important to consider the National Vegetation Classification communities present at each of the lakes. Table 6.1 details the number of NVC aquatic and swamp communities present at each site, and lists these communities by code (see section 5.4). Of the two Snowdonia sites, Llyn Idwal has twice as many NVC communities present as Llyn Cwellyn. Llyn Penrhyn has five NVC communities, the highest number of the three Anglesey sites. By contrast Llyn Dinam, a near neighbour to Llyn Penryn and similar in many respects (see earlier discussion), has only three NVC communities.

It is not appropriate to present a full evaluation of the applicability of these different approaches to Welsh lakes on the basis of only five sites. However, some preliminary observations can be made. The Dillon and Rigler (1975) scheme provides an assessment for lake utilisation and as such it is inappropriate for conservation purposes. The OECD (1982) scheme has become the standard for describing the trophic state of standing waters. The approach has the advantage of being based on relatively straightforward chemical determinations, and is therefore simple to apply. However, the extent to which such a classification adequately represents variation in biological communities is questionable.

The UKAWRG (1989) scheme allows sites to be identified which may be vulnerable to acidification and is simple to apply, requiring only basic measurements of water chemistry (pH and alkalinity). This classification is relatively crude, however, and a much more complete assessment of acidification status is provided by the critical loads approach. Critical loads calculations require more complete water chemistry, but can be used to classify lakes on the basis of a state-change. These schemes are both designed to provide information relevant to a specific form of environmental change (acidification).

The NCR scheme is based on variation in water chemistry and recognises only five categories of lake system. Within these broad categories significant variation in biological status has been observed (Ratcliffe 1977). This is apparent when applying the scheme to the five study sites. Significant differences in biological communities are apparent in the three Anglesey sites, yet they are all classed as eutrophic. As a mechanism for summarising whole ecosystem variation the scheme lacks resolution. This is confirmed when comparing the NCR scheme to that of Palmer *et al.* (1992). The latter scheme contains a greater range of site types, and places the three Anglesey lakes in different categories. The Palmer classification is also based on biological parameters and describes macrophyte assemblages, an aspect of variation in lake ecosystems of direct relevance to nature conservation. The scheme indirectly allows assessment of trophic state. The extent to which this scheme adequately represents ecosystem variation in Welsh lakes will be of primary interest once a large enough number of sites are available.

Table 6.1 Site classifications based on existing schemes

Classification Scheme	Idwal	Cwellyn	Coron	Dinam	Penrhyn
Thermal mixing (Lewis 1983)	Warm monomictic	Warm monomictic	Continuous warm polymictic	Continuous warm polymictic	Continuous warm polymictic
Dillon and Rigler (1975)	Class I	Class I	Class IV	Class I	Class II
OECD (1982)	Oligotrophic	Oligotrophic	Hyper-eutrophic	Eutrophic	Hyper-eutrophic
UKAWRG (1989)	Category ii (Occasionally acid)	Category ii (Occasionally acid)	Category iii (Never acid)	Category iii (Never acid)	Category iii (Never acid)
Critical load (Henriksen model) (keq S ha^{-1} yr^{-1})	2.45	1.19	18.85	15.02	20.16
Critical load exceedance (Henriksen model) (keq S ha^{-1} yr^{-1})	Not exceeded	0.17	Not exceeded	Not exceeded	Not exceeded
Critical load (diatom model) (keq S ha^{-1} yr^{-1})	0.84	0.65	20.10	16.17	23.11
Critical load exceedance (Diatom model) (keq S ha^{-1} yr^{-1})	1.37	0.71	Not exceeded	Not exceeded	Not exceeded
Nature Conservation Review (Ratcliffe 1977)	Oligotrophic	Oligotrophic	Eutrophic	Eutrophic	Eutrophic
Palmer *et al.* (1992)					
Site type	3	3	5A	10B	10A
Category	Oligotrophic	Oligotrophic	Mesotrophic	Eutrophic	Eutrophic
Trophic Ranking Score	5.57	5.32	8.59	8.59	8.68
National Vegetation Classification (Rodwell in prep.)					
Number of communities	8	4	4	3	5
Community types present (Swamp and aquatic)	A9, A14, A22, A23, A24, S4, S9, S10.	A9, A14, A22, A23.	A10, A16, S4, S20.	A7, A11, S4.	A5, A7, A12, S4, S8.

6.4 Preliminary classifications based on physio-chemical data and individual biological groups

The data generated within this programme can be used to generate classification systems based on individual biological groups, physical and chemical data. Although far more than five sites are required for a widely applicable classification scheme, this section uses selected data from the five sites studied to date to exemplify classifications based on different data types.

The techniques employed to produce these classifications are based on multivariate data analyses. Ordination is the collective term for multivariate techniques which arrange samples or sites along axes on the basis of species composition data (Jongmann *et al.* 1997). An advantage of ordination is that it can be used to summarise the major patterns of variation within environmental or ecological data. Significant variation is captured on the first few ordination axes, and an ordination diagram allows the visualisation of this variation. Sites with similar characteristics will be positioned close together on the plot, sites positioned far apart are dissimilar. This feature of ordination allows inspection of the underlying structure of a data-set. If there are discreet groups of sites which share common characteristics the ordination plot will indicate these as clusters. If the variables analysed show continuous variation between the sites the plot will have a more scattered appearance. In this latter case it is more difficult to objectively classify sites, as arbitrary boundaries between different site types will be required.

In contrast to ordination, cluster analysis provides an explicit way of identifying groups in raw data, and is widely used to classify ecological and environmental data (e.g. Palmer *et al.* 1992). However, cluster analysis imposes a group structure on data even if continuous gradients of variation are present (Jongmann *et al.* 1987). This can lead to rather arbitrary partitioning of sites into types or classes. A combination of the two approaches, ordination and cluster analysis, will therefore be necessary for the development of objective, robust and widely applicable classification schemes.

In later stages of this research programme classifications will be developed using a combination of approaches. For simplicity, however, the preliminary classifications presented below are illustrated using ordination, implemented through the computer programme CANOCO 3.10 (ter Braak 1987, 1990).

Preliminary classification based on physical data

A site classification based on physical data has been constructed using principal components analyses (PCA). The analysis included the lake and catchment variables listed in Tables 3.1 - 3.5; lake area, catchment area, catchment:lake ratio (Cat:lake), altitude, net relief (NetRel), maximum depth (MaxDep), mean depth (MeanDep), estimated hydraulic residence time (HRT), sulphur deposition (SDep), nitrogen deposition (NDep), shoreline index (ShoreI) and rainfall. In this analysis all data were log transformed apart from sulphur and nitrogen deposition. The eigenvalues and cumulative variance accounted for by the first four axes are listed in Table 6.2. The size of the eigenvalue is a direct indication of the importance of the ordination axis in explaining the total variation within the data-set. The PCA biplot for the first two ordination axes is shown in Figure 6.1. In a PCA correlation biplot, variables with high positive correlations generally have small angles between their biplot arrows. Variables with long arrows have high variance, and are usually the most important within the data (Jongman *et al.* 1987).

Table 6.2 **Eigenvalues and cumulative variance accounted for in a PCA of the 5 sites by 12 physical variables data-set**

	Eigenvalue	Cumulative variance
Axis 1	0.622	62.2
Axis 2	0.236	85.8
Axis 3	0.132	99.0
Axis 4	0.010	100.0

The PCA summarises the variation in physical data well, with over 85% of the variation being represented on the first two axes. Most of the variables are strongly co-variable, and relate to the first axis. This first axis (62.2%) clearly contrasts lakes with low to high rainfall, net relief, altitude, depth and acid deposition. Shoreline index is negatively correlated with these variables. The axes effectively splits the three Anglesey lakes from the two Snowdonia sites. Axis two represents a lower proportion of the total variance in the data (23.6%) and relates to catchment area. It effectively contrasts sites with large catchment areas and catchment:lake ratios, and therefore low hydraulic residence time, from those with small catchment areas. A classification based on this analysis would recognise three categories of lake, as shown in Table 6.3. This scheme does not provide a key for the boundaries between each class, and could be refined by defining how the physical variables differ among sites of different classes using techniques such as canonical variates analysis (CVA) and discriminant analysis (Jongmann *et al.* 1987). This approach could also be used to refine the other preliminary classifications presented in this report.

Table 6.3 **Preliminary classification based on physical data**

Category	**Characteristics**	**Lakes**
1	Higher altitude, deep lakes with high net relief and levels of acid deposition. Low shoreline index.	Idwal and Cwellyn
2a	Low altitude, shallow lakes with low net relief and low levels of acid deposition. High shoreline index. Distinguished from 2b by large catchment area and low hydraulic residence time.	Dinam and Coron
2b	Similar to 2a, but with a small catchment area and high hydraulic residence time.	Penrhyn

The ordination demonstrates that due to the co-variance between the 12 physical variables, these five sites could be classified on the basis of a sub-set of these variables. A classification based only on altitude, hydraulic residence time, catchment area, shoreline index and mean depth, for example, would result in the same three categories as indicated in Table 6.3. This feature of ordination will allow identification of the most important physical, chemical and biological variables for use in an integrated classification scheme.

Preliminary classification based on chemical data

A similar approach can be taken to classifying the sites on the basis of mean water chemistry. PCA has been used to analyse a data-set of the five sites and 18 chemical variables presented in Tables A.1 - E.1. All variables were log transformed for this analysis, with the exception of pH. Table 6.4 demonstrates that within the PCA the majority of chemical variation between the sites is represented by axis 1 (84.5%). This is due to the very high degree of co-variance in chemical variables, as demonstrated by the biplot (Figure 6.2). Axis 1 effectively contrasts Llynnau Cwellyn and Idwal, with low pH, conductivity, alkalinity, phosphorus and levels of major ions with the Anglesey lakes which have high values of these variables. Axis 2 (12.1%) is considerably less important, but is correlated to nitrate and total monomeric aluminium levels. The relative similarity in the chemical characteristics of the two Snowdonia sites is emphasised by their close proximity on the biplot (Figure 6.2).

Table 6.4 Eigenvalues and cumulative variance accounted for in a PCA of the 5 sites by 18 chemical variables data-set

	Eigenvalue	Cumulative variance
Axis 1	0.845	84.5
Axis 2	0.121	96.6
Axis 3	0.024	99.0
Axis 4	0.010	100.0

A classification based on this analysis would recognise two categories; the low alkalinity, low conductivity, nutrient-poor Snowdonia sites and the high alkalinity, high conductivity, nutrient-rich Anglesey lakes. Although clear chemical differences exist between the Anglesey lakes (Tables C.1 - E.1, Figure 6.2), it is difficult to make objective distinctions on the basis of the current analysis. Llyn Coron could be placed in a sub-category on the basis of its comparatively low total phosphorus and high nitrate levels, but similarly Llyn Penrhyn could be separated on the basis of the very high total phosphorus levels at this site.

Figure 6.1 Principal components analysis (PCA) correlation biplot of axes 1 and 2 for the 5 sites by 12 physical variables data-set

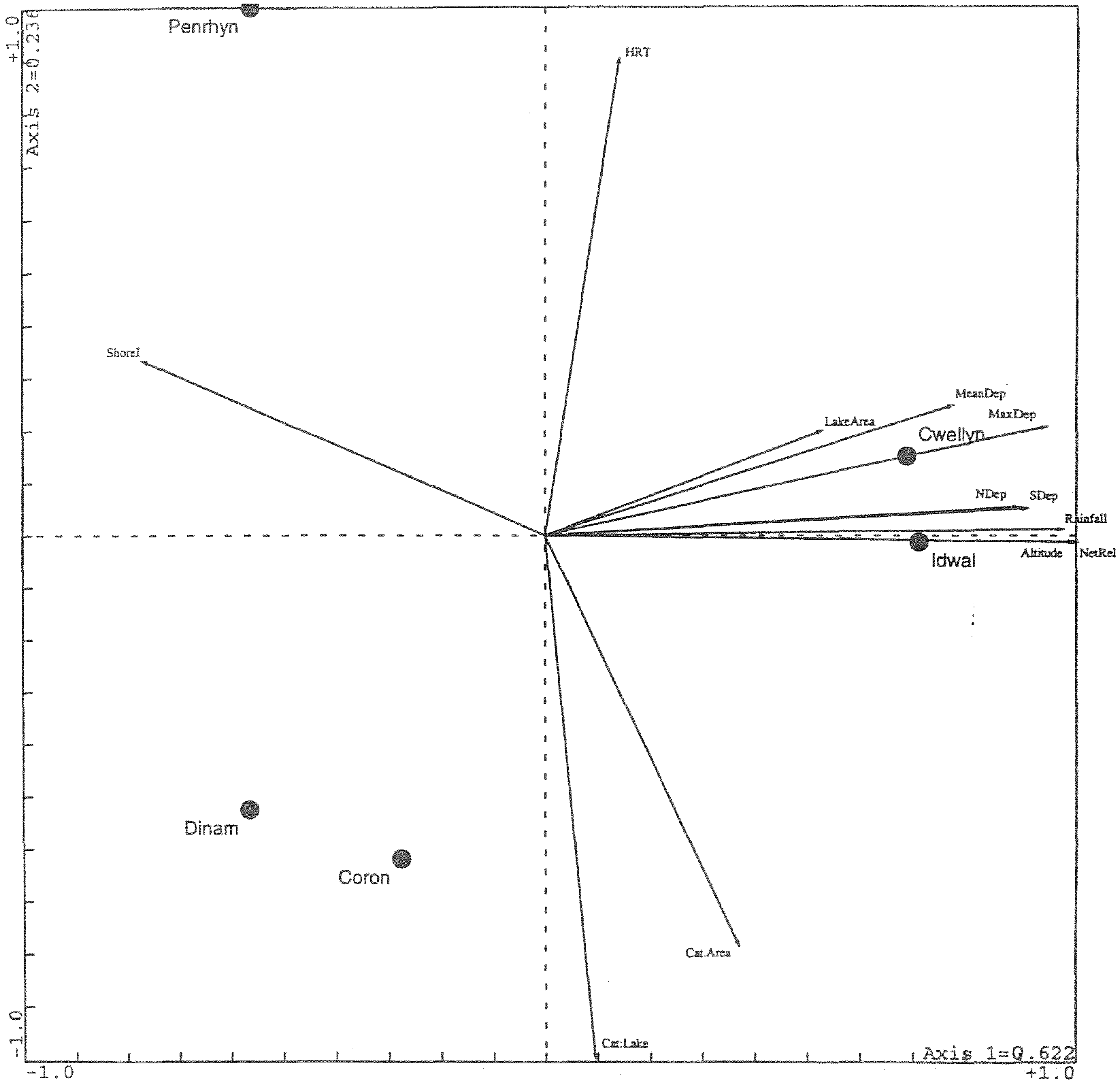
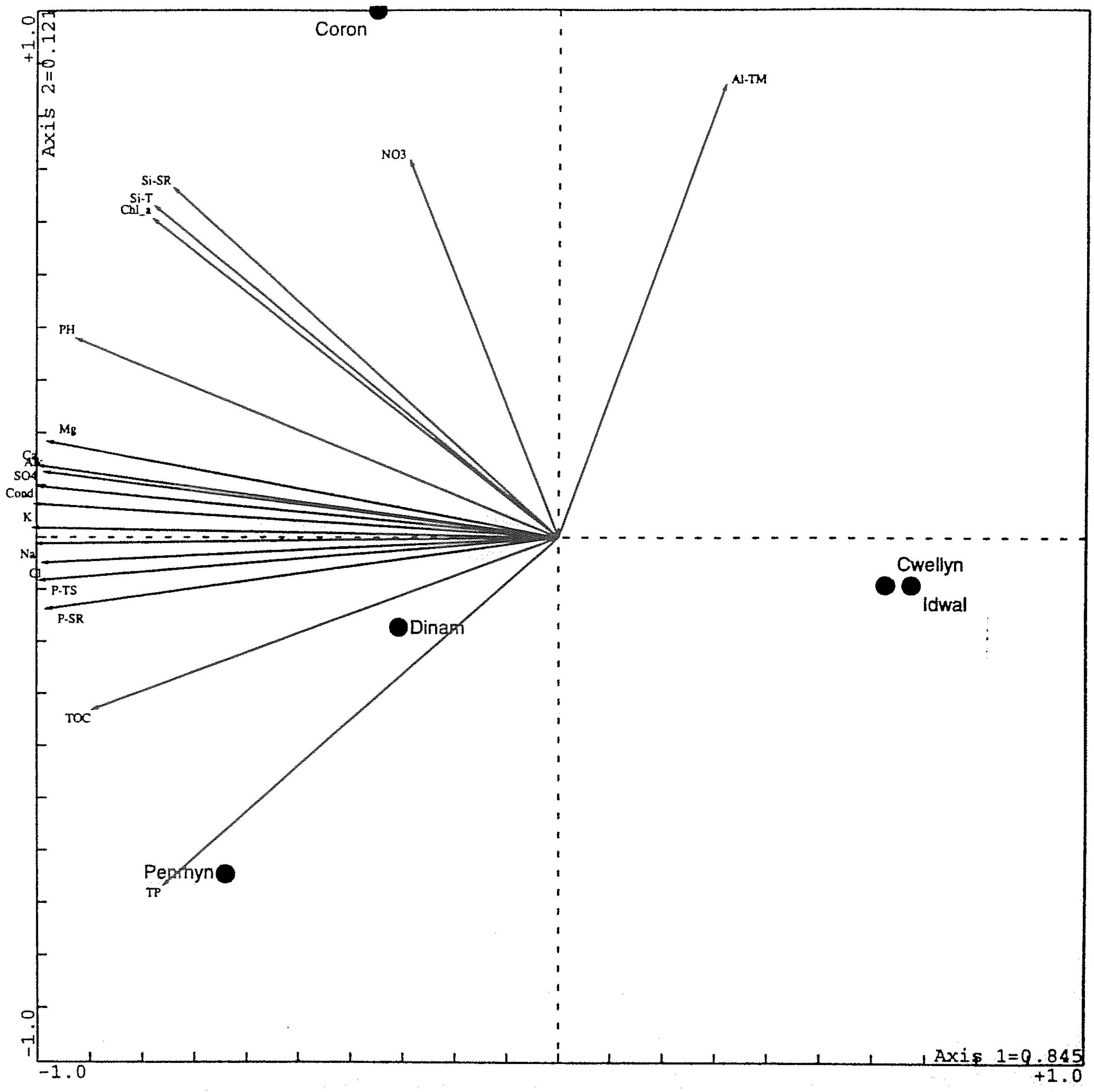


Figure 6.2 Principal components analysis (PCA) correlation biplot of axes 1 and 2 for the 5 sites by 18 chemical variables data-set



Preliminary classification based on surface sediment diatom assemblages

Classifications can also be developed using individual biological groups. The surface sediment diatom assemblages have been analysed using detrended correspondence analysis (DCA) (Hill 1979a). Correspondence analysis is an ordination technique related to the method of weighted averaging, and assumes unimodal species response. It is therefore more suitable than PCA for analysing ecological data, unless the amount of variation in a data-set is restricted (Jongmann *et al.* 1987). In a DCA joint plot both sites and species are represented as points. The closer a species plots to a site, the higher the abundance of the species at that site. A DCA ordination can therefore be used to explore the principal patterns of floristic or faunal variation in an ecological data-set.

Table 6.5 Eigenvalues and cumulative variance accounted for in a DCA of the 5 surface sediment diatom assemblages

Sum of all eigenvalues of CA = 2.06

	Eigenvalue	Cumulative variance
Axis 1	0.908	44.1
Axis 2	0.402	63.6
Axis 3	0.032	65.1
Axis 4	0.001	65.1

The DCA of the surface sediment diatom assemblages captures nearly 64% of the variance in species data on the first two axes (Table 6.5). The DCA joint plot (Figure 6.3) indicates three groups of sites. The two Snowdonia sites have low axis 1 scores, and are associated with species such as *Brachysira vitrea* (BR001A), *Achnanthes minutissima* (AC013A) and *Tabellaria flocculosa* (TA001A). Although the three Anglesey lakes have broadly similar diatom assemblages, they can be divided into two groups. Llynnau Dinam and Penrhyn have high scores on both axes 1 and 2, and are characterised by *Fragilaria* species such as *F. construens* var. *venter* (FR002C), *F. brevistriata* (FR006A) and *F. pinnata* (FR001A). Llyn Coron has a high axis 1 score and a low score on axis 2, and is characterised by *Cyclostephanos* [cf. *tholiformis*] (CC9997) and *Stephanodiscus hantzschii* (ST001A). A classification based on the surface sediment diatom assemblages would therefore recognise three classes of site.

Preliminary classification based on submerged and floating aquatic macrophytes

A preliminary classification has also been produced using the submerged and floating aquatic macrophyte assemblages. The ordination technique used is PCA, as the total amount of variation within this data-set is low and a unimodal technique would not be appropriate.

Table 6.6 **Eigenvalues and cumulative variance accounted for in a PCA of the five submerged and floating aquatic macrophyte assemblages**

Sum of all eigenvalues of CA = 1.68

	Eigenvalue	Cumulative variance
Axis 1	0.595	59.5
Axis 2	0.219	81.5
Axis 3	0.130	94.5
Axis 4	0.055	100.0

The primary division in the PCA is on axis 1 between the Snowdonia lakes, characterised by species such as *Isoetes lacustris* (350302) and *Myriophyllum alterniflorum* (365401), and the three Anglesey lakes. Axis 2 (21.9%) represents variation between the Anglesey sites, Llyn Coron having a particularly high axis 2 score and Llyn Dinam a low score. The ordination emphasises the difference between the Snowdonia and Anglesey lakes (figure 6.4), but also indicates the distinctive nature of the macrophyte assemblages in each of the Anglesey lakes (see Section 5.4). A classification based on this analysis would contain four groups; the Snowdonia lakes would be classed together but the three Anglesey sites would form separate groups. The PCA therefore supports the classification of the sites based on the scheme of Palmer *et al.* (1992).

Discussion

In the later stages of this research programme when a larger lake data-set is available site classifications will be made on the basis of all the individual data types presented within this report. These include physical data, chemical data, epilithic diatom assemblages, surface sediment diatom assemblages, aquatic macrophytes, littoral Cladocera, open water zooplankton and littoral macroinvertebrates. However, the preliminary analyses already demonstrate the differences in site classification that would result from the use of different data types. All four preliminary classification emphasise the significant differences between the Anglesey and Snowdonia sites, and each of the classifications places Llynnau Idwal and Cwellyn in the same group. Categorisation of the Anglesey lakes, however, varies significantly with the four different schemes providing four different site groupings.

Figure 6.3 **Detrended correspondence analysis (DCA) joint plot of the five surface sediment diatom assemblages**

Diatom species are labelled using diatcodes (see Tables A.3 - E.3)

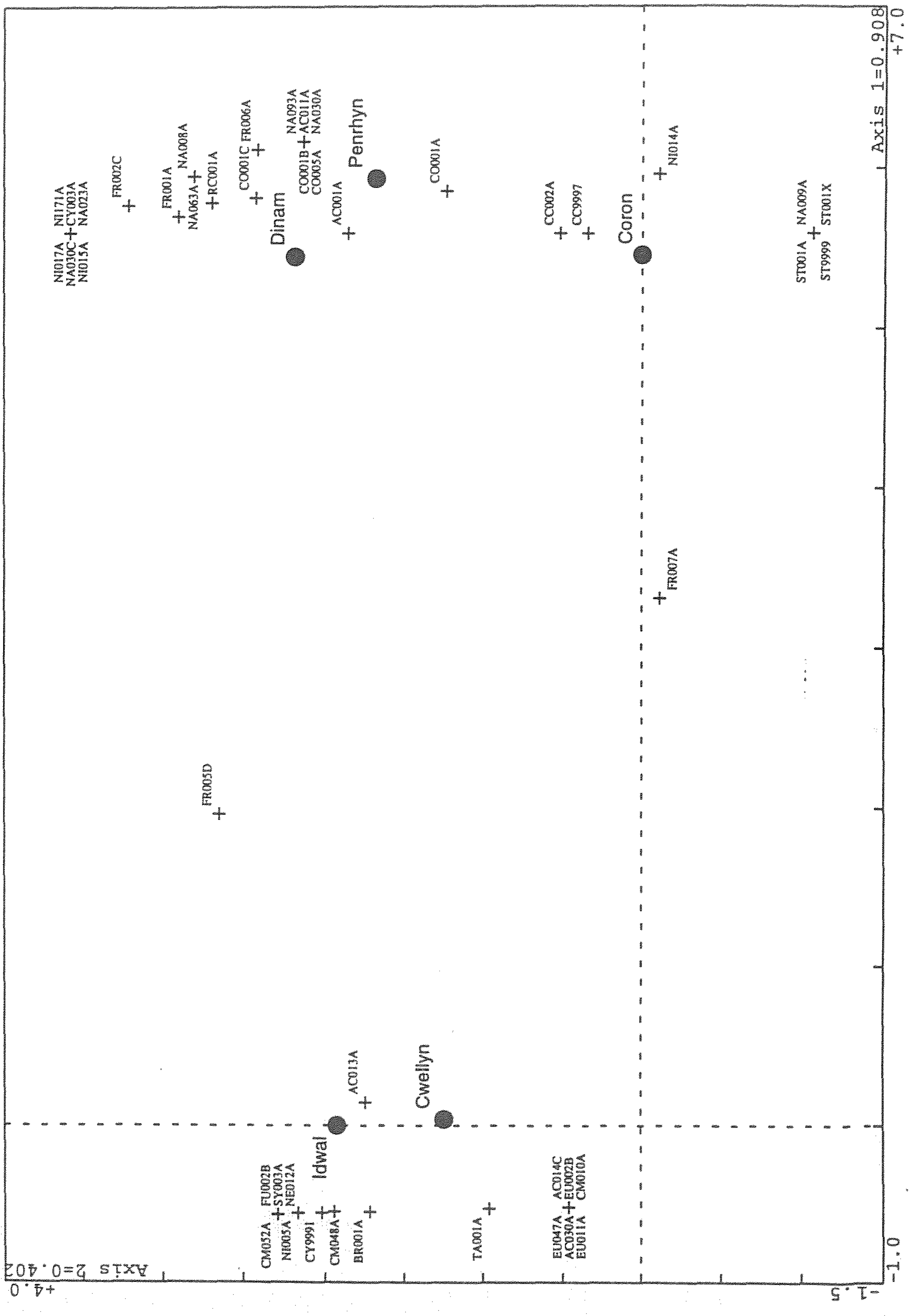
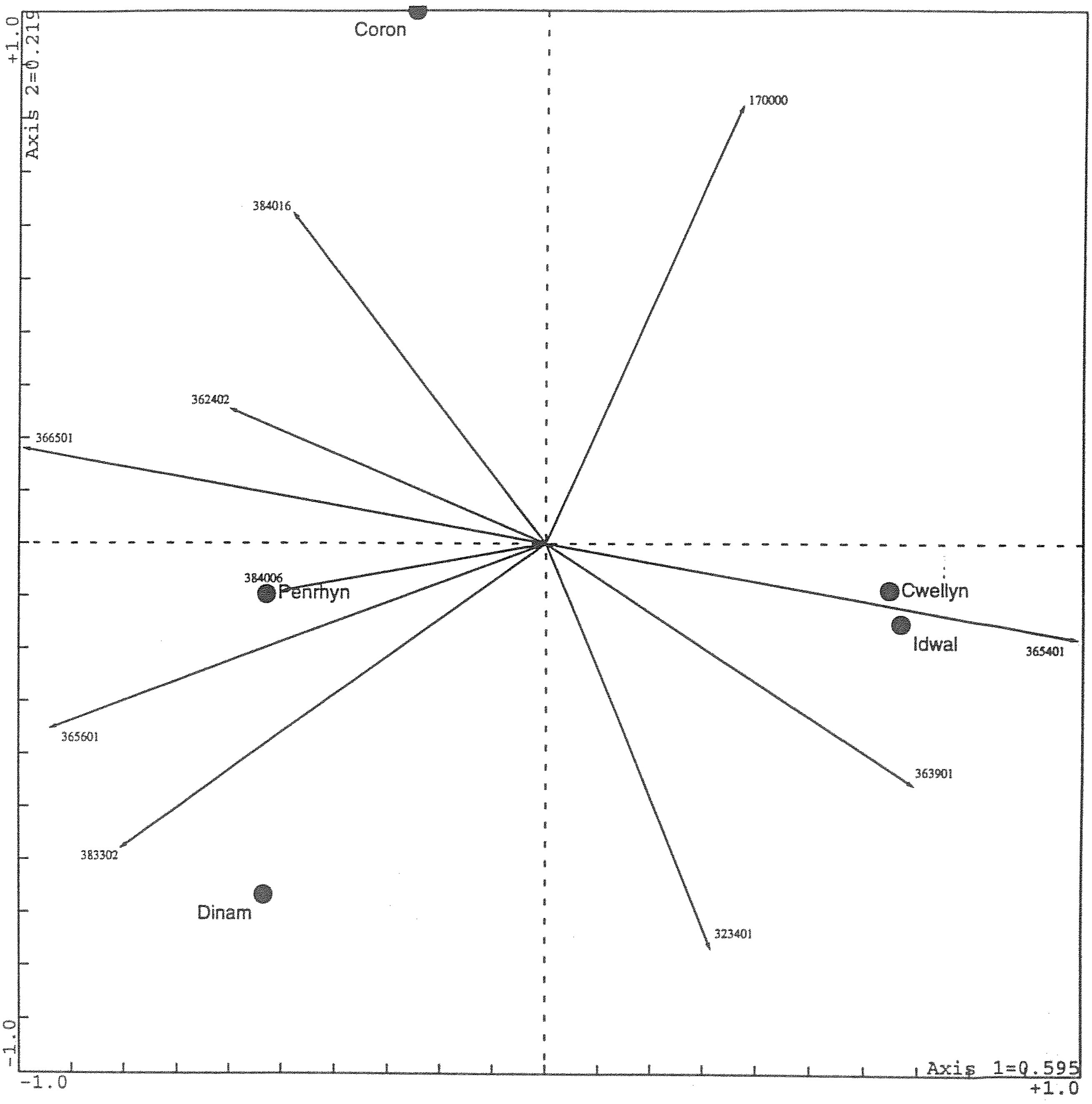


Figure 6.4 **Principal components analysis (PCA) correlation biplot of the five submerged and floating aquatic macrophyte assemblages**

Selected species vectors are displayed using codes (see Tables A.4 - E.4)



6.5 Comparison of study sites with existing lake data-sets

The data on water chemistry and selected biological groups collected as part of this study can be compared to existing lake data-sets. Such comparisons will help allow the assessment of the representivity of the lake ecosystems, and place them in a wider regional or national context. The lake data-sets available at the ECRC are as follows:

i) Surface Waters Acidification Programme (SWAP) data-set containing water chemistry and surface sediment diatom assemblages from 167 soft-water lakes throughout north-west Europe (Stevenson *et al.* 1991). This data-set was collected from across a chemical gradient of lakes susceptible to acidification.

ii) ENSIS eutrophic lake data-set containing water chemistry and surface sediment diatom assemblages from 30 sites in Shropshire and Cheshire (Monteith & Bennion unpublished). This data-set contains detailed nutrient chemistry and covers the range of nutrient conditions in the Shropshire/Cheshire meres.

iii) Critical Loads Advisory Group (Freshwater Subgroup) water chemistry data-set (Kreiser *et al.* 1993). This contains a sample from each 10 km x 10 km grid square in the UK, the sites selected representing the most sensitive to acidification within the grid square. The data-set covers the range of chemistry within lakes in the UK, with a bias to upland sites. It can be used to create regional sub-sets, for instance a data-set of water chemistry from upland lakes in Wales.

v) The 33 lake data-set of Flower *et al.* (1989) from upland lakes in mid and north Wales. This data contains water chemistry and surface sediment diatom analyses from lakes susceptible to acid deposition.

vii) The lake data-set of the Acid Waters Monitoring Network (AWMN) (Patrick *et al.* 1991). This contains extensive physio-chemical and biological data from 11 lake sites including epilithic and surface sediment diatom assemblages, aquatic macrophytes, macroinvertebrates and fish populations.

An example of how such data-sets might be used is provided by a comparison of the surface sediment diatom assemblages from the SWAP data-set with those from Llynnau Idwal and Cwellyn, the low alkalinity Snowdonia sites. Detrended correspondence analysis has been used to analyse the assemblages from the 167 SWAP sites and 2 Snowdonia sites together. A DCA plot of the diatom samples is shown in Figure 6.5. This plot also shows vectors of selected physio-chemical variables, which have been analysed passively and do not influence the ordination. However, the vectors can be used to help interpret the DCA in terms of physio-chemical variation. Axis 1 represents a gradient from assemblages associated with low to high levels of pH, calcium and conductivity. Assemblages with low scores on axis 2 are associated with deep lakes at high altitude, whereas assemblages with high axis 2 scores are associated with elevated levels of total aluminium.

The positions of Llynnau Cwellyn and Idwal have been isolated in Figure 6.6. This indicates that both assemblages have relatively high axis 1 scores. On the basis of diatom assemblages the sites would be grouped with the higher pH lakes within the SWAP data-set. The plot also reveals that the assemblages of Llyn Idwal are indicative of higher pH and calcium levels than those of Llyn Cwellyn.

This comparison demonstrates that although within the five lakes surveyed in this study the Snowdonia sites have diatom assemblages indicative of low alkalinity and pH conditions, set in a wider context the assemblages are indicative of relatively high pH soft-water lakes. The SWAP data-set represents a wide gradient of soft-water lakes, and therefore includes sites with much lower pH and alkalinities levels than measured in the Snowdonia lakes. Correspondingly more acidic diatom floras are present in the SWAP data than are represented by Llynnau Idwal and Cwellyn.

6.6 Preliminary Integrated Classification

The following section presents a preliminary integrated classification scheme for the five study sites. The integrated data-set used for this classification is based on a restricted amount of the total physio-chemical and biological data available from the surveys.

Although the present survey has measured a large number of physical, chemical and biological parameters at each site, not all of these will be necessarily utilised in the final integrated classification scheme developed. Analyses of individual data types, as presented in section 6.4, can help identify key variables which summarise important gradients of ecosystem variation. For example, the ordinations demonstrated that physio-chemical variation between the five sites can be effectively represented using a sub-set of the available parameters. This allows a reduced number of key variables to be used in an integrated scheme without losing effective representation of total ecosystem variation. It is envisaged that the identification of key physio-chemical and biological variables will be an important feature of the final integrated classification scheme developed within this programme.

The following ten physio-chemical variables only have therefore been included in the integrated data-set; altitude, hydraulic residence time, catchment area, shoreline index, maximum depth, conductivity, pH, alkalinity, total phosphorus (TP) and nitrate. In addition the integrated data-set includes surface sediment diatom assemblages and submerged and emergent aquatic macrophyte assemblages. The resulting integrated classification effectively combines the preliminary classifications presented earlier based on individual biological groups, chemical and physical data. Until further sites are available the additional biological data types (e.g. epilithic diatoms, littoral Cladocera, open water zooplankton, and macroinvertebrates) have been excluded from the scheme.

Data is presented in this report in a variety of formats. For instance, physio-chemical data are generally given as absolute values, diatom assemblages are expressed as proportions and aquatic macrophytes assemblages are quantified using the DAFOR scheme. Other data types which might be utilised in the final integrated classification could be nominal (e.g. presence/absence of rare species), ordinal or ratio. It is therefore important to use statistical techniques suitable for such mixed data. Gower's similarity index can be used to produce a similarity matrix from mixed data which can then be applied to site ordination and cluster analysis. It is envisaged that this index will be used in the analyses to produce the final integrated classification scheme.

Figure 6.5 **Detrended correspondence analysis (DCA) plot of the 167 SWAP and 2 Snowdonia surface sediment diatom assemblages on axes 1 and 2.**

Selected physio-chemical vectors (analysed passively) are shown; water depth (Depth), Altitude, pH, calcium (Ca), conductivity (Cond), total organic carbon (TOC) and total aluminium (Altot).

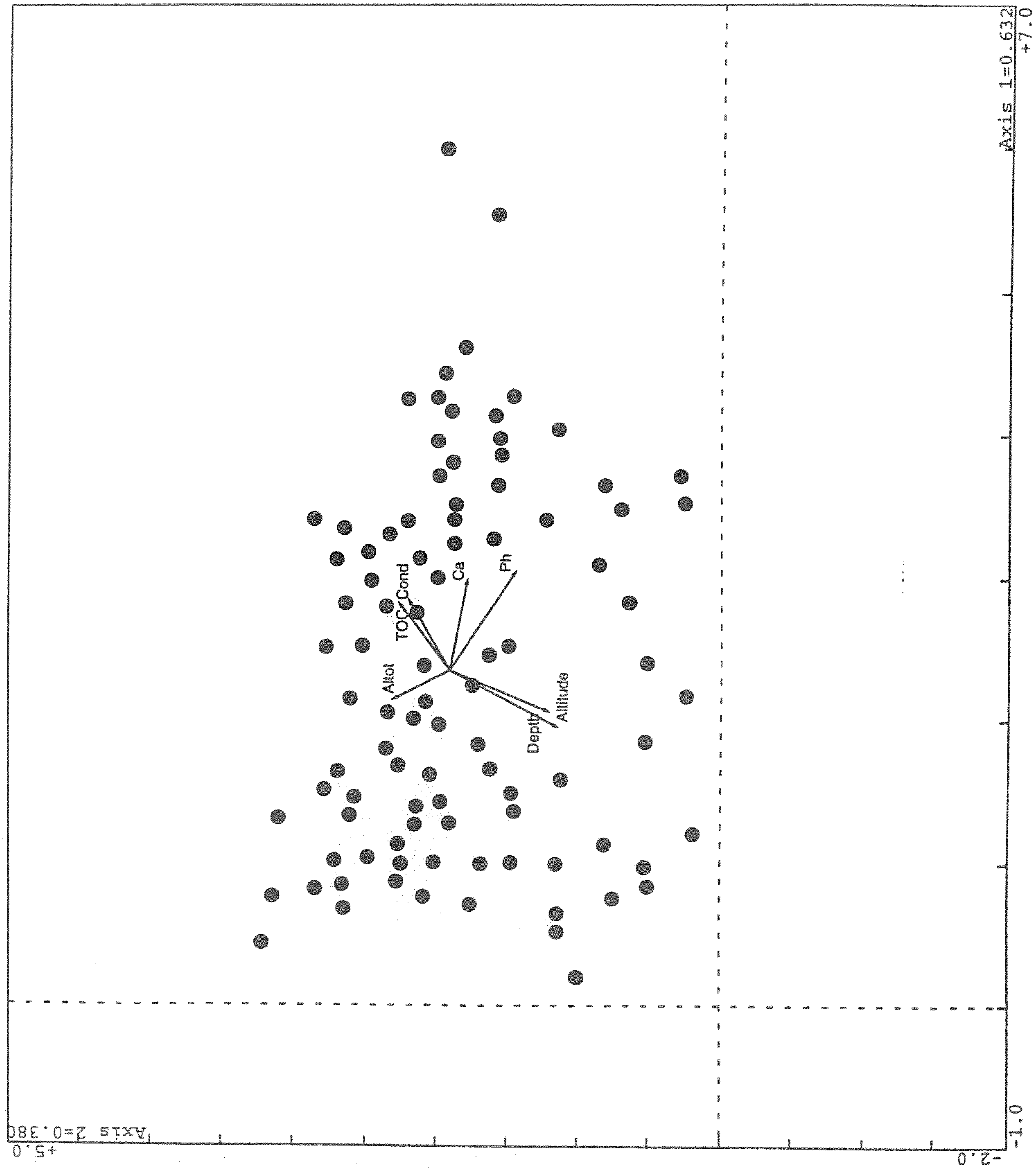
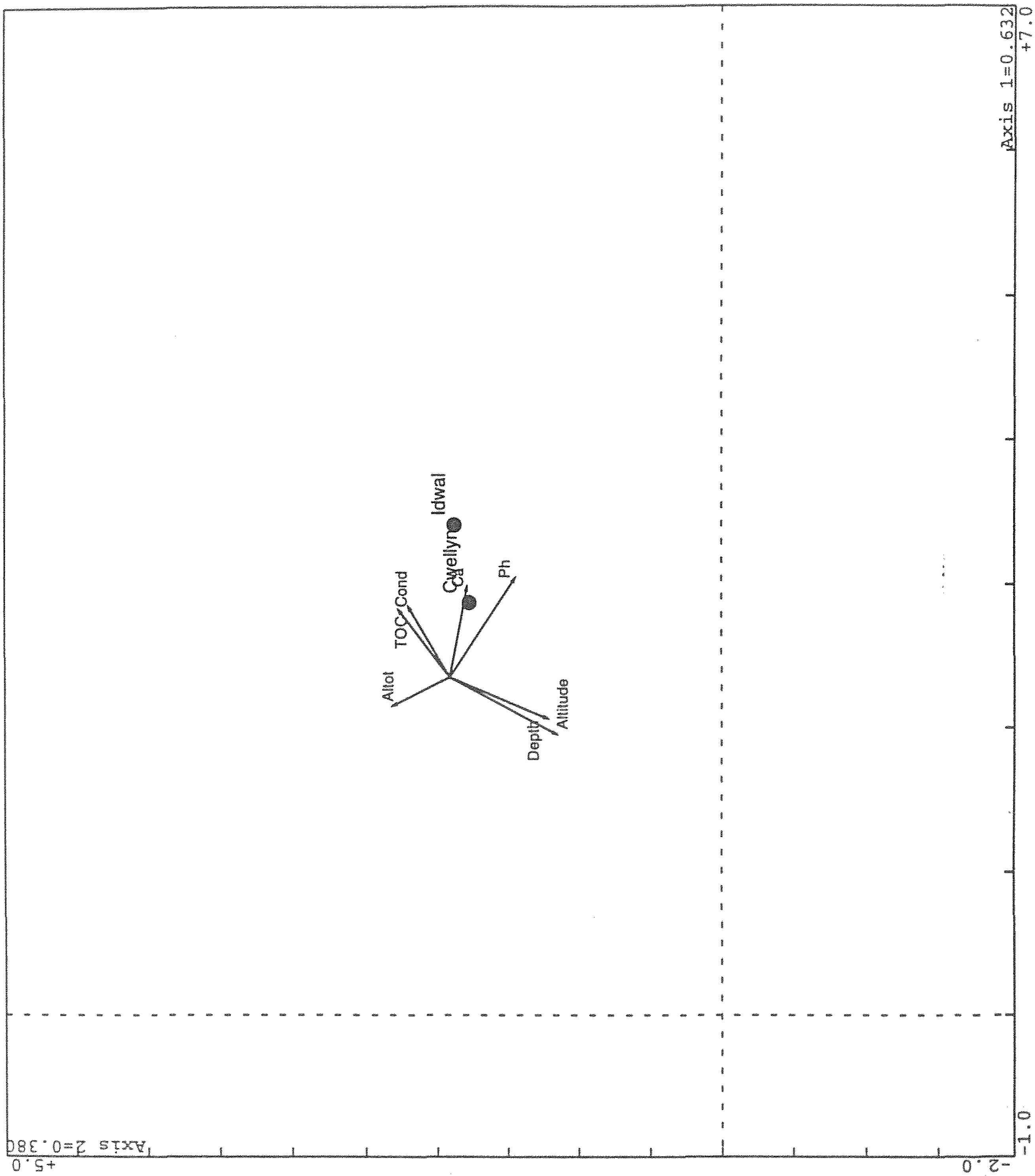


Figure 6.6 **Detrended correspondence analysis (DCA) plot of the 167 SWAP and 2 Snowdonia surface sediment diatom assemblages on axes 1 and 2, isolating Llynnau Idwal and Cwellyn.**

Selected physio-chemical vectors (analysed passively) are shown; water depth (Depth), Altitude, pH, calcium (Ca), conductivity (Cond), total organic carbon (TOC) and total aluminium (Altot).



Gower's similarity index was used to calculate a similarity matrix of sites from the integrated data-set. This matrix was used to provide a site ordination using principal coördinates analysis (PCO). The matrix was also used as the basis of a cluster analysis of the sites, using the unweighted pair group average-linkage approach (Jongmann *et al.* 1987). All analyses were implemented using the computer programme MVSP Plus 2.0 (Kovach 1990).

The PCO represents the variation in the data-set well, with nearly 75% of the total variation captured by the first two axes (Table 6.7). The first axis (52.6%) effectively separates the two Snowdonia sites from the Anglesey lakes. High scores on axis 1 are associated with high altitude, large maximum depth and the presence of *Achnanthes minutissima*, *Brachysira vitrea*, *Isoetes lacustris*, *Lobelia dortmanna* and *Juncus bulbosus* var. *fluitans*. Low axis 1 scores are related to high pH, alkalinity, conductivity, and TP, and the presence of *Stephanodiscus parvus* and *Nymphaea alba*.

Axis 2 (21.7%) separates Llyn Coron from the other two Anglesey lakes and is rather difficult to interpret in terms of environmental and ecological variation, although low axis 2 scores are clearly associated with high nitrate concentration.

Table 6.7 Eigenvalues and cumulative variance accounted for in a PCO of the integrated data-set

	Eigenvalue	Cumulative variance
Axis 1	1.041	52.6
Axis 2	0.428	74.3
Axis 3	0.315	90.2
Axis 4	0.194	

The ordination diagram (Figure 6.7) suggests that two, possibly three, distinct site types can be recognised. Cluster analysis can be used in combination with the ordination to establish the number of discreet site types more objectively. The resulting dendrogram confirms the clear distinction between the Snowdonia and Anglesey lakes (Figure 6.8), and demonstrates the relative similarity of the three Anglesey lakes. These analyses therefore suggest that the five lakes should be classified into only two categories; class I including the two Snowdonia sites, and class II containing the Anglesey lakes. The characteristics of these groups are shown in Table 6.8. In later reports the characteristics of each class can be defined more objecively using techniques such as canonical variates analysis (CVA) and discriminant analysis (Jongmann *et al.* 1987). This will allow the generation of a key of discreet site characteristics with which future survey data can be classified based on different levels of information.

The preliminary integrated classification, and the associated key, is based on a restricted amount of the survey data from the five sites. It is intended merely as an exemplification of the methodologies which will be adopted to generate an integrated classification scheme once a greater number of sites are available. Wider application of any of the preliminary classification schemes presented in this report would be innappropriate. This can be illustrated by the inclusion of

Nymphaea alba as an indicator species for the nutrient-rich sites in the preliminary integrated scheme (Table 6.8). This species is known to have a broad trophic range, and would usually be considered a poor indicator species. It has been designated a characteristic species in the preliminary integrated classification due to of its lack of occurrence at Llynnau Idwal and Cwellyn. Such anomolies would not be expected from classifications based on a larger range of sites.

Table 6.8 Key for the preliminary integrated classification scheme

	Class I	Class II
Altitude (m)	> 100	< 20
Maximum depth (m)	> 10	< 5
pH	< 7	> 7
Alkalinity (μeq l^{-1})	< 100	> 1000
Conductivity (μS cm^{-1})	< 50	> 250
Total phosphorus (μg l^{-1})	< 10	> 50
Indicative diatom species	*Achnanthes minutissima* *Brachysira vitrea*	*Stephanodiscus parvus*
Indicative macrophyte species	*Isoetes lacustris* *Lobelia dortmanna* *Juncus bulbosus*	*Nymphaea alba*

Figure 6.7 Principal coordinates analysis (PCO) site plot of axes 1 and 2 for the integrated data-set

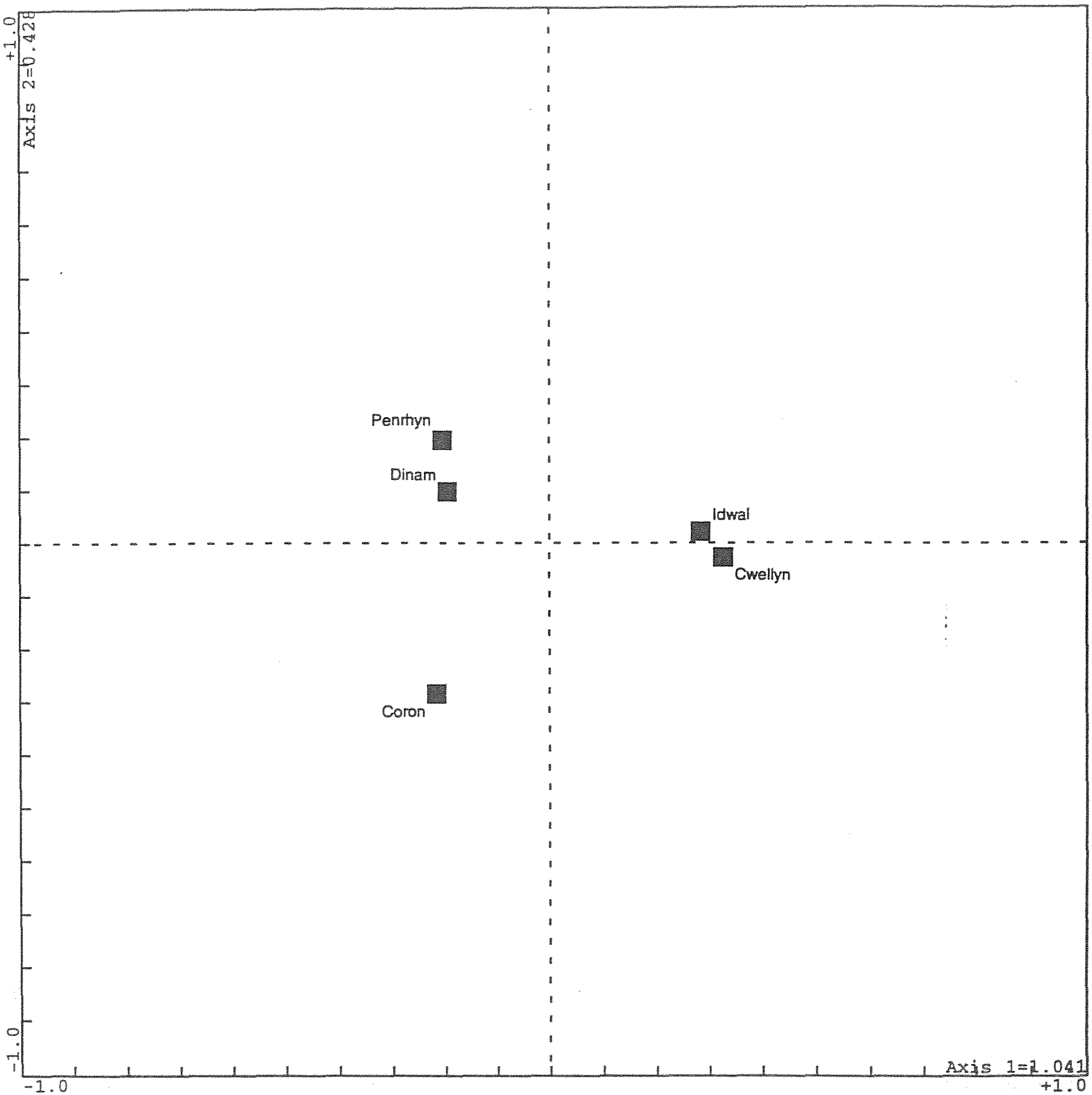
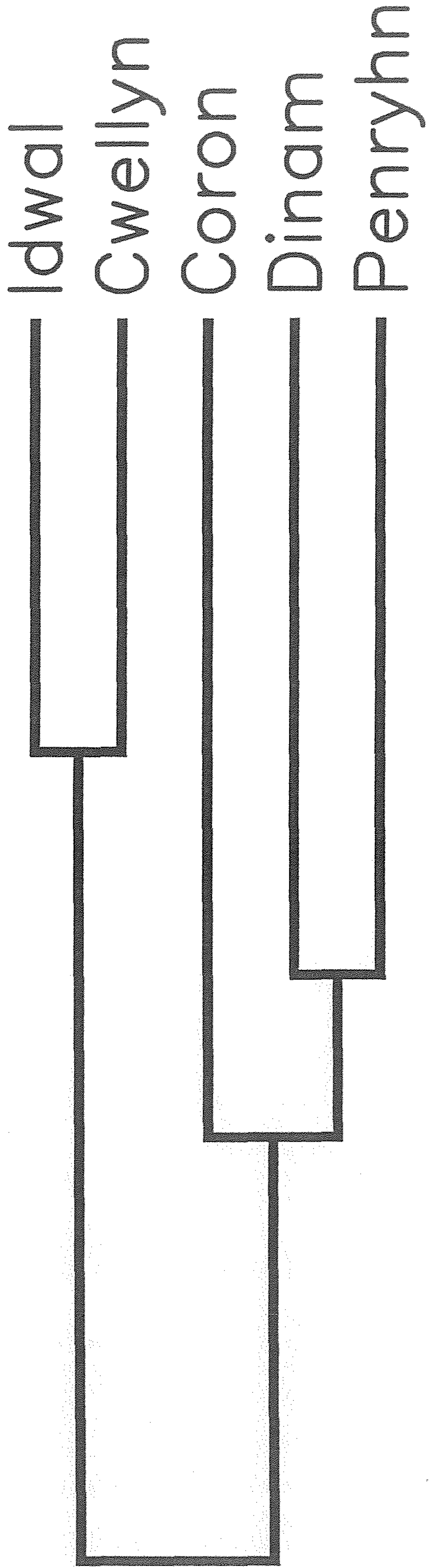


Figure 6.8 Average-linkage dendrogram of the integrated data-set using Gower's similarity index



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Appendix A Data Tables and Figures: Llyn Idwal

Table A.1 Llyn Idwal water chemistry

Determinand		Sample				
		11-7-93	5-9-93	6-12-93	29-3-94	mean
pH		6.81	6.77	6.67	6.61	6.72
field pH		6.92	6.48	6.42	6.85	6.67
Alkalinity 1	μeq l^{-1}	82	91	58	49	70
Alkalinity 2	μeq l^{-1}	72	83	49	40	61
Conductivity	μS cm^{-1}	28	27	28	27	28
field conductivity	μS cm^{-1}	30	25	35	27	29
Sodium	μeq l^{-1}	105	108	101	122	109
Potassium	μeq l^{-1}	3	4	5	4	4
Magnesium	μeq l^{-1}	31	31	32	40	34
Calcium	μeq l^{-1}	100	113	90	99	101
Chloride	μeq l^{-1}	99	98	100	124	105
Aluminium $_{\text{total monomeric}}$	μg l^{-1}	3	1	2	3	2
Aluminium $_{\text{non-labile}}$	μg l^{-1}	3	0	2	3	2
Aluminium $_{\text{labile}}$	μg l^{-1}	0	1	0	0	0.3
Absorbtion	(250nm)	.027	.044	.029	.006	.027
Carbon $_{\text{total organic}}$	mg l^{-1}	1.1	1.4	1.4	0.3	1.1
Phosphorus $_{\text{total}}$	μgP l^{-1}	4.6	6.9	5.8	3.8	5.3
Phosphorus $_{\text{total soluble}}$	μgP l^{-1}	3.8	6.2	3.4	3.4	4.2
Phosphorus $_{\text{soluble reactive}}$	μgP l^{-1}	2.8	4.2	1.1	1.4	2.4
Nitrate	μgN l^{-1}	42	49	231	126	112
Silica $_{\text{total}}$	μg l^{-1}	-	0.84	1.32	0.96	1.04
Silica $_{\text{soluble reactive}}$	mg l^{-1}	0.36	0.60	1.28	1.13	0.84
Chlorophyll a	μg l^{-1}	0.4	1.9	0.9	-	1.1
Sulphate	μeq l^{-1}	67	67	67	55	64
Copper $_{\text{total soluble}}$	μg l^{-1}				<1	
Iron $_{\text{total soluble}}$	μg l^{-1}				3	
Lead $_{\text{total soluble}}$	μg l^{-1}				<1	
Manganese $_{\text{total soluble}}$	μg l^{-1}				1	
Zinc $_{\text{total soluble}}$	μg l^{-1}				<5	

Table A.2 Llyn Idwal epilithic diatom taxon list (including taxa >1.0%)

code	Taxon	Relative frequency (%)
AC013A	*Achnanthes minutissima*	39.3
BR001A	*Brachysira vitrea*	17.3
NI005A	*Nitzschia* [cf. *perminuta*]	10.9
DE001A	*Denticula tenuis*	3.6
TA001A	*Tabellaria flocculosa*	3.1
NI008A	*Nitzschia frustulum*	2.7
CM004A	*Cymbella microcephela*	2.7
ST003A	*Synedra acus*	2.7
CM015A	*Cymbella cesatii*	2.2
AC025A	*Achnanthes flexella*	1.5
BR006A	*Brachysira brebissonii*	1.3
CM010A	*Cymbella lunata*	1.3
NA003B	*Navicula radiosa* var. *tenella*	1.1

Total count = 550
Total number of taxa = 29

Table A.3 Llyn Idwal surface sediment diatom taxon list (including taxa >1.0%)

code	Taxon	Relative frequency (%)
AC013A	*Achnanthes minutissima*	30.7
BR001A	*Brachysira vitrea*	6.2
NI005A	*Nitzschia* [cf. *perminuta*]	5.7
FR005D	*Fragilaria virescens* var. *exigua*	5.7
CM010A	*Cymbella lunata*	3.3
CM004A	*Cymbella microcephela*	2.9
CY006D	*Cyclotella* [*kuetzingiana* var. *minor*]	2.7
NA003B	*Navicula radiosa* var. *tenella*	2.7
SY003A	*Synedra acus*	2.2
TA001A	*Tabellaria floculosa*	2.0
FU002B	*Frustulia rhomboides* var. *saxonica*	1.8
FR007A	*Fragilaria vaucheriae*	1.6
NE012A	*Neidium alpinum*	1.6
AC022A	*Achnanthes marginulata*	1.5
CM020A	*Cymbella gaeumannii*	1.5
NA032A	*Navicula cocconeiformis*	1.3
AC9999	*Achnanthes* sp.	1.1
CM052A	*Cymbella descripta*	1.1

Total count = 548
Total number of taxa = 74

Table A.4 Llyn Idwal aquatic macrophyte abundance summary: 5 September 1993

Taxon	code	Abun	comments
Emergent taxa			
Caltha palustris	361201	R	
Juncus articulatus	383003	F	widespread on shoreline
Equisetum fluviatile	350202	O	locally abundant
Menyanthes trifoliata	364701	R	south end only
Ranunculus flammula	366904	O	
Carex rostrata	381129	R	locally abundant in south
Juncus effusus	383010	F	widespread on shoreline
Phragmites australis	383801	R	one stand in south end
Floating taxa			
Glyceria fluitans	382502	R	
Potamogeton natans	384012	R	one stand in south end
Potamogeton polygonifolius	384017	O	in stream inlets, mainly in south
Sparganium angustifolium	384601	O	locally abundant in south
Submergent taxa			
Filamentous green algae	170000	F	
Nitella spp.	220000	O	abundant in shallows in north-east
Fontinalis antipyretica	323401	O	
Hygrohypnum sp. (to be verified)	323900	R	in deeper water in north
Polytrichum sp.	326200	O	
Sphagnum auriculatum	327401	O	
Isoetes lacustris	350302	A	present in shallows,dominant 2-2.5m
Callitriche hamulata	361103	F	
Littorella uniflora	363901	F	patchy but widespread
Lobelia dortmanna	364001	A	
Myriophyllum alterniflorum	365401	F	
Subularia aquatica	368701	F	
Juncus bulbosus var. fluitans	383006	F	
Potamogeton berchtoldii	384003	O	recovered from deeper water in north

Table A.5 Llyn Idwal littoral Cladocera taxon list

Sample date 3-9-93

Taxon	Sample number							
	1	2a	2b	3	4	5	6	7
	number of individuals							
Acroperus harpae								1
Alona affinis							1	
Alona guttata			2			1		
Alonopsis elongata 24050102	8	2	5	3	13	12	1	1
Alonella excisa 24050201	3	1	2		1	2	1	
Chydorus piger	1		3	s			2	1
Chydorus sphaericus	1							
Drepanothrix dentata					5		5	
Eubosmina longispina							3	3
Eurycerus lamellatus 24051002	5	3	9	2		1	6	1
Monospilus dispar	s	s	s					
Pleuroxus aduncus					2		1	
Pleuroxus trigonellus							1	
Pleuroxus truncatus						1	3	
Scapholeberis mucronata							1	
Streblocerus serricaudatus						2		
TOTAL COUNT	18	6	21	5	21	19	25	7

s = shell fragment

Table A.6 Analysis of the cladoceran species composition in the samples from Llyn Idwal; S = sand-rock substrate; MV = mud-vegetation substrate.

Sample number	1	2a	2b	3	4	5	6	7
Substrate	S	S	S	S	MV	MV	S	S
No. Species	6	4	6	3	4	6	11	5
Cum. Species	6	6	7	7	9	11	15	16
Cum. % Species	38						>75	

Table A.7 Llyn Idwal open water zooplankton taxon list: 5 September 1993

Taxon	Abundance
Cyclops abyssorum	2
Eubosmina longispina	2
Daphnia longispina	2
Alonopsis elongatus	+
Arctodiaptomus laticeps	2

2 = Species common (abundance >5%)
1 = Species rare (found in both samples analysed)
+ = Species rare (found in one of samples analysed)

Table A.8 Llyn Idwal zooplankton characteristics: 5 September 1993

Station sampled: A

Depth of Station (m)	10.5
Total zooplankton biomass (gDM m^{-2})	0.81
Net algal biomass (gDM m^{-2})	0
% Cladoceran biomass in total zooplankton biomass	32
% large Cladocera (>710 µm) in total zooplankton biomass	0.1
% large Copepoda (>420 µm) in total zooplankton biomass	50

Table A.9 Llyn Idwal littoral invertebrate data

Macro-invertebrate species present and mean number per one minute kick/sweep sample in autumn (September 1993) and spring (April 1994).

code	species	mean no.	
		autumn	spring
	MOLLUSCA		
13 07 01 07	*Lymnaea peregra* (Müller)		2.8
13 10 01 01	*Acroloxus lacustris* (L.)		1.6
	BIVALVIA		
14 03 02 00	*Pisidium* spp.	56.0	42.8
	HIRUDINIA		
17 02 03 02	*Glossiphonia complanata* (L.)		0.4
17 04 01 02	*Erpobdella octoculata* (L.)	0.3	
	MALACOSTRACA		
28 07 03 03	*Gammarus lacustris* Sars	1.0	
	EPHEMEROPTERA		
30 01 01 02	*Siphlonurus lacustris* Eaton		10.4
30 02 01 00	*Baetis* sp.		2.8
30 03 02 04	*Heptagenia lateralis* (Curtis)		0.8
30 04 01 00	*Leptophlebia* sp.	15.3	
30 04 01 01	*Leptophlebia marginata* (L.)		0.4
30 08 02 04	*Caenis horaria* (L.)	36.0	4.4
	PLECOPTERA		
31 05 03 01	*Diura bicaudata* (L.)	1.0	0.8
	HEMIPTERA		
33 11 00 00	Corixidae sp. - immatures	28.3	231.2
	COLEOPTERA		
35 01 00 00	Haliplidae sp. - larvae	0.3	0.4
35 01 03 11	*Haliplus fluvus* (Fabricius)		0.4
35 03 00 00	Dytiscidae - larvae	0.3	
35 11 01 01	*Elmis aenea* (Müller)		0.4
35 11 06 02	*Oulimnius troglodytes* (Gyllenhal)	47.3	78.0
	TRICHOPTERA		
38 03 03 01	*Polycentropus flavomaculatus* (Pictet)	1.3	
38 03 04 01	*Holocentropus dubius* (Rambur)		1.2
38 03 05 01	*Cyrnus trimaculatus* (Curtis)	0.7	0.4
38 06 03 00	*Hydroptila* sp.	6.0	8.0
38 06 06 00	*Oxyethira* sp.	2.0	0.4
38 08 05 00	*Limnephilus* sp.		0.8
38 08 05 01	*Limnephilus rhombicus* (L.)		0.4

	contd.		
38 12 01 07	*Athripsodes cinereus* (Curtis)		
38 12 02 03	*Mystacides longicornis* (L.)	1.0	2.0
	DIPTERA		
40 01 00 00	Tipulidae	2.7	4.0
40 09 00 00	Chironomidae	70.0	316.0
	Total invertebrates	270.0	720.8
	Species richness (minimum)[1]	18	25
	Minimum richness (both seasons)	30	

Notes

1 to avoid duplication, this measure of species richness does not include unidentified immatures where more mature specimens in the same group were present

Figure A.1 Llyn Idwal: sample location & substrate map

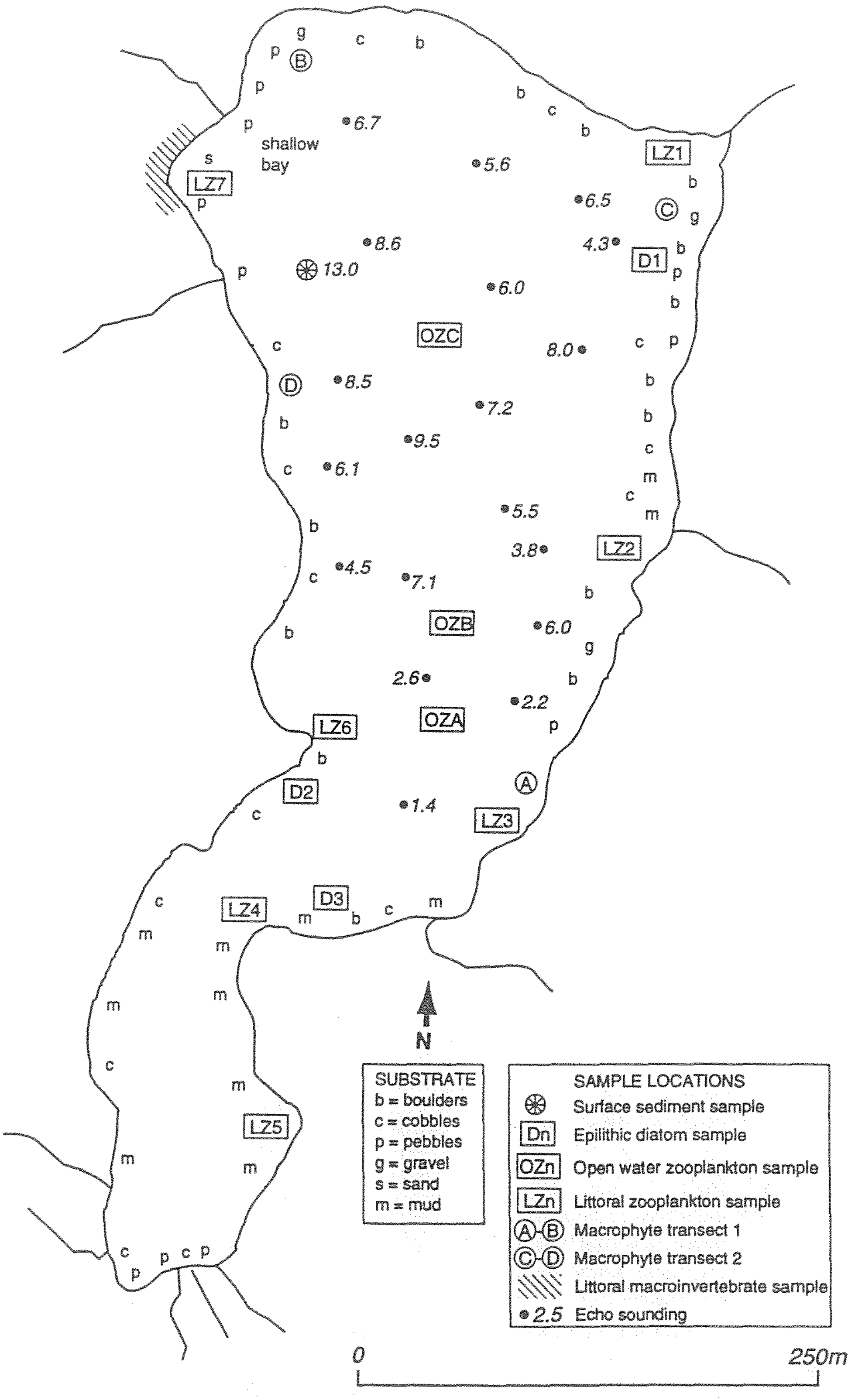


Figure A.2 Llyn Idwal: aquatic macrophyte distribution map

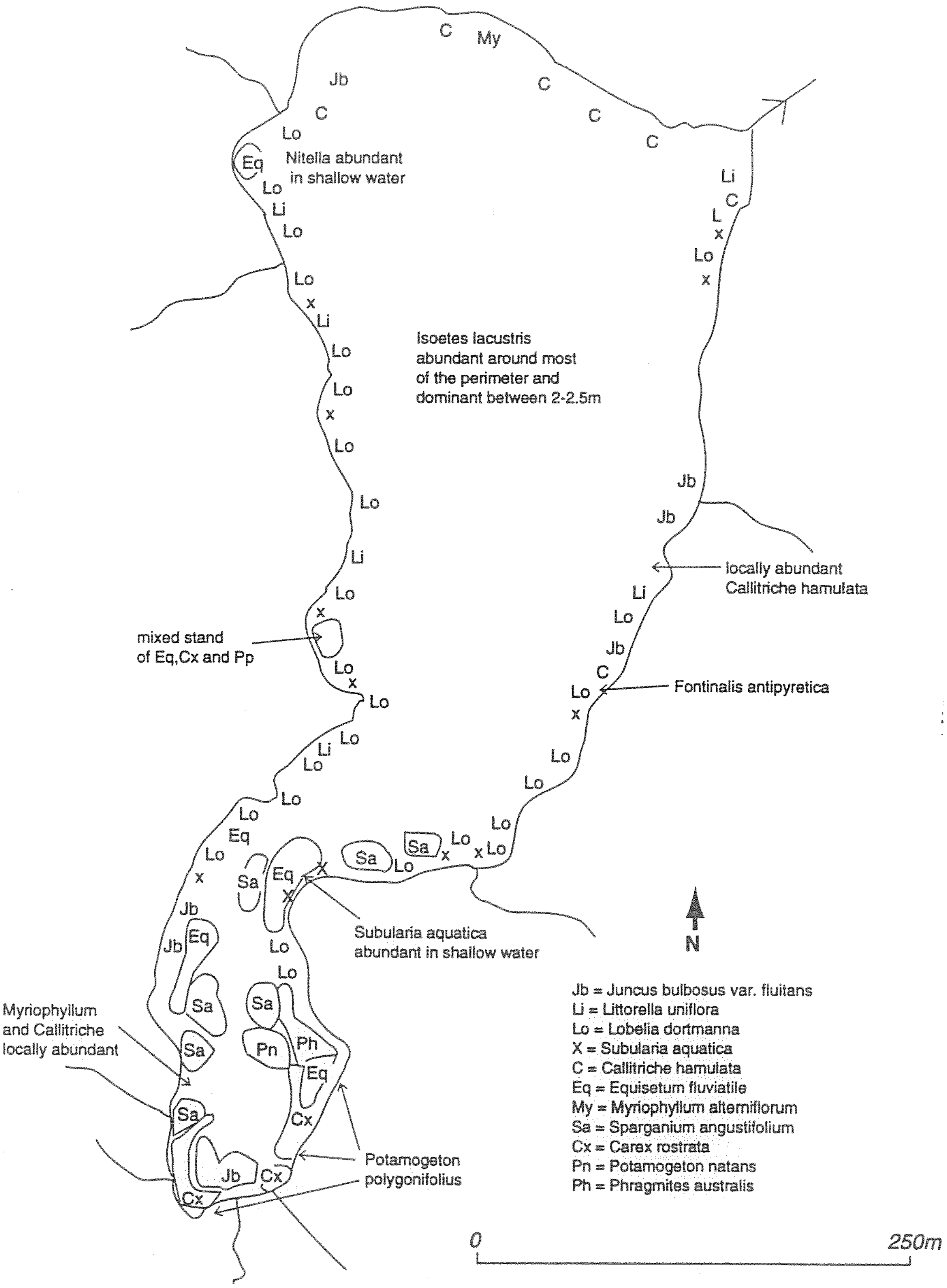


Figure A.3 Llyn Idwal: Temperature profiles

10 July 1993 **5 September 1993**

Air temperature = 10°C
Secci disc transparency = 6.3 m

Air temperature = 14°c
Secci disc transparency = 7.3 m

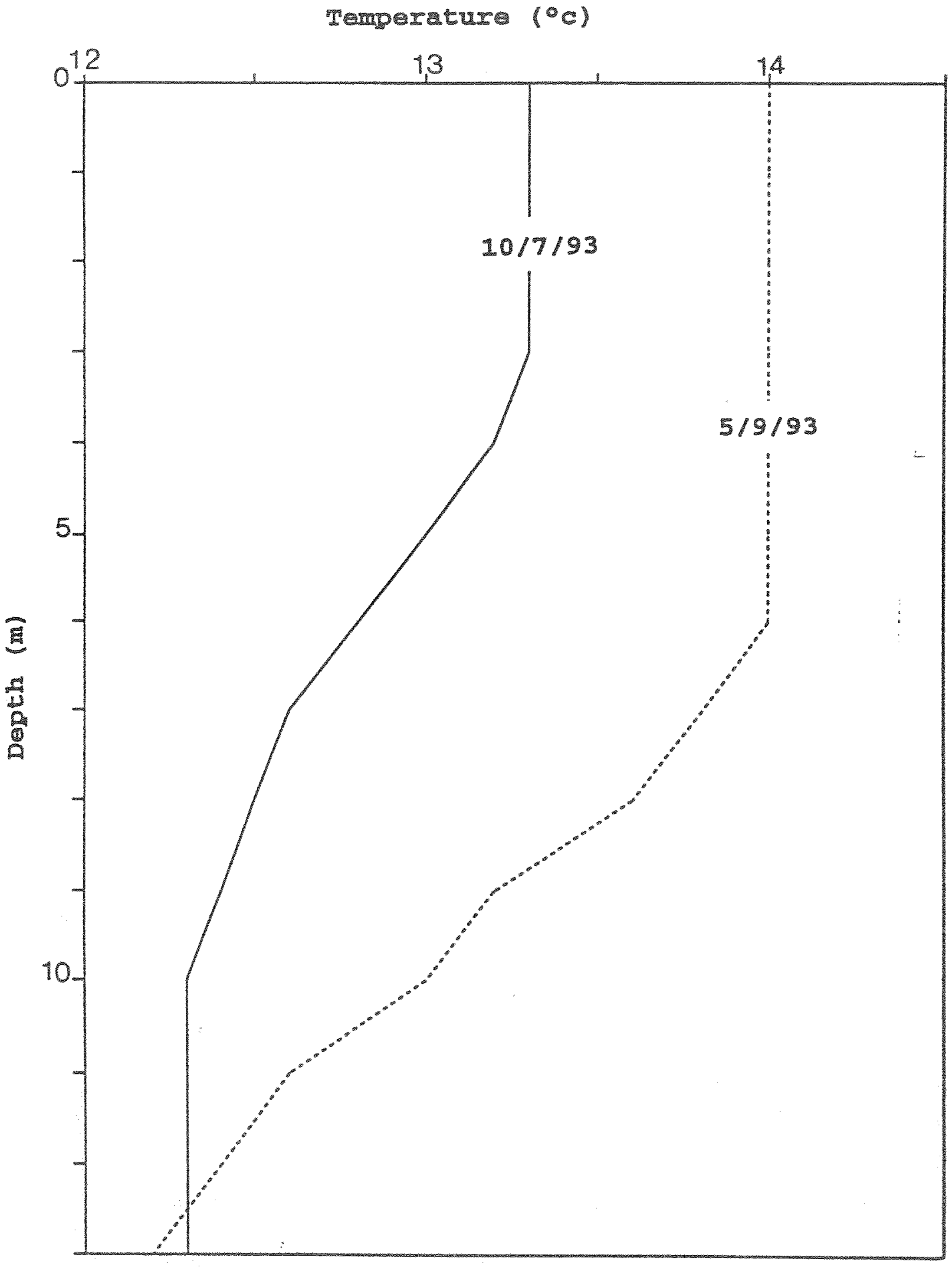
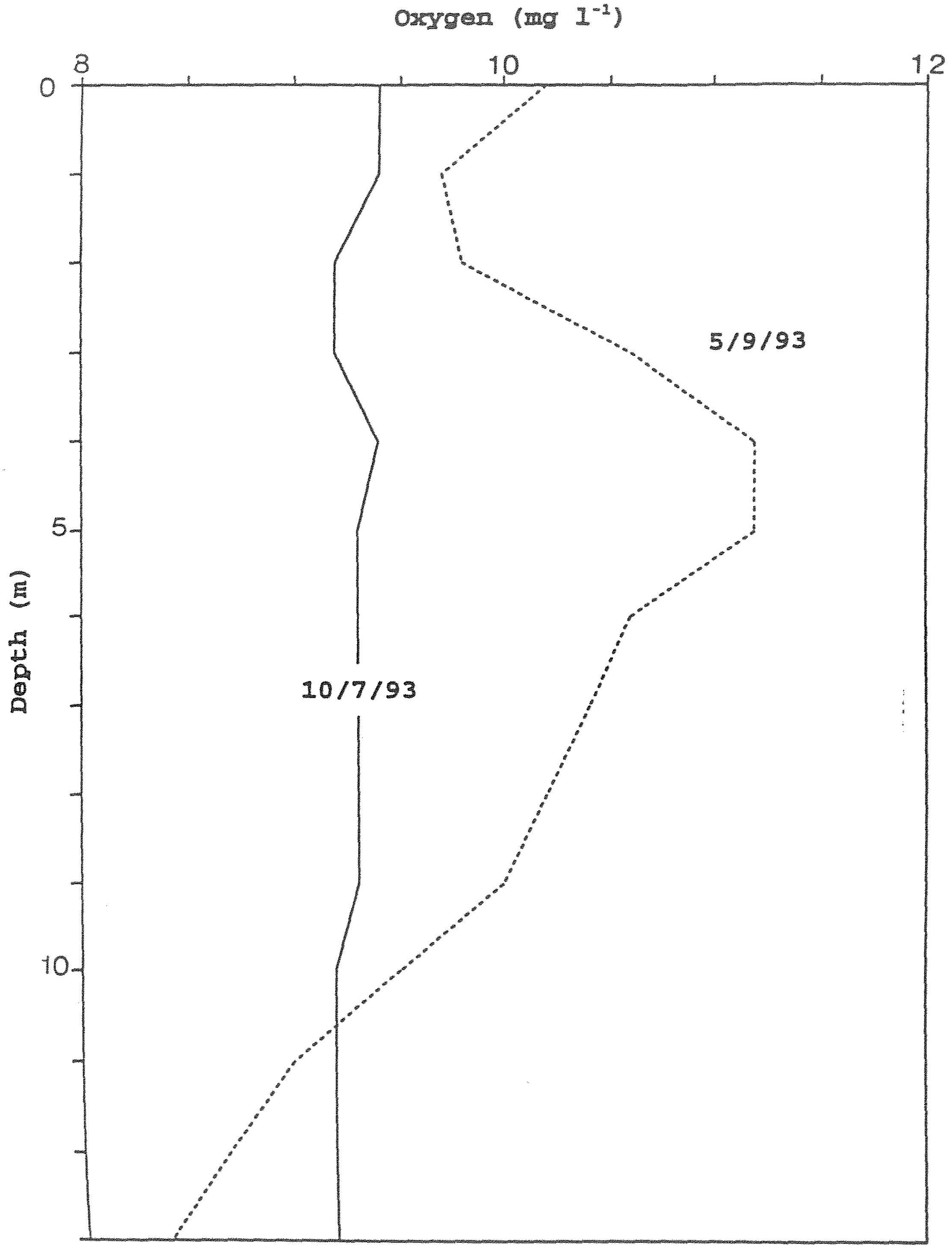


Figure A.4 Llyn Idwal: Oxygen profiles



Appendix B Data tables and Figures: Llyn Cwellyn

Table B.1 Llyn Cwellyn water chemistry

Determinand		Sample date				
		10-7-93	4-9-93	6-12-93	29-3-93	mean
pH		6.44	6.41	6.39	6.39	6.35
field pH		5.84	6.02	6.38	6.17	6.10
Alkalinity 1	μeq l^{-1}	38	39	41	31	37
Alkalinity 2	μeq l^{-1}	30	31	32	22	29
Conductivity	μS cm^{-1}	36	34	36	38	36
field conductivity	μS cm^{-1}	42	45	53	38	45
Sodium	μeq l^{-1}	172	170	160	198	175
Potassium	μeq l^{-1}	5	6	7	8	7
Magnesium	μeq l^{-1}	40	40	41	63	46
Calcium	μeq l^{-1}	89	95	76	95	89
Chloride	μeq l^{-1}	194	189	168	218	192
Aluminium $_{\text{total monomeric}}$	μg l^{-1}	3	1	2	10	4
Aluminium $_{\text{non-labile}}$	μg l^{-1}	3	0	2	5	3
Aluminium $_{\text{labile}}$	μg l^{-1}	0	1	0	5	2
Absorbtion	(250nm)	.021	.054	.048	.027	.038
Carbon $_{\text{total organic}}$	mg l^{-1}	1.2	1.1	1.7	1.1	1.3
Phosphorus $_{\text{total}}$	μgP l^{-1}	5.1	9.0	7.0	7.2	7.1
Phosphorus $_{\text{total soluble}}$	μgP l^{-1}	4.7	6.7	4.2	3.3	4.7
Phosphorus $_{\text{soluble reactive}}$	μgP l^{-1}	4.2	5.0	1.5	1.4	4.7
Nitrate	μgN l^{-1}	161	112	175	231	170
Silica $_{\text{total}}$	mg l^{-1}	-	1.49	1.53	1.44	1.49
Silica $_{\text{soluble reactive}}$	μg l^{-1}	1.4	1.4	1.51	1.13	1.36
Chlorophyll a	μg l^{-1}	0.9	3.4	1.5	-	1.9
Sulphate	μeq l^{-1}	82	80	81	77	80
Copper $_{\text{total soluble}}$	μg l^{-1}				<1	
Iron $_{\text{total soluble}}$	μg l^{-1}				23	
Lead $_{\text{total soluble}}$	μg l^{-1}				<1	
Manganese $_{\text{total soluble}}$	μg l^{-1}				12	
Zinc $_{\text{total soluble}}$	μg l^{-1}				21	

Table B.2 **Llyn Cwellyn epilithic diatom taxon list (including taxa >1.0%)**

code	Taxon	Relative frequency (%)
AC013A	*Achnanthes minutissima*	47.9
TA001A	*Tabellaria flocculosa*	21.3
FR007A	*Fragilaria vaucheriae*	11.4
BR001A	*Brachysira vitrea*	5.6
PE002A	*Peronia fibula*	2.9
CM048A	*Cymbella lunata*	1.4
AC046A	*Achnanthes altaica*	1.1
EU002B	*Eunotia pectinalis* var. *minor*	1.1

Total count = 553
Total number of taxa = 26

Table B.3 **Llyn Cwellyn surface sediment diatom taxon list (including taxa >1.0%)**

code	Taxon	Relative frequency (%)
AC013A	*Achnanthes minutissima*	24.7
TA001A	*Tabellaria flocculosa*	7.6
BR001A	*Brachysira vitrea*	6.0
EU047A	*Eunotia incisa*	4.5
FR007A	*Fragilaria vaucheriae*	4.2
EU009A	*Eunotia exigua*	4.0
FR005D	*Fragilaria virescens* var. *exigua*	2.9
AC014C	*Achnanthes austriaca* var. *helvetica*	2.5
EU002B	*Eunotia pectinalis* var. *minor*	2.0
CM048A	*Cymbella lunata*	1.8
PE002A	*Peronia fibula*	1.8
EU011A	*Eunotia rhomboidea*	1.6
AC022A	*Achnanthes marginulata*	1.6
CM010A	*Cymbella perpusilla*	1.6
AC030A	*Achnanthes subatomoides*	1.3
CY9991	*Cyclotella rossii*	1.1
NI005A	*Nitzschia perminuta*	1.1

Total count = 552
Total number of taxa = 76

Table B.4 Llyn Cwellyn aquatic macrophyte abundance summary: 4 September 1994

Taxon	code	Abun	comments
Emergent taxa			
Caltha palustris	361201	O	on east shore-line
Equisetum fluviatile	350202	R	one small stand in south
Ranunculus flammula	366904	O	on southern shoreline
Juncus effusus	383010	F	
Floating taxa			
Potamogeton natans	384012	R	one bed near north-west shore
Potamogeton polygonifolius	384017	R	in stream inflows in south
Submergent taxa			
filamentous green algae	170000	F	
Batrachospermum sp.	20000	O	
Fontinalis antipyretica	323401	O	locally abundant in south end
Sphagnum auriculatum	327401	O	
Drepanocladus sp. (to be verified)	322900		
Scapania undulata	345410	R	on submerged boulders
Isoetes lacustris	350302	A	abundant from 1.5m dominant 3-5m
Callitriche hamulata	361103	F	widespread to depth of 3m
Elatine hexandra	362401	R	in shallow water on north shore
Littorella uniflora	363901	A	widespread to depth of 1.5m
Lobelia dortmanna	364001	F	widespread to depth of 1m
Myriophyllum alterniflorum	365401	F	
Subularia aquatica	368701	F	in shallow water on east shore
Juncus bulbosus var.fluitans	383006	A	prolific growth at south end
other wetland taxa			
Oenanthe crocata	365802	O	
Deschampsia caespitosa	381801	F	
Juncus articulatus/acutiflorus	383001/3	F	
Molinia caerulea	383501	O	
Phalaris arundinacea	383701		
Angelica sylvestris	360302	O	
Filipendula ulmaria	362701	O	
Viola palustris	369901	O	
Alnus glutinosa	360201	O	
Salix sp.	367500	O	

Table B.5 Llyn Cwellyn littoral Cladocera taxon list

Sample date 4-9-93

Taxon	Sample number						
	1a	1b	2	3	4	5	6
	number of individuals						
Alona affinis	2	1					+
Alona rustica					+		
Alonopsis elongata	4	4		1	6	29	7
Alonella excisa	3	2			+		
Camptocerus rectirostris	3	2		1			
Chydorus piger				2			
Chydorus sphaericus		2			1		
Diaphanosoma brachyurum					1		8
Eurycerus lamellatus	98	107	20	14	4	10	3
Graptoleberis testudinaria	3	9		11			
Pleuroxus aduncus							1
Pleuroxus truncatus	11	1	9	12	6	2	1
Polyphemus pediculus	14	2	2	14	34	254	57
Sida crystallina	493	1354	398	34	174	549	69
TOTAL COUNT	631	1484	429	89	226	844	146

+ = Species present

Table B.6 Analysis of the cladoceran species composition in the samples from Llyn Cwellyn; S = sand-rock substrate.

Sample number	1a	1b	2	3	4	5	6
Substrate	S	S	S	S	S	S	S
No. Species	9	10	4	8	9	5	8
Cum. Species	9	10	10	11	13	13	14
Cum. % Species	64			>75			

Table B.7 Llyn Cwellyn open water zooplankton taxon list: 4th September 1993

Taxon	Abundance
Eudiaptomus gracilis	2
Diaphanosoma brachyurum	2
Leptodora kindti	+
Sida crystalina	2
Alona affinis	+
Cyclops abyssorum	2
Bythotrephes longimanus	2
Conochilus sp.	2
Kellicottia longospina	+

2 = Species common (abundance >5%)
1 = Species rare (found in both samples analysed)
+ = Species rare (found in one of samples analysed)

Table B.8 Llyn Cwellyn zooplankton characteristics: 4th September 1993

Station sampled: A	
Depth of Station (m)	34.5
Total zooplankton biomass (gDM m^{-2})	1.39
Net algal biomass (gDM m^{-2})	0
% Cladoceran biomass in total zooplankton biomass	43
% large Cladocera (>710 µm) in total zooplankton biomass	4
% large Copepoda (>420 µm) in total zooplankton biomass	28

Table B.9 Llyn Cwellyn littoral invertebrate data

Macro invertebrate species present and mean number per one minute kick/sweep sample in autumn (September 1993) and spring (April 1994).

code	Taxon	mean no.	
		autumn	spring
	TURBELLARIA		
03 12 00 00	Tricladida	0.3	
	MOLLUSCA		
13 07 01 07	*Lymnaea peregra* (Müller)	6.7	0.4
13 10 01 01	*Acroloxus lacustris* (L.)	0.3	0.4
	BIVALVIA		
14 03 02 00	*Pisidium* spp.	10.7	0.8
	HIRUDINIA		
17 04 01 02	*Erpobdella octoculata* (L.)	5.7	
	EPHEMEROPTERA		
30 01 01 02	*Siphlonurus lacustris* Eaton		60.4
30 02 00 00	Baetidae	1.7	
30 02 02 01	*Centroptilium luteolum* (Müller)		3.6
30 03 02 04	*Heptagenia lateralis* (Curtis)		2.4
30 04 01 00	*Leptophlebia* sp.	45.0	4.4
30 04 01 01	*Leptophlebia marginata* (L.)		11.2
30 08 02 04	*Caenis horaria* (L.)	25.0	0.4
30 08 02 06	*Caenis luctuosa* (Burmeister)	128.0	0.4
	PLECOPTERA		
31 02 02 01	*Amphinemura sulcicollis* (Stephens)		2.0
31 02 03 01	*Nemurella pictetii* Klapálek		1.2
31 02 04 03	*Nemoura avicularis* Morton		10.4
31 02 04 04	*Nemoura cambrica* (Stephens)	58.3	
31 03 01 00	*Leuctra* spp.		120.8
31 03 01 02	*Leuctra inermis* (Kempny)		0.4
31 03 01 03	*Leuctra hippopus* Kempny	2.3	1.2
31 03 01 04	*Leuctra nigra* (Olivier)		0.8
31 04 01 01	*Capnia bifrons* (Newman)		53.2
31 08 01 01	*Siphonoperla torrentium* (Pictet)	5.0	2.0
	HEMIPTERA		
33 11 00 00	Corixidae sp. - immatures	33.7	4.8
	COLEOPTERA		
35 03 00 00	Dytiscidae - larvae	0.3	0.4
35 03 07 03	*Potamonectes elegans* (Panzer)	0.7	
35 11 03 01	*Limnius vockmari* (Panzer)	6.0	12.4

	contd.		
35 11 06 02	*Oulimnius troglodytes* (Gyllenhal)	31.0	13.2
	MEGALOPTERA		
36 01 01 01	*Sialis lutaria* (L.)	0.7	2.4
	TRICHOPTERA		
38 03 02 00	*Plectrocnemia* sp.		0.8
38 03 03 01	*Polycentropus flavomaculatus* (Pictet)	30.0	
38 03 04 01	*Holocentropus dubius* (Rambur)	2.7	0.4
38 03 05 01	*Cyrnus trimaculatus* (Curtis)	11.0	0.4
38 04 02 01	*Tinodes waeneri* (L.)	9.3	
38 05 01 00	*Hydropsyche* sp.		0.4
38 06 03 00	*Hydroptila* sp.	8.3	1.6
38 07 04 03	*Agrypnia varia* (Fabricus)	0.3	
38 12 01 07	*Athripsodes cinereus* (Curtis)	23.0	4.0
38 12 02 03	*Mystacides longicornis* (L.)		0.4
38 14 02 01	*Lepidostoma hirtum* (Fabricius)	3.3	
38 15 01 01	*Sericostoma personatum* (Spence)	1.0	0.4
	DIPTERA		
40 01 00 00	Tipulidae	0.7	1.2
40 08 00 00	Ceratopogonidae		1.2
40 09 00 00	Chironomidae	479.0	153.6
40 17 00 00	Empididae		0.7
	Total invertebrates	930.7	474.0
	Species richness (minimum)[1]	29	33
	Minimum richness (both seasons)	41	

Notes

[1] to avoid duplication, this measure of species richness does not include unidentified immatures where more mature specimens in the same group were present

Figure B.1 Llyn Cwellyn: sample location & substrate map

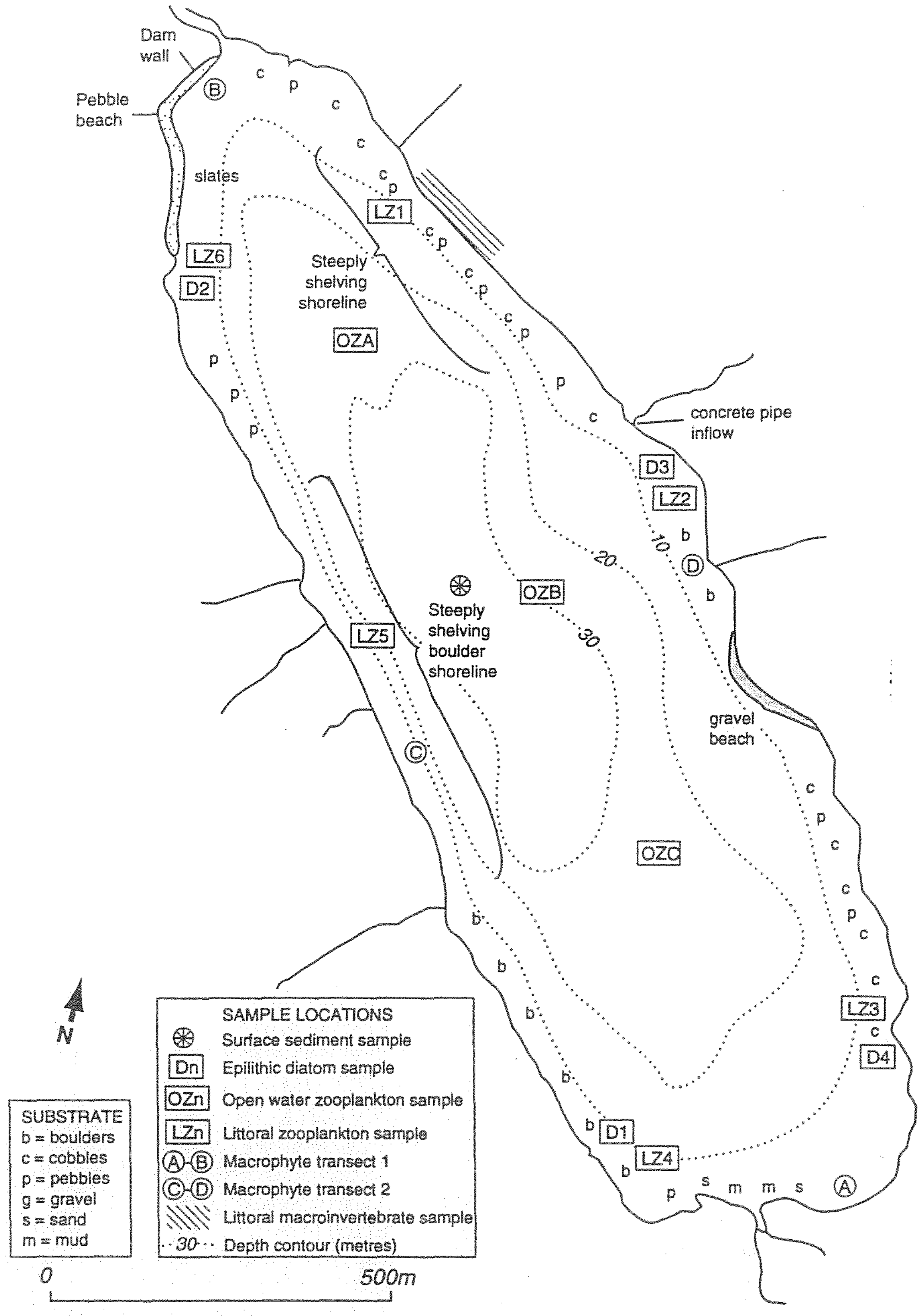


Figure B.2 Llyn Cwellyn: aquatic macrophyte distribution map

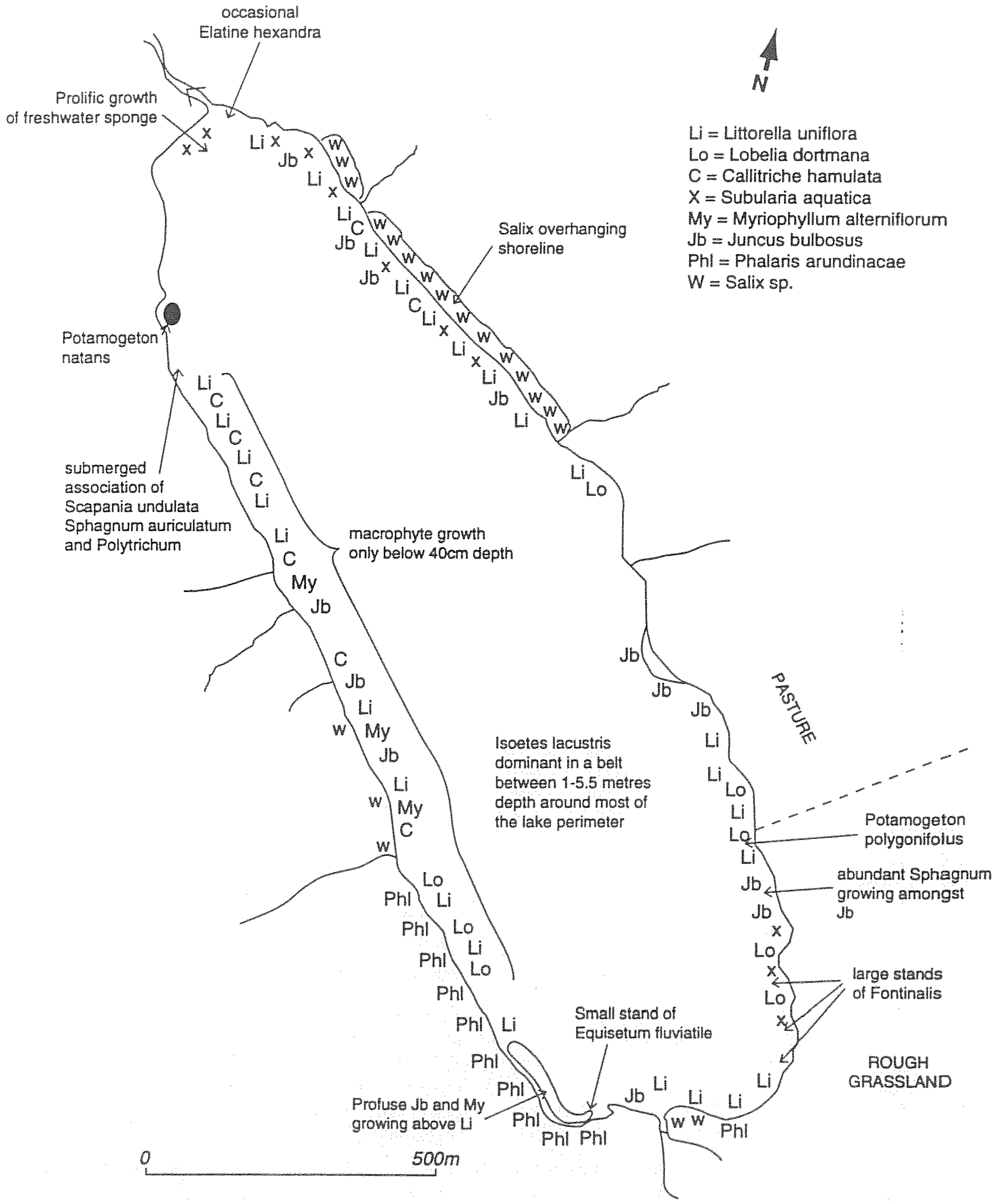


Figure B.3 Llyn Cwellyn: Temperature profiles

10 July 1993	September 1993
Air temperature = 13.0°c	Air temperature = 14.8°c
Secci disc transparency = 6.9 m	Secci disc transparency = 9.0 m

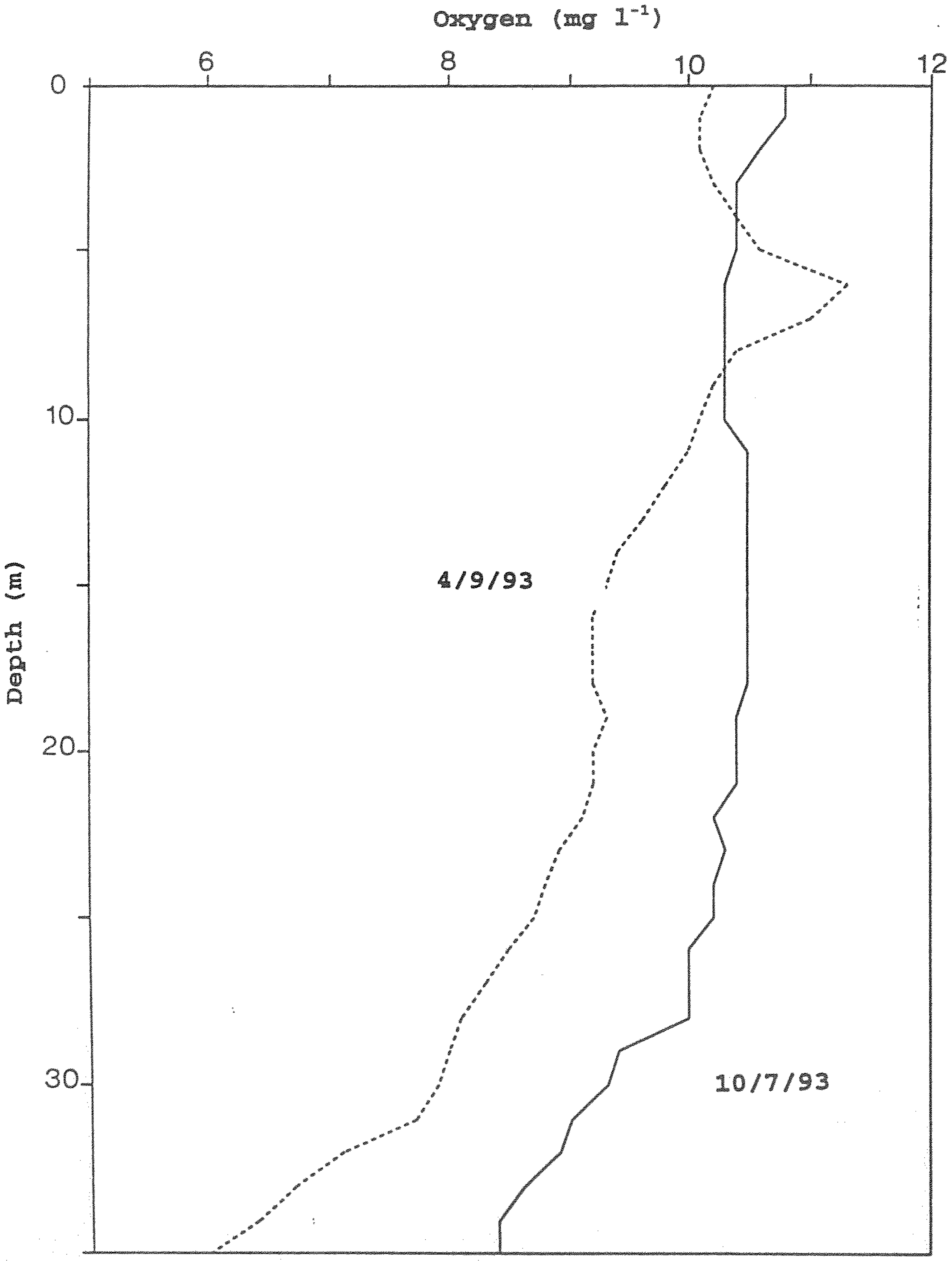
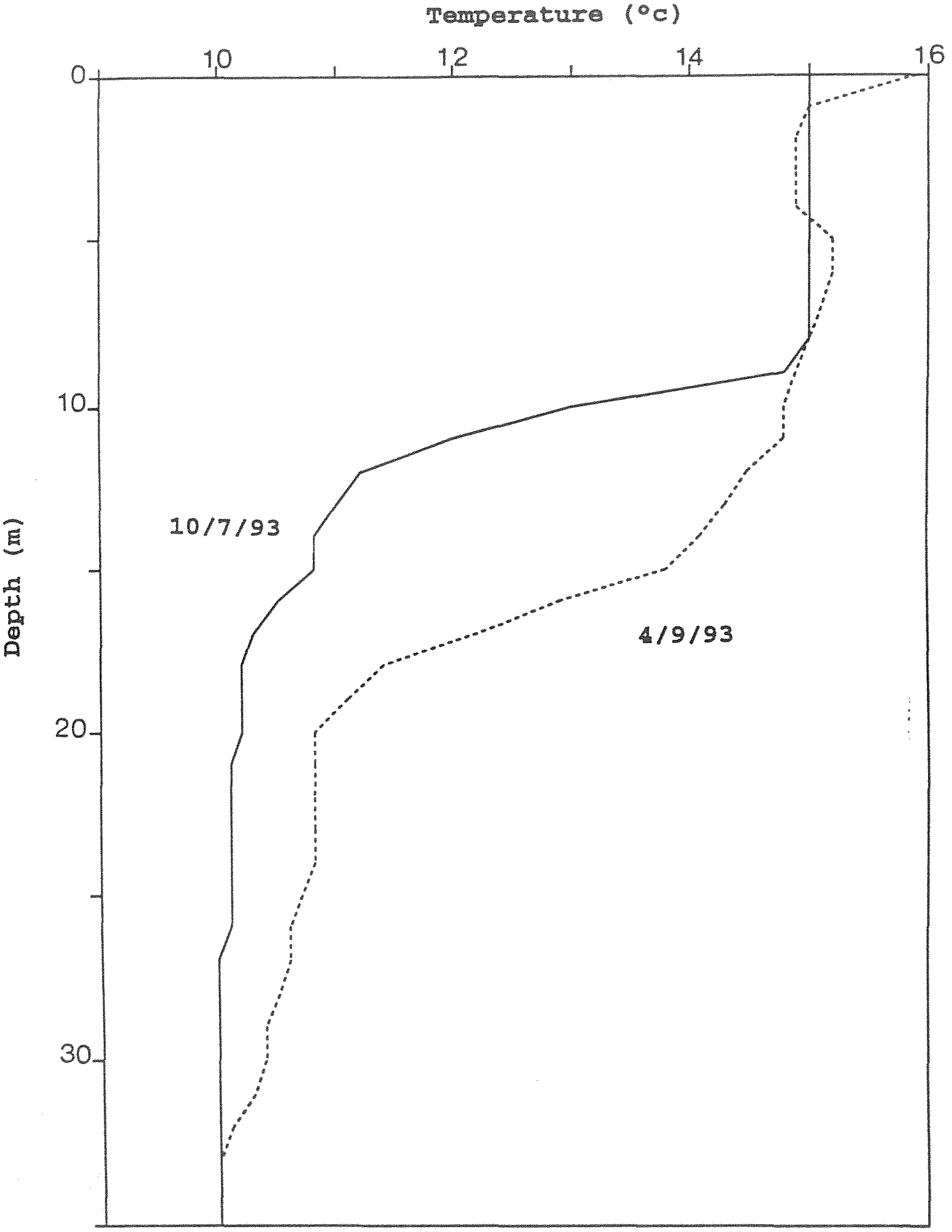


Figure B.4 Llyn Cwellyn: Oxygen profiles



Appendix C Data tables and Figures: Llyn Coron

Table C.1 Llyn Coron water chemistry

Determinand		Sample date				
		10-7-93	1-9-93	6-12-93	29-3-94	mean
pH		8.39	9.17	7.90	8.97	8.61
field pH		8.20	8.95	8.24	8.83	8.56
Alkalinity	µeq l^{-1}	2069	2150	1745	1512	1869
Alkalinity 2	µeq l^{-1}	2045	2171	1766	1529	1878
Conductivity	µS cm^{-1}	334	326	336	291	322
field conductivity	µS cm^{-1}	330	305	420	300	339
Sodium	µeq l^{-1}	821	884	828	837	1050
Potassium	µeq l^{-1}	55	60	98	66	70
Magnesium	µeq l^{-1}	580	616	705	635	634
Calcium	µeq l^{-1}	1971	2124	2067	1788	1988
Chloride	µeq l^{-1}	967	1027	896	939	957
Aluminium $_{\text{total monomeric}}$	µg l^{-1}	5	15	4	3	7
Aluminium $_{\text{non-labile}}$	µg l^{-1}	4	0	3	3	3
Aluminium $_{\text{labile}}$	µg l^{-1}	1	15	1	0	4
Absorbtion	(250nm)	.279	.246	.309	.214	.262
Carbon $_{\text{total organic}}$	mg l^{-1}	7.2	6.5	6.8	6.5	6.8
Phosphorus $_{\text{total}}$	µgP l^{-1}	98.6	348.2	111.1	66.5	156.1
Phosphorus $_{\text{total soluble}}$	µgP l^{-1}	88.4	203.4	89.5	16.4	99.4
Phosphorus $_{\text{soluble reactive}}$	µgP l^{-1}	64.5	166.5	61.2	3.1	73.8
Nitrate	µg l^{-1}	322	14	1050	1414	700
Silica $_{\text{total}}$	mg l^{-1}	-	15.80	11.03	4.44	10.4
Silica $_{\text{soluble reactive}}$	µg l^{-1}	2.22	14.90	10.95	3.1	7.79
Chlorophyll a	µg l^{-1}	5.0	56.2	2.3	-	21.2
Sulphate	µeq l^{-1}	392	325	513	341	393
Copper $_{\text{total soluble}}$	µg l^{-1}				<1	
Iron $_{\text{total soluble}}$	µg l^{-1}				279	
Lead $_{\text{total soluble}}$	µg l^{-1}				<1	
Manganese $_{\text{total soluble}}$	µg l^{-1}				53	
Zinc $_{\text{total soluble}}$	µg l^{-1}				<5	

Table C.2 Llyn Coron epilithic diatom taxon list (including taxa >1.0%)

code	Taxon	Relative frequency (%)
FR007A	*Fragilaria vaucheriae* (fine)	17.0
FR007A	*Fragilaria vaucheriae* (coarse)	14.2
NI002A	*Nitzschia fonticola*	13.4
NA095A	*Navicula tripunctata*	7.7
FR009A	*Fragilaria capucina* types (chains)	5.6
AU003B	*Aulacoseira granulata* var. *angustissima*	5.2
AM012A	*Amphora pediculus*	4.3
NI9999	*Nitzschia* sp.	3.9
NI014A	*Nitzschia amphibia*	3.6
RC001A	*Rhoicosphenia curvata*	3.2
NI008A	*Nitzschia frustulum*	2.6
DT003A	*Diatoma vulgaris*	2.2
NI005A	*Nitzschia perminuta*	1.5
FR9999	*Fragilaria* sp.	1.2

Total count = 647
Total number of taxa = 48

Table C.3 Llyn Coron surface sediment diatom taxon list (including taxa >1.0%)

code	Taxon	Relative frequency (%)
ST001A	*Stephanodiscus parvus*	24.4
AU003B	*Aulacoseira granulata* var. *angustissima*	11.6
CC9997	*Cyclostephanos* [cf. *tholiformis*]	7.5
ST001A	*Stephanodiscus hantzschii*	5.9
FR009B	*Fragilaria capucina* var. *mesolepta*	4.9
NI044A	*Nitzschia intermedia*	3.1
CC002A	*Cyclostephanos invisitatus*	2.4
AC013A	*Achnanthes minutissima*	2.3
CO001A	*Cocconeis placentula*	2.1
AM012A	*Amphora pediculus*	1.9
AC001A	*Achnanthes lanceolata*	1.9
FR007A	*Fragilaria vaucheriae* (coarse)	1.9
RC001A	*Rhoicosphenia curvata*	1.7
FR001A	*Fragilaria pinnata*	1.7
ST001D	*Stephanodiscus hantschii* fo. *tenuis*	1.6
CO001C	*Cocconeis placentula* var. *lineata*	1.6
AS001A	*Asterionella formosa*	1.4
NI014A	*Nitzschia amphibia*	1.4
FR007A	*Fragilaria vaucheriae* (fine)	1.2
ST9999	*Stephanodiscus* sp.	1.0
NA009A	*Navicula lanceolata*	1.0
FR002B	*Fragilaria construens* var. *binodis*	1.0

Total count = 574
Total number of taxa = 64

Table C.4 Llyn Coron aquatic macrophyte abundance summary: 1 September 1994

Taxon	code	Abun	comments
Emergent taxa			
Equisetum fluviatile	350202	R	
Caltha palustris	361201	O	
Hydrocotyle vulgaris	363401	R	
Mentha aquatica	364601	R	
Eleocharis acicularis *	382001	O	
Eleocharis palustris	382004	O	
Iris pseudacorus	382901	O	locally abundant
Alisma plantago aquatica	380303	O	
Juncus effusus	383010	A	
Phalaris arundinacea	383701	O	
Phragmites australis	383801	R	one large stand in south-east
Scirpus lacustris ssp. *tabernaemontani* *	384504	A	several stands in west
Sparganium erectum	384603	O	
Floating taxa			
Nymphaea alba	365601	R	on west shore only
Polygonum amphibium	366501	O	locally abundant in west
Submergent taxa			
Enteromorpha sp.	170000	A	widespread
Chara sp.	220000	O	in deeper water
Callitriche stagnalis	361108	A	widespread
Elatine hydropiper	362402	F	locally abundant on N+S shore
Littorella uniflora	363901	R	north shore only
Myriophyllum alterniflorum	365403	R	north shore only
Ranunculus circinatus *	366970	O	
Elodea canadensis	382101	R	
Potamogeton perfoliatus *	384016	O	
Potamogeton trichoides *	384021	R	in deeper water in north
Zannichellia palustris *	385201	O	
other wetland taxa			
Achillea ptarmica	360101	A	
Bidens triparta	360904	F	
Filipendula ulmaria	362701	O	
Juncus acutiflorus/articulatus	383001	O	
Juncus bufonius	383005	R	
Lythrum salicaria	364502	A	
Mentha arvensis	364600	R	
Myosotis laxa	365100	O	
Salix sp.	367500	F	
Scutellaria galericulata	367901	R	
Solanum dulcamara	368301	F	
Stachys palustris	368501	O	

* = taxon regionally rare for NRA Welsh Region (after Palmer and Newbold, 1983)

Table C.5 Llyn Coron littoral Cladocera taxon list

Sample date 1-9-93

Taxon	Sample number						
	1	2	3	4	5	6	7
	number of individuals						
Alona affinis		1		+			
Chydorus sphaericus	1	4			2		
Daphnia hyalina	3	48	4	2	11	10	1
Eurycerus lamellatus							1
Leptodora kindti					1	1	
Oxyurella tenuicaudis	2						
Pleuroxus aduncus	18	23	5	26	94	3	2
Pleuroxus trigonellus					200	22	
Pseudochydorus globosus		1	s				
Scapholeberis mucronata				16	4		
Simocephalus vetulus	1				2	1	
TOTAL COUNT	25	77	9	44	315	37	4

+ = species present

S = shell fragment

Table C.6a Analysis of the cladoceran species composition in the samples from Llyn Coron; S = sand-rock substrate; MV = mud-vegetation substrate, C = combination substrate (MV+S).

Sample number	1	2	3	4	5	6	7
Substrate	MV	MV	S	C	S	S	S
No. Species	5	5	3	4	8	5	3
Cum. Species	5	7	7	8	10	10	11
Cum. % Species	46				>75		

Table C.6b Analysis of selected samples from the three different substrate types recorded in Llyn Coron

Sample number	1	3	4
Substrate	MV	S	C
No. Species	5	3	4
Cum. Species	5	6	8
Cum. % Species			73

Table C.7 Llyn Coron open water zooplankton taxon list: 1st September 1993

Taxon	Abundance
Eudiaptomus gracilis	2
Cyclops strenuus	2
Eucyclops serrulatus	+
Daphnia hyalina var. *galeata*	2
Megacyclops viridis	1
Leptodora kindti	1
Cyclops vicinus	2
Pleuroxus uncinatus	1
Keratella cochlearis	1
Keratella quadrata	+

2 = Species common (abundance >5%)
1 = Species rare (found in both samples analysed)
+ = Species rare (found in one of samples analysed)

Table C.8 Llyn Coron zooplankton characteristics: 1st September 1993

Station sampled: B

Depth of Station (m)	2.5
Total zooplankton biomass (gDM m^{-2})	2.11
Net algal biomass (gDM m^{-2})	2.87
% Cladoceran biomass in total zooplankton biomass	58
% large Cladocera (>710 μm) in total zooplankton biomass	33
% large Copepoda (>420 μm) in total zooplankton biomass	12

Table C.9 Llyn Coron littoral invertebrate data

Macro-invertebrate species present and mean number per one minute kick/sweep sample in autumn (October 1993) and spring (April 1994).

code	Taxon	mean no.	
		autumn	spring
	TURBELLARIA		
03 12 00 00	*Tricladida*	19.0	148.0
	MOLLUSCA		
13 03 01 03	*Valvata piscinalis* (Müller)	27.5	120.4
13 07 01 01	*Lymnaea truncatula*	2.5	0.4
13 07 01 06	*Lymnaea auricularia* (L.)		1.2
13 07 01 07	*Lymnaea peregra* (Müller)	14.5	0.4
13 08 02 01	*Physa fontinalis* (L.)	126.5	19.2
13 09 03 07	*Planorbis albus* (Müller)	5.0	4.4
13 09 03 10	*Planorbis contortus* (L.)	19.0	15.6
13 09 04 01	*Segmentina complanata*	1.0	
13 10 01 01	*Acroloxus lacustris* (L.)	1.5	0.8
	BIVALVIA		
14 03 02 00	*Pisidium* spp.	1.0	4.0
	HIRUDINIA		
17 02 01 01	*Theromyzon tessulatum* (Müller)	6.0	0.4
17 02 02 01	*Hemiclepsis marginata* (Müller)		0.4
17 02 03 01	*Glossiphonia heteroclita* (L.)	0.5	
17 02 03 02	*Glossiphonia complanata* (L.)	3.0	1.2
17 02 05 01	*Helobdella stagnalis* (L.)		0.4
17 04 01 02	*Erpobdella octoculta* (L.)	1.0	
	MALACOSTRACA		
28 03 01 04	*Asellus meridianus* Racovitza	630.5	160.4
28 07 03 05	*Gammarus pulex* (L.)	2.0	2.8
	EPHEMEROPTERA		
30 02 01 00	*Baetis* sp.		2.4
30 02 03 01	*Cloen dipterum* (L.)	0.5	
30 08 02 04	*Caenis horaria* (L.)	24.5	20.4
	ODONATA		
32 02 02 01	*Ischnura elegans* (Linden)	5.0	
32 02 03 01	*Enallagma cyathigerum* (Charpentier)	2.0	4.0
	HEMIPTERA		
33 11 00 00	Corixidae sp. - immatures	5.0	
33 11 04 01	*Callicorixa praeusta* (Fieber)	1.5	1.2

	contd.		
33 11 05 02	*Corixa punctata* (Illinger)	0.5	0.4
33 11 07 02	*Arctocorisa germari* (Fieber)		0.8
33 11 08 01	*Sigara dorsalis* (Leach)	1.0	11.2
33 11 08 04	*Sigara falleni* (Fieber)	112.5	225.2
33 11 08 10	*Sigara concinna* (Fieber)	0.5	
	COLEOPTERA		
35 01 00 00	Haliplidae sp. - larvae	38.5	8.4
35 01 03 01	*Haliplus confinis* (Stephens)	1.0	0.4
35 01 03 03	*Haliplus lineatocollis* (Marsham)	0.5	
35 01 03 04	*Haliplus ruficollis* group	12.0	5.6
35 01 03 11	*Haliplus fluvus* (Fabricus)	1.0	
35 03 00 00	Dytiscidae - larvae	3.0	1.2
35 03 07 02	*Potamonectes assimilis* (Paykull)	0.5	0.4
35 03 07 03	*Potamonectes depressus elegans* (Panzer)	0.5	2.4
35 03 07 06	*Stictotarsus duodecimpustulatus* (Fabricus)	0.5	
35 11 06 02	*Oulimnius troglodytes* (Gyllenhal)	131.5	10.8
	TRICHOPTERA		
38 04 02 01	*Tinodes waeneri* (L.)	1.0	0.8
38 06 01 01	*Agraylea multipunctata* Curtis		4.8
38 08 05 00	*Limnephilus sp.*	5.5	
38 08 05 10	*Limnephilus lanatus* Curtis		0.8
38 08 05 17	*Limnephilus affinis* Curtis		0.4
38 08 09 01	*Anabolia nervosa* Curtis		3.2
	DIPTERA		
40 01 00 00	Tipulidae	0.5	0.8
40 08 00 00	Ceratopogonidae		0.4
40 09 00 00	Chironomidae	122.0	537.2
	Total invertebrates	1331.5	1323.2
	Species richness (minimum)[1]	37	37
	Minimum richness (both seasons)	46	

Notes

1 to avoid duplication, this measure of species richness does not include unidentified immatures where more mature specimens in the same group were present

Figure C.1 Llyn Coron: sample location & substrate map

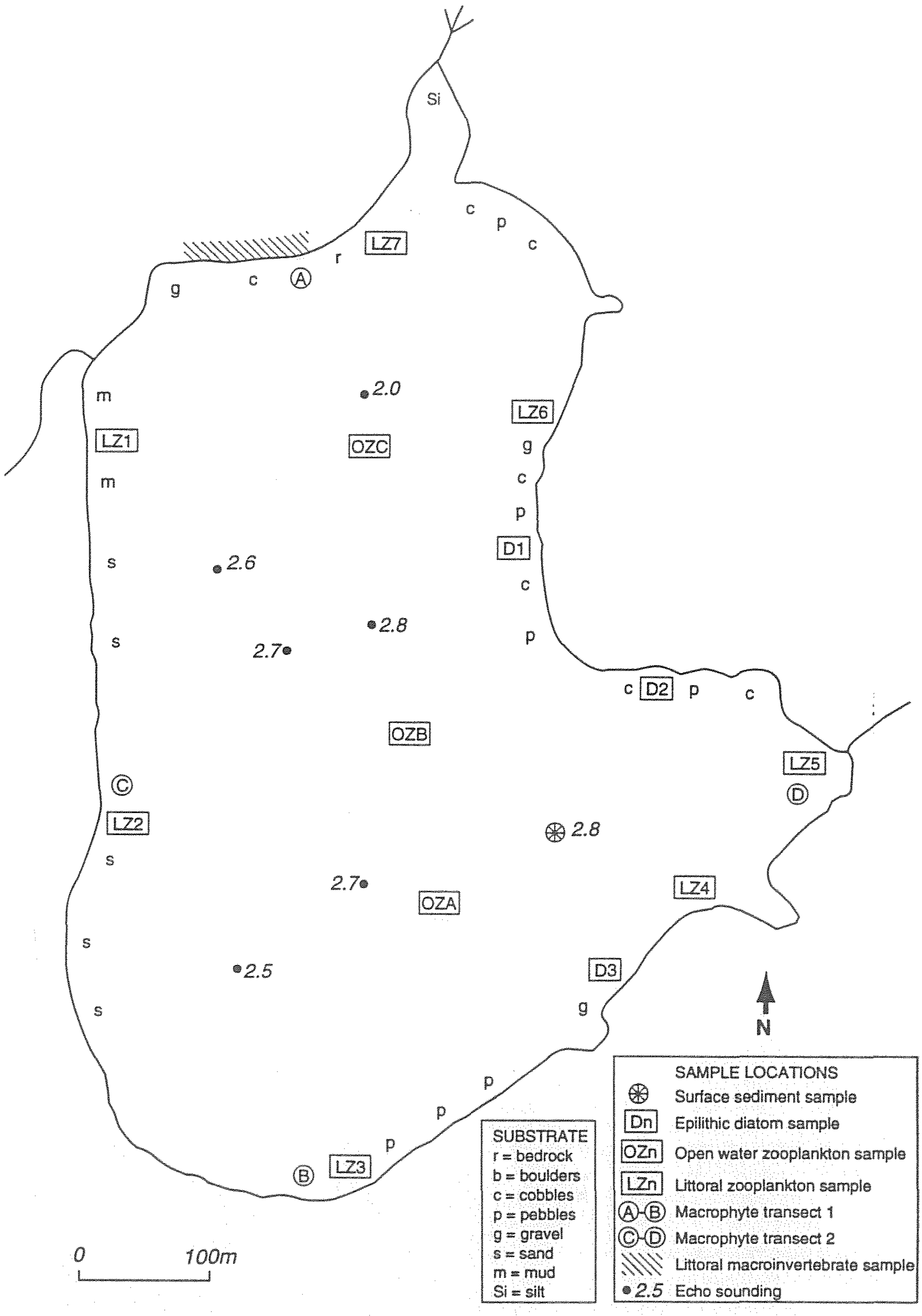


Figure C.2 Llyn Coron: aquatic macrophyte distribution map

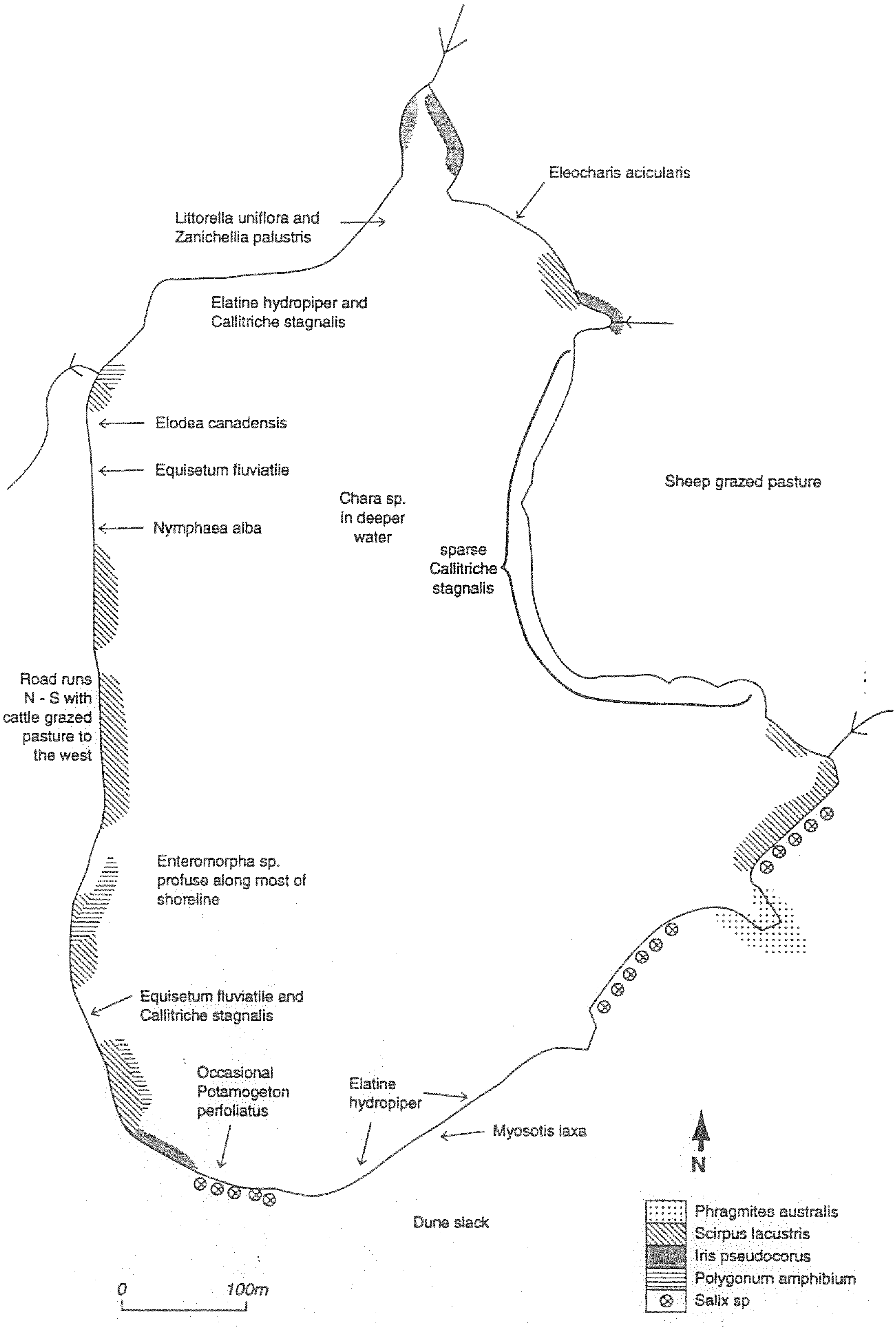


Figure C.3 Llyn Coron: Temperature profiles

10 July 1993

Air temperature = 15.0°c
Secci disc transparency = 1.3 m

1 September 1993

Air temperature = 22.0°c
Secci disc transparency = 0.5 m

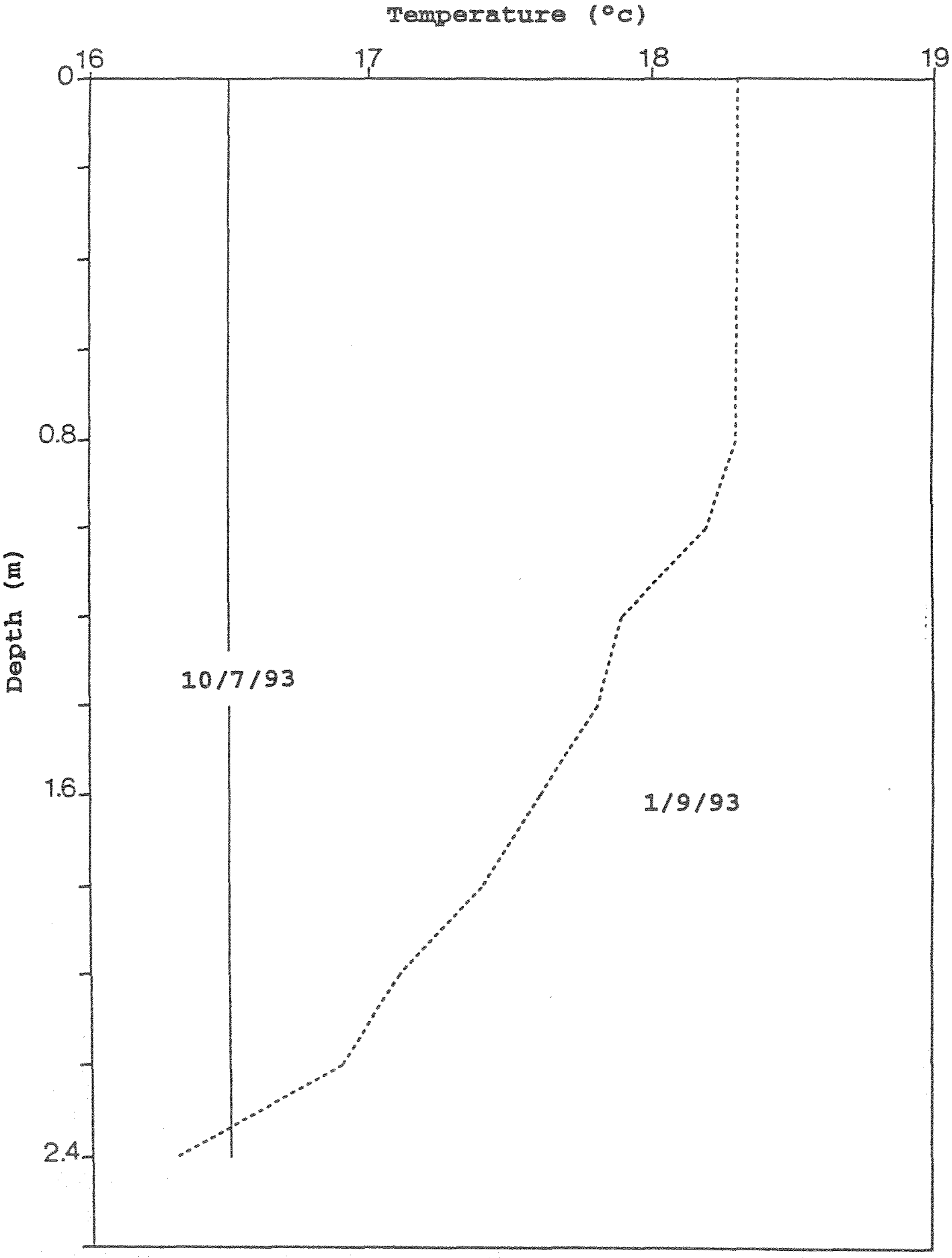
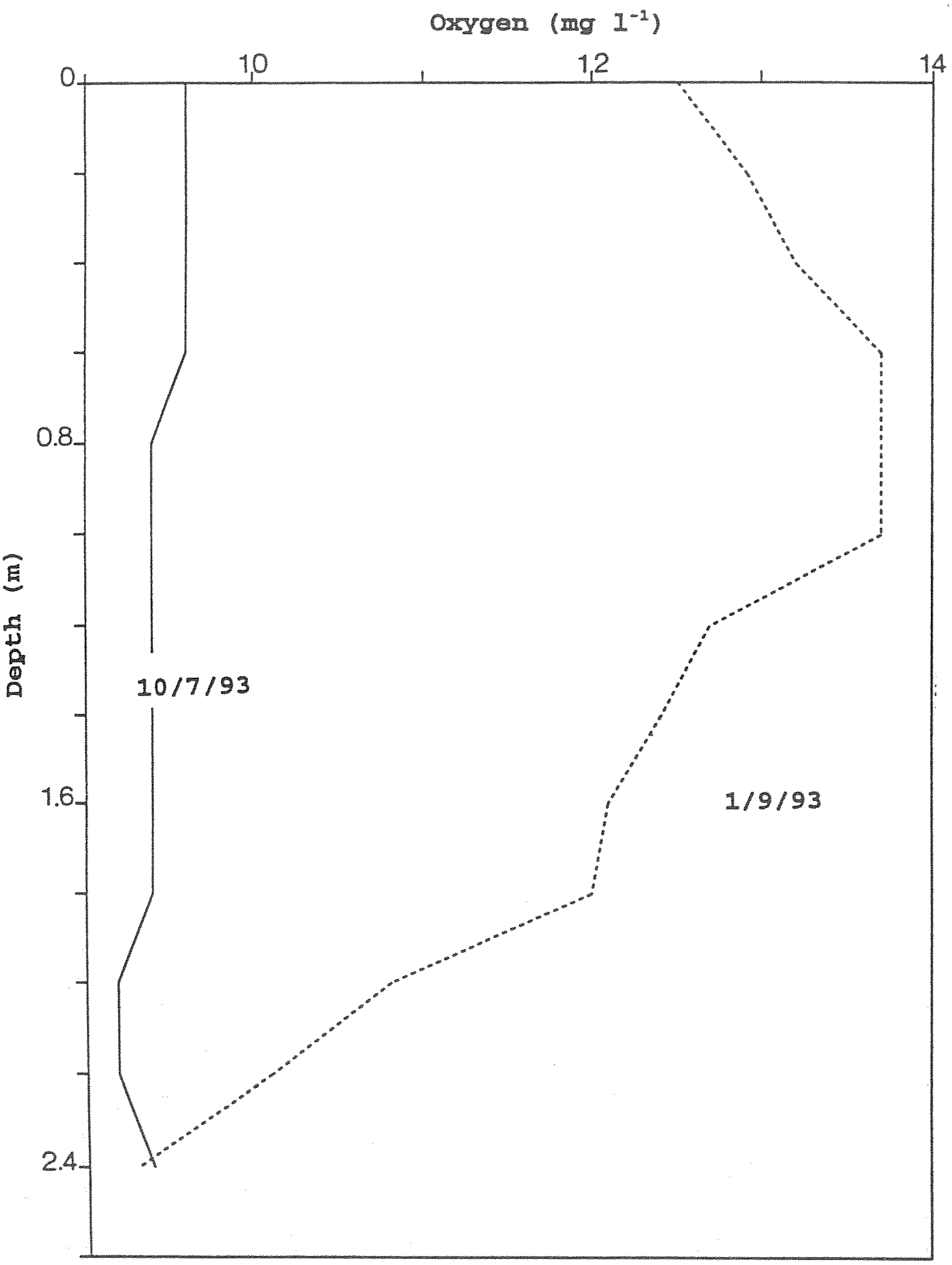


Figure C.4 Llyn Coron: Oxygen profiles



Appendix D Data tables and Figures: Llyn Dinam

Table D.1 Llyn Dinam water chemistry

Determinand		Sample				
		10-7-93	2-9-93	6-12-93	29-3-94	mean
pH		7.81	7.74	7.93	7.88	7.84
field pH		7.68	7.84	7.99	7.78	7.82
Alkalinity 1	μeq l^{-1}	1659	1706	1473	1293	1533
Alkalinity 2	μeq l^{-1}	1683	1727	1490	1309	1552
Conductivity	μS cm^{-1}	336	342	349	314	335
field conductivity	μS cm^{-1}	290	310	430	290	330
Sodium	μeq l^{-1}	1285	1400	1355	1323	1341
Potassium	μeq l^{-1}	42	48	97	72	65
Magnesium	μeq l^{-1}	500	537	629	602	567
Calcium	μeq l^{-1}	1542	1600	1490	1431	1516
Chloride	μeq l^{-1}	1465	1596	1488	1438	1497
Aluminium total monomeric	μg l^{-1}	2	1	2	0	1
Aluminium non-labile	μg l^{-1}	2	0	2	0	1
Aluminium labile	μg l^{-1}	0	1	0	0	0.3
Absorbtion	(250nm)	.424	.396	.387	.303	.378
Carbon total organic	mg l^{-1}	12	11.9	9.9	7.5	10.3
Phosphorus total	μgP l^{-1}	142.6	134.3	110.0	60.7	111.9
Phosphorus total soluble	μgP l^{-1}	116.3	130.8	78.9	22.3	87.1
Phosphorus soluble reactive	μgP l^{-1}	89.0	104.0	60.6	7.6	65.3
Nitrate	μg l^{-1}	0	0	210	63	68
Silica total	mg l^{-1}	-	1.05	6.38	1.02	2.82
Silica soluble reactive	μg l^{-1}	4.79	0.99	6.09	0.12	2.99
Chlorophyll a	μg l^{-1}	3.6	3.1	16.6	-	7.8
Sulphate	μeq l^{-1}	211	160	337	314	256
Copper total soluble	μg l^{-1}				<1	
Iron total soluble	μg l^{-1}				237	
Lead total soluble	μg l^{-1}				<1	
Manganese total soluble	μg l^{-1}				161	
Zinc total soluble	μg l^{-1}				<5	

Table D.2 Llyn Dinam epilithic diatom taxon list (including taxa >1.0%)

code	Taxon	Relative frequency (%)
NI043A	*Nitzschia inconspicua*	15.9
RC001A	*Rhoicosphenia curvata*	12.8
NI196A	*Nitzschia palaeo* var. *debilis*	9.1
AM012A	*Amphora pediculus*	7.8
NI009A	*Nitzschia palea*	5.5
NI008A	*Nitzschia fonticola*	5.3
EP001A	*Epithemia sorex*	5.2
NI007A	*Nitzschia gracilis*	4.8
NI9999	*Nitzschia* sp.	3.9
CO001A	*Cocconeis placentula*	3.2
CO001B	*Cocconeis placentula* var. *euglypta*	2.7
CO001C	*Cocconeis placentula* var. *lineata*	2.7
AC001A	*Achnanthes lanceolata*	1.8
AC013A	*Achnanthes minutissima*	1.8
NA028A	*Navicula scutelloides*	1.8
FR002C	*Fragilaria construens* var. *venter*	1.6
NA745A	*Navicula capitoradiata*	1.2
CM007A	*Cymbella sinuata*	1.2

Total count = 561
Total number of taxa = 47

Table D.3 Llyn Dinam surface sediment diatom taxon list (including taxa >1.0%)

code	Taxon	Relative frequency (%)
FR002C	*Fragilaria construens* var. *venter*	15.4
ST010A	*Stephanodiscus parvus*	14.2
FR001A	*Fragilaria pinnata*	6.7
CC9997	*Cyclostephanos* [cf. *tholiformis*]	6.2
FR002A	*Fragilaria construens*	5.3
RC001A	*Rhoicosphenia curvata*	4.8
FR005D	*Fragilaria exigua*	3.1
NI015A	*Nitzschia dissipata*	2.6
CO001C	*Cocconeis placentula* var. *lineata*	2.6
CC002A	*Cyclostephanos invisitatus*	2.1
CY003A	*Cyclotella meneghiniana*	2.1
AC001A	*Achnanthes lanceolata*	2.1
AC013A	*Achnanthes minutissima*	2.1
CO001A	*Cocconeis placentula*	1.7
NA063A	*Navicula trivialis*	1.7
NA030C	*Navicula menisculus* var. *upsaliensis*	1.7
NA023A	*Navicula gregaria*	1.5
NI171A	*Nitzschia subacicularis*	1.2
FR006A	*Fragilaria brevistriata*	1.2
FR9999	*Fragilaria* sp.	1.2
AS001A	*Asterionella formosa*	1.0
NI017A	*Nitzschia gracilis*	1.0
AM012A	*Amphora pediculus*	1.0
NA008A	*Navicula* [cf. *rhyncocephela*]	1.0

Total count = 584
Total number of taxa = 71

Table D.4 Llyn Dinam aquatic macrophyte abundance summary: 2 September 1993

Species	code	Abun	comments
Emergent taxa			
Caltha palustris	361201	R	
Eleocharis acicularis *	382001	O	locally abundant in north
Hydrocotyle vulgaris	363401	R	in north
Mentha aquatica	364601	F	
Menyanthes trifoliata	364701	F	locally abundant
Polygonum hydropiper	366504	R	in north
Veronica beccabunga	369802	O	locally abundant in north-west arm
Iris pseudocorus	382901	F	
Juncus effusus	383010	F	
Phalaris arundinacea	383701	F	
Phragmites australis	383801	A	dominant around much of the lake margin
Scirpus lacustris *	384504	F	locally dominant stands
Typha latifolia	384902	O	locally abundant
Floating taxa			
Nuphar lutea	365501	R	locally abundant in north-west arm
Nymphaea alba	365601	F	particularly in west
Polygonum amphibium	366501	O	locally abundant in north-east
Lemna minor	383302	R	
Lemna trisulca *	383304	F	locally abundant
Submergent taxa			
Chara sp.	220000	R	in north
Nitella sp.	220000	O	in north
Campylium sp. (to be verified)	321400	R	in north-east bay
Fontinalis antipyretica	323401	F	locally abundant in north-west bay
Callitriche hermaphroditica *	361104	A	mainly in north
Ceratophyllum demersum *	361401	A	widespread
Elatine hydropiper	362402	F	in north
Littorella uniflora	363901	F	in north
Myriophyllum spicatum *	365403	O	locally abundant on north-east shoreline
Ranunculus aquatilus	366969	O	in north
Potamogeton pectinatus	384015	R	
Potamogeton perfoliatus *	384016	R	in north
Potamogeton pusillus *	384019	O	

contd.

Taxon	code	Abun	comments
other wetland taxa			
Achillea ptarmica	360101	O	
Angelica sylvestris	360302	O	
Epilobium hirsutum	362504	O	
Lysmachia vulgaris	364404	O	
Lythrum salicaria	364502	O	
Myosotis laxa	365100	O	
Ranunculus ligua	366908	R	
Senecio aquaticus	368101	O	
Solanum dulcamara	368301	O	
Carex paniculata	381124	R	
Juncus bufonius	383005	O	

* = taxon regionally rare for NRA Welsh Region (after Palmer and Newbold, 1983)

Table D.5 Llyn Dinam littoral Cladocera taxon list

Sample date 2-9-93

Taxon	Sample number					
	1	2	3	4	5	6
	number of individuals					
Alona affinis	7	+	1	2		
Alona rectangula				+		
Bosmina longirostris	6		5	+		
Ceriodaphnia dubia	32	44				15
Chydorus sphaericus	1	+	+	+		
Daphnia hyalina				1		
Diaphanosoma brachyurum	4			2		1
Eubosmina longispina		7				1
Eurycerus lamellatus	39	29	102	95	109	81
Pleuroxus aduncus		+		1		
Pseudochydorus globosus	2	+				
Simocephalus vetulus	780	69	134	520	166	143
TOTAL COUNT	871	149	242	621	275	241

+ = Species present

Table D.6 Analysis of the cladoceran species composition in the samples from Llyn Dinam; MV = mud-vegetation substrate.

Sample number	1	2	3	4	5	6
Substrate	MV	MV	MV	MV	MV	MV
No. Species	8	8	5	9	2	5
Cum. Species	8	10	10	12	12	12
Cum. % Species	67		>75			

Table D.7 Llyn Dinam open water zooplankton taxon list: 2nd September 1993

Taxon	Abundance
Eudiaptomus gracilis	2
Cyclops strenuus	+
Eucyclops serrulatus	2
Daphnia galeata	1
Diaphanosoma brachyurum	2
Ceriodaphnia dubia	2
Eurycercus lamellatus	2
Macrocyclops albidus	2
Megacyclops viridis	1
Bosmina longirostris	2
Pseudochydorus globosus	1

2 = Species common (abundance >5%)
1 = Species rare (found in both samples analysed)
+ = Species rare (found in one of samples analysed)

Table D.8 Llyn Dinam zooplankton characteristics: 2nd September 1993

Station sampled: A

Depth of Station (m)	1.4
Total zooplankton biomass (gDM m^{-2})	0.38
Net algal biomass (gDM m^{-2})	0
% Cladoceran biomass in total zooplankton biomass	55
% large Cladocera (>710 µm) in total zooplankton biomass	12
% large Copepoda (>420 µm) in total zooplankton biomass	24

Table D.9 Llyn Dinam littoral invertebrate data

Macro-invertebrate species present and mean number per one minute kick/sweep sample in autumn (October 1993) and spring (April 1994).

code	species	mean no.	
		autumn	spring
	TURBELLARIA		
03 12 00 00	Tricladida	41.5	86.4
	MOLLUSCA		
13 03 01 03	*Valvata piscinalis* (Müller)	7.5	61.2
13 07 01 01	*Lymnaea trunculata* (Müller)		1.6
13 07 01 06	*Lymnaea auricularia* (L.)	2.5	0.4
13 07 01 07	*Lymnaea peregra* (Müller)	2.0	0.4
13 08 02 01	*Physa fontinalis* (L.)	2.5	
13 09 03 01	*Planorbis carinatus* (Müller)	0.5	0.8
13 09 03 07	*Planorbis albus* Müller	59.5	42.8
13 09 03 09	*Planorbis crista* (L.)	2.5	0.4
13 09 03 10	*Planorbis contortus* (L.)	5.0	6.8
13 09 04 01	*Segmentia complanata*	3.0	19.6
13 10 01 01	*Acroloxus lacustris* (L.)	5.0	17.2
	BIVALVIA		
14 03 02 00	*Pisidium* spp.	38.0	88.8
	HIRUDINIA		
17 02 01 01	*Theromyzon tessulatum* (Müller)	1.5	2.4
17 02 02 01	*Hemiclepsis marginata* (Müller)	0.5	
17 02 03 01	*Glossiphonia heteroclita* (L.)	1.5	0.8
17 02 03 02	*Glossiphonia complanata*	9.0	0.8
17 02 05 01	*Helobdella stagnalis* (L.)	6.5	1.6
17 04 01 02	*Erpobdella octoculata* (L.)	7.5	
	MALACOSTRACA		
28 03 01 01	*Asellus aquaticus* (L.)	2788.0	871.6
28 07 03 05	*Gammarus pulex* (L.)	399.5	164.4
	EPHEMEROPTERA		
30 02 00 00	Baetidae	0.5	
30 02 03 01	*Cloen dipterum* (L.)	0.5	
30 08 02 04	*Caenis horaria* (L.)	87.5	116.4
30 08 02 06	*Caenis luctuosa* (Burmeister)	15.0	25.2
	ODONATA		
32 02 02 01	*Ishnura elegans* (Linden)	130.5	

32 02 03 01	*Enallagma cyathigerum* (Charpentier)	17.5	6.8
	contd.		
	HEMIPTERA		
33 11 00 00	Corixidae sp. - immatures	5.5	
33 11 04 01	*Callicorixa praeusta* (Fieber)	2.0	
33 11 08 01	*Sigara dorsalis* (Leach)	6.0	3.6
33 11 08 04	*Sigara falleni* (Fieber)	5.5	0.4
	COLEOPTERA		
35 01 00 00	Haliplidae sp. - larvae	3.5	3.6
35 01 03 04	*Haliplus ruficollis* group	4.0	2.8
35 03 07 02	*Potamonectes assimilis* (Paykull)	0.5	
35 03 07 03	*Potamonectes depressus elegans* (Panzer)	3.0	2.0
35 03 07 06	*Stictotarsus duodecimpustulatus* (Fabricus)	0.5	
35 11 06 02	*Oulimnius troglodytes*	0.5	0.8
	MEGALOPTERA		
36 01 01 01	*Sialis lutaria* (L.)	2.0	
	TRICHOPTERA		
38 03 03 01	*Polycentropus flavomaculatus* (Pictet)	12.5	4.4
38 03 04 01	*Holocentropus dubius* (Rambur)	8.0	
38 04 01 01	*Economus tenellus* (Rambur)	2.5	0.8
38 04 02 01	*Tinodes waeneri* (L.)	3.0	4.0
38 04 03 02	*Lype reducta* (Hagen)	1.0	0.4
38 06 01 01	*Agraylea multipunctata* Curtis	7.0	0.8
38 06 06 00	*Oxyethira* sp.	8.0	49.6
38 08 05 05	*Limnephilus marmoratus* Curtis		5.2
38 08 09 01	*Anabolia nervosa* Curtis		0.8
38 12 02 03	*Mystacides longicornis* (L.)	18.5	14.8
	DIPTERA		
40 01 00 00	Tipulidae		0.4
40 09 00 00	Chironomidae	250.5	896.4
	Total invertebrates	3979.0	2507.2
	Species richness (minimum)[1]	43	37
	Minimum richness (both seasons)	47	

Notes

1 to avoid duplication, this measure of species richness does not include unidentified immatures where more mature specimens in the same group were present

Figure D.1 Llyn Dinam: sample location & substrate map

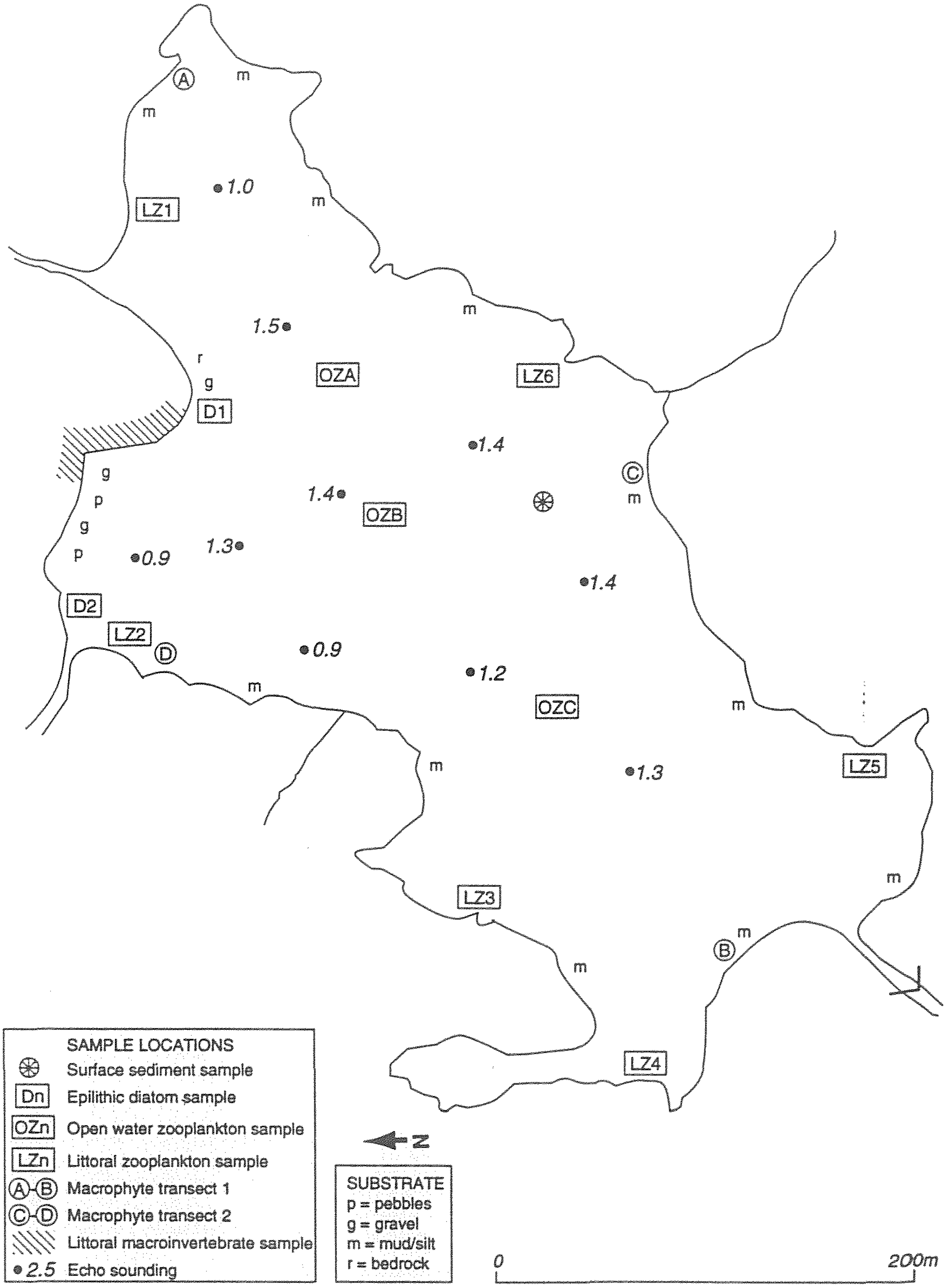


Figure D.2 Llyn Dinam: aquatic macrophyte distribution map

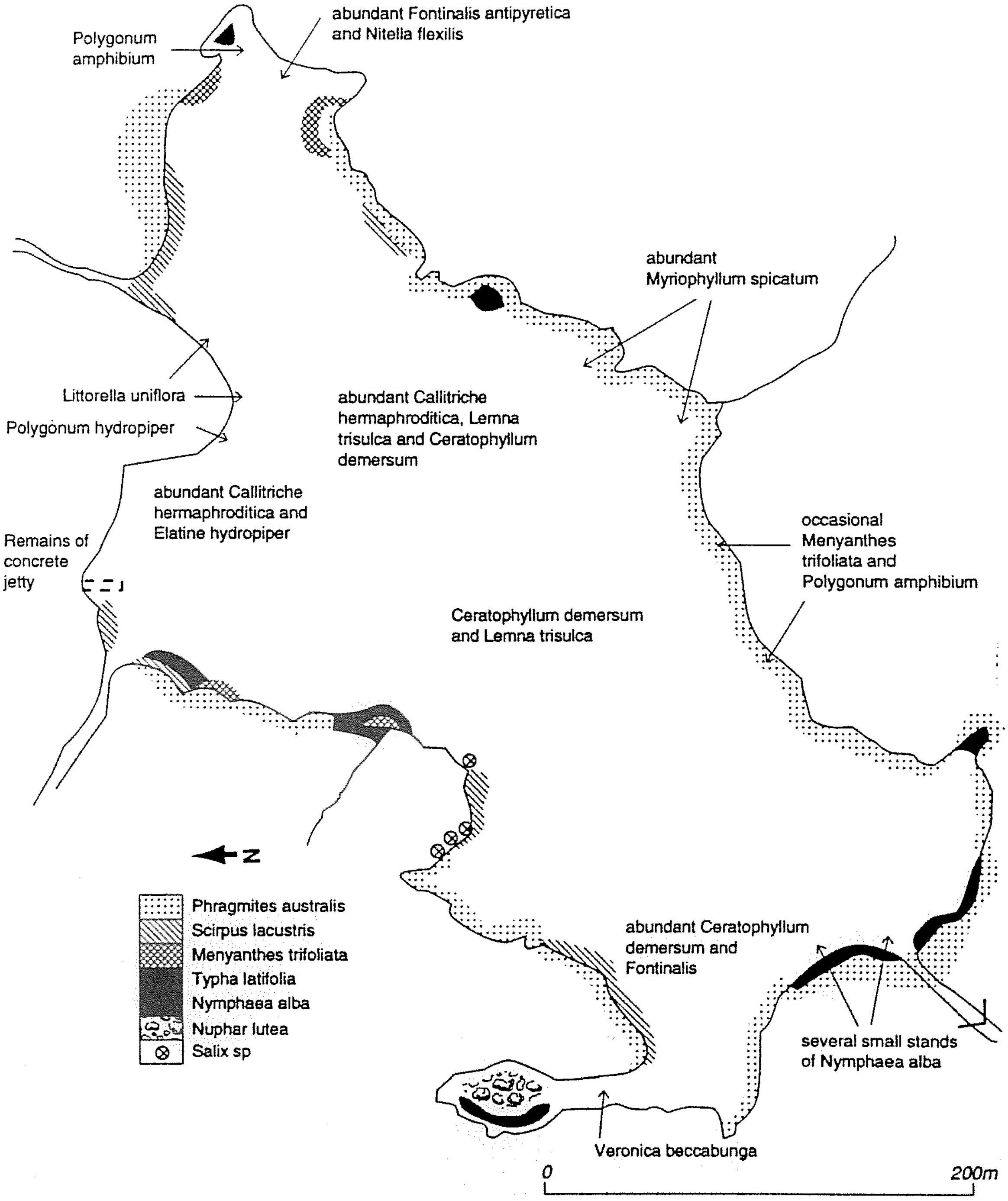


Figure D.3 Llyn Dinam: Temperature profiles

10 July 1993

Air temperature = 13.0°c
Secci disc transparency = 0.9 m

2 September 1993

Air temperature = 17.1°c
Secci disc transparency = >1.6 m

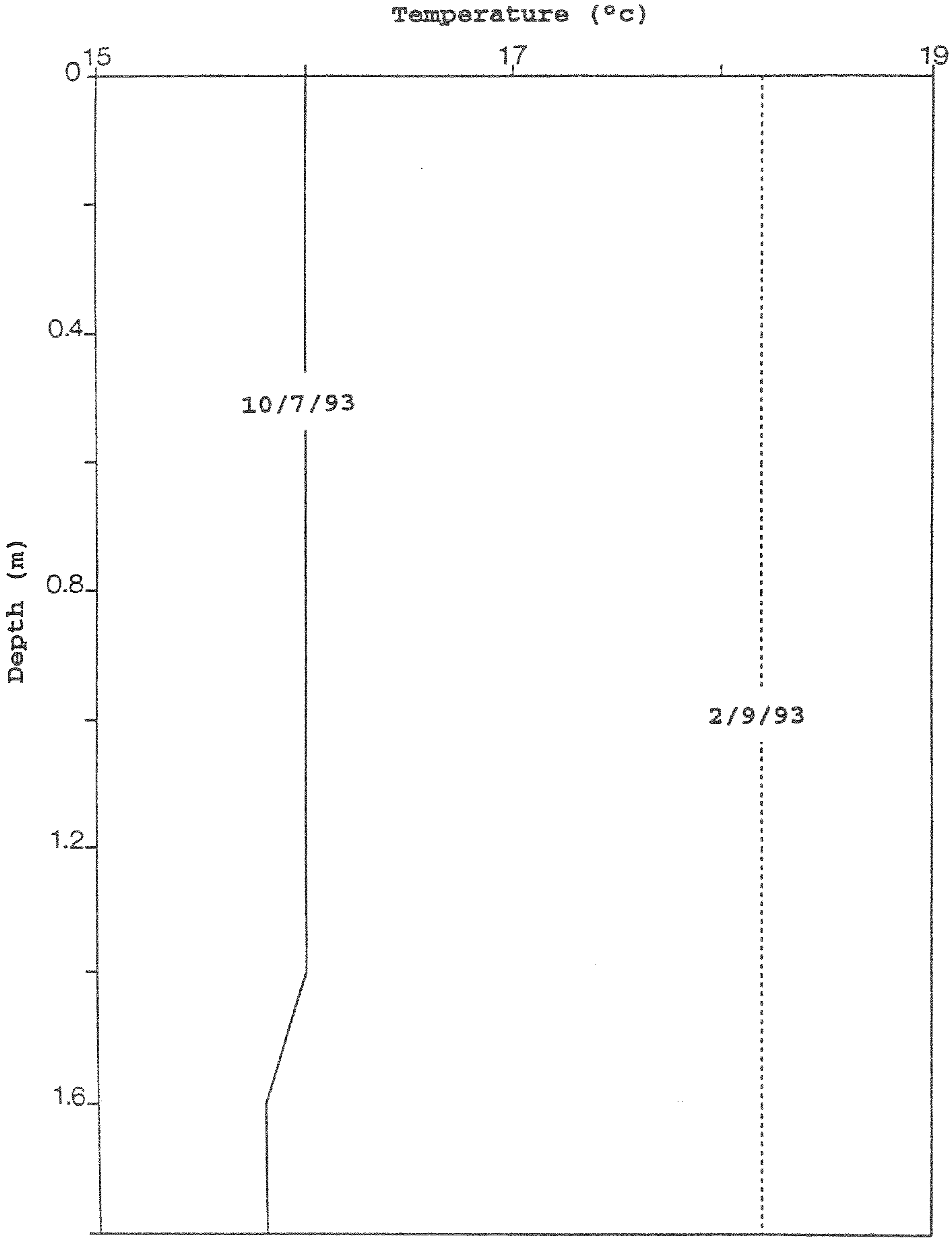
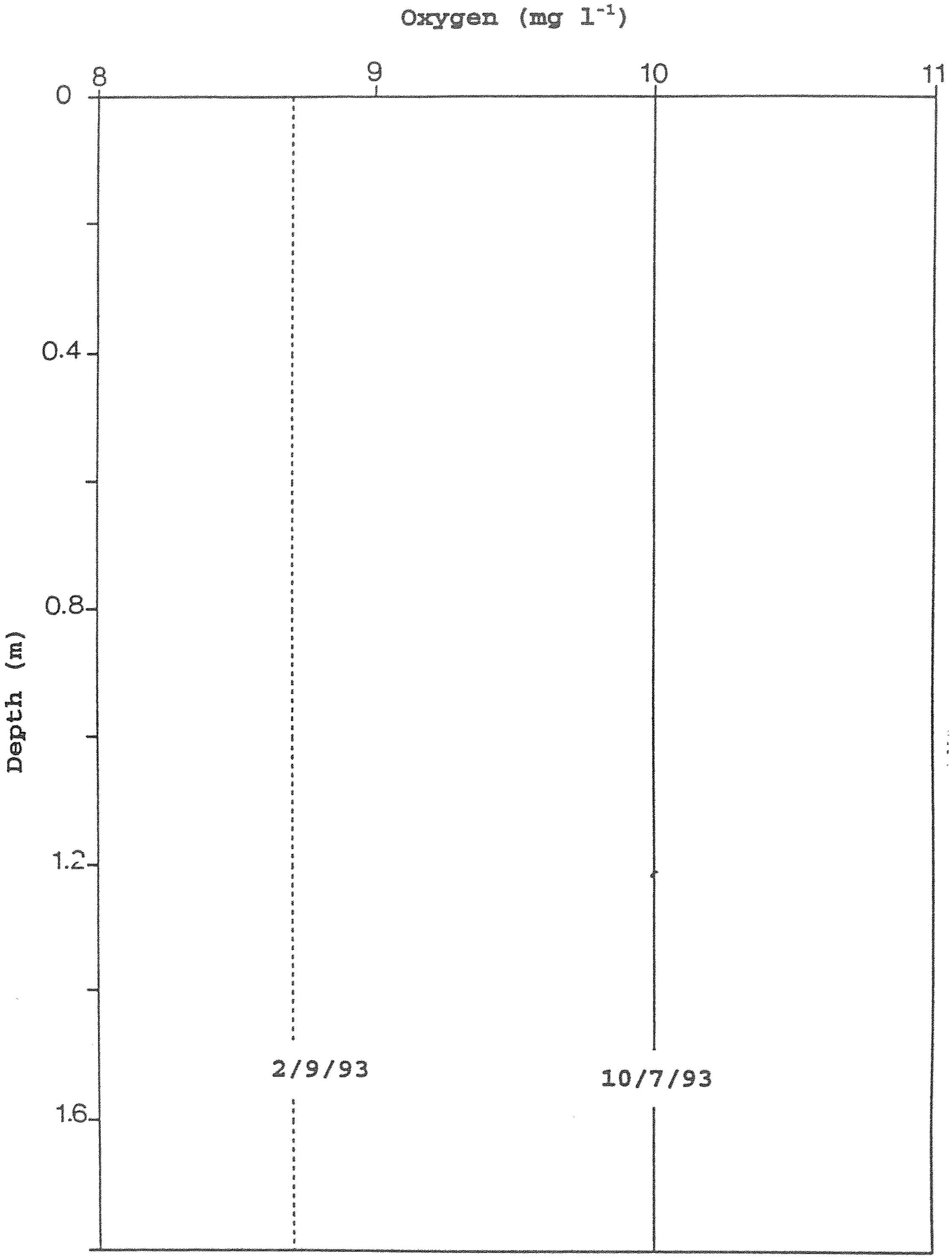


Figure D.4 Llyn Dinam: Oxygen profiles



Appendix E Data Tables and Figures: Llyn Penrhyn

Table E.1 Llyn Penrhyn water chemistry

Determinand		Sample date				
		10-7-93	3-9-93	6-12-93	29-3-94	mean
pH		8.04	7.88	7.66	8.69	8.07
field pH		8.22	7.85	7.98	8.56	8.15
Alkalinity 1	µeq l^{-1}	2180	2252	2187	1994	2153
Alkalinity 2	µeq l^{-1}	2197	2276	2219	2018	2178
Conductivity	µS cm^{-1}	446	455	453	414	442
field conductivity	µS cm^{-1}	485	520	550	405	490
Sodium	µeq l^{-1}	1869	1995	1750	1768	1846
Potassium	µeq l^{-1}	115	132	157	131	134
Magnesium	µeq l^{-1}	456	487	581	573	524
Calcium	µeq l^{-1}	2176	2283	2271	2077	2202
Chloride	µeq l^{-1}	1887	1973	1727	1707	1824
Aluminium $_{\text{total monomeric}}$	µg l^{-1}	3	0	2	0	1
Aluminium $_{\text{non-labile}}$	µg l^{-1}	3	0	1	0	1
Aluminium $_{\text{labile}}$	µg l^{-1}	0	0	1	0	0.3
Absorbtion	(250nm)	.247	.257	.256	.206	.242
Carbon $_{\text{total organic}}$	mg l^{-1}	9.6	10.4	8.8	6.5	8.8
Phosphorus $_{\text{total}}$	µgP l^{-1}	1064.5	1335.0	1247.5	693.5	1085
Phosphorus $_{\text{total soluble}}$	µgP l^{-1}	1048.5	1324.5	1200.5	578.2	1038
Phosphorus $_{\text{soluble reactive}}$	µgP l^{-1}	1037.0	1300.0	1181.0	546.3	1016
Nitrate	µgN l^{-1}	42	63	413	49	142
Silica $_{\text{total}}$	mg l^{-1}		1.17	4.57	4.44	3.39
Silica $_{\text{soluble reactive}}$	µg l^{-1}	2.22	1.14	4.50	1.00	2.22
Chlorophyll a	µg l^{-1}	3.9	5.1	3.9	-	4.3
Sulphate	µeq l^{-1}	487	421	432	457	449
Copper $_{\text{total soluble}}$	µg l^{-1}				<1	
Iron $_{\text{total soluble}}$	µg l^{-1}				151	
Lead $_{\text{total soluble}}$	µg l^{-1}				<1	
Manganese $_{\text{total soluble}}$	µg l^{-1}				174	
Zinc $_{\text{total soluble}}$	µg l^{-1}				<5	

Table E.2 Llyn Penrhyn epilithic diatom taxon list (including taxa >1.0%)

code	Taxon	Relative frequency (%)
RC001A	*Rhoicosphenia curvata*	15.9
NA003B	*Navicula radiosa* var. *tenella*	9.8
NI014A	*Nitzschia amphibia*	7.0
NA095A	*Navicula tripunctata*	6.2
NI009A	*Nitzschia palea*	5.2
AC013A	*Achnanthes minutissima*	4.9
AM012A	*Amphora pediculus*	4.9
NI002A	*Nitzschia fonticola*	3.6
CO001C	*Cocconeis placentula* var. *lineata*	3.6
NA168A	*Navicula vitabunda*	3.4
NI9999	*Nitzschia* sp.	3.1
CO001A	*Cocconeis placentula*	3.0
CO005A	*Cocconeis pediculus*	3.0
NI008A	*Nitzschia frustulum*	2.8
CO001B	*Cocconeis placentula* var. *euglypta*	2.6
NI033A	*Nitzschia paleacea*	2.1
ZZZ999	*Nitzschia silesiaca*	2.1
FR002C	*Fragilaria construens* var. *venter*	2.0
FR009A	*Fragilaria capucina* types (chains)	2.0
EI001A	*Ellerbeckia arenaria*	1.5
CM031A	*Cymbella minuta*	1.3

Total count = 610
Total number of taxa = 44

Table E.3 **Llyn Penrhyn surface sediment diatom taxon list (including taxa >1.0%)**

code	Taxon	Relative frequency (%)
ST010A	*Stephanodiscus parvus*	22.6
NA030A	*Navicula menisculus*	14.0
FR006A	*Fragilaria brevistriata*	11.6
FR002C	*Fragilaria construens* var. *venter*	6.6
FR009B	*Fragilaria capucina* var. *mesolepta*	3.6
RC001A	*Rhoicosphenia curvata*	3.3
CO001A	*Cocconeis placentula*	3.3
AM011A	*Amphora lybica*	3.1
NA063A	*Navicula trivialis*	2.8
NI014A	*Nitzschia amphibia*	2.6
CO001C	*Cocconeis placentula* var. *lineata*	2.6
AC006A	*Achnanthes clevei*	2.3
FR001A	*Fragilaria pinnata*	2.0
CO005A	*Cocconeis pediculus*	2.0
AM012A	*Amphora pediculus*	2.0
EI001A	*Ellerbeckii arenaria*	1.7
NA008A	*Navicula* [cf. *rhyncocephela*]	1.7
CO001B	*Cocconeis placentula* var. *euglypta*	1.5
NA023A	*Navicula gregaria*	1.3
FR007A	*Fragilaria vaucheriae* (fine)	1.2

Total count = 605
Total number of taxa = 48

Table E.4 Llyn Penrhyn aquatic macrophyte abundance summary: 3 September 1993

Taxon	code	Abun	comments
Emergent taxa			
Equisetum fluviatile	350202	R	in western bay
Menyanthes trifoliata	364701	R	in north-west bay
Rumex hydrolapathum	367303	R	
Veronica beccabunga	369802	R	
Alisma plantago aquatica	380303	O	
Eleocharis acicularis *	382001	R	
Iris pseudocorus	382901	O	in west
Phalaris arundinacea	383701	O	in north bay
Phragmites australis	383801	D	around most of the margin
Sparganium erectum	384603	O	
Scirpus lacustris ssp.*lacustris* *	384504	F	
Typha latifolia	384902	O	locally abundant on southern shore
Floating taxa			
Nuphar lutea	365501	O	often fringing stands of *Nymphaea*
Nymphaea alba	365601	F	locally abundant in western bays
Polygonum amphibium	366501	O	
Glyceria fluitans	382502	O	
Lemna minor	383302	R	in west
Lemna trisulca *	383304	O	in west
Submergent taxa			
Enteromorpha sp.	170000	F	
Callitriche hermaphroditica *	361104	A	widespread
Ceratophyllum demersum *	361401	F	locally dominant particularly in south
Elodea canadensis	382101	F	widespread
Potamogeton crispus *	384006	O	locally abundant in north bay
Potamogeton pectinatus	384015	O	in west
Potamogeton pusillus *	384019	R	in west
Zannichelia palustris *	385201	R	in north
other wetland taxa			
Berula erecta	360801	O	
Butomus umbellatus	380801	R	
Carex acutiformis	381102	O	
Carex paniculata	381124	R	
Epilobium hirsutum	362504	F	
Lysmachia vulgaris	364404	O	
Lythrum salicaria	364502	F	
Salix sp.	367500	R	
Senecio aquaticus	368101	O	
Solanum dulcamara	368301	F	
Stachys palustris	368501	O	

* = taxon regionally rare for NRA Welsh Region (after Palmer and Newbold, 1983)

Table E.5 Llyn Penrhyn littoral Cladocera taxon list

Sample date 3-9-93

Taxon	Sample number						
	1	2	3	4	5	6	7
	number of individuals						
Acroperus harpae	1						
Alona affinis			1	1			
Alona rustica		+					
Ceriodaphnia dubia				2		220	
Chydorus sphaericus	7	5	1			+	
Daphnia hyalina var. *galeata*	4					+	
Daphnia longispina			15	24	1		30
Daphnia obtusa							3
Daphnia pulex			1			5	
Eurycerus lamellatus	1	1	4	10	2	+	
Pleuroxus aduncus	110	134	30	40	11	9	4
Pseudochydorus globosus	+	1					
Simocephalus vetulus	+	1		1	3	2	
TOTAL COUNT	123	142	52	78	17	236	37

+ = Species present

Table E.6a Analysis of the cladoceran species composition in the samples from Llyn Penrhyn; S = sand-rock substrate; MV = mud-vegetation substrate.

Sample number	1	2	3	4	5	6	7
Substrate	MV	MV	MV	S	S	S	MV
No. Species	7	6	6	6	4	7	3
Cum. Species	7	8	11	12	12	12	13
Cum. % Species	54	>75					

Table E.6b Analysis of selected samples from the three different substrate types recorded in Llyn Penrhyn.

Selected samples	1	4
Substrate	MV	S
No. Species	7	6
Cum. Species	7	10
Cum. % Species	54	78

Table E.7 **Llyn Penrhyn open water zooplankton taxon list: 3rd September 1993**

Taxon	Abundance
Eudiaptomus gracilis	2
Cyclops strenuus	2
Eucyclops serrulatus	1
Daphnia galeata	2
Ceriodaphnia dubia	1
Eurycercus lamellatus	1
Macrocyclops albidus	1
Daphnia pulicaria	2
Asplanchna sp.	2
Daphnia magma/ephippium	+

2 = Species common (abundance >5%)
1 = Species rare (found in both samples analysed)
+ = Species rare (found in one of samples analysed)

Table E.8 **Llyn Penryn zooplankton characteristics: 3rd September 1993**

Station sampled: C

Depth of Station (m)	2.2
Total zooplankton biomass (gDM m^{-2})	0.72
Net algal biomass (gDM m^{-2})	0
% Cladoceran biomass in total zooplankton biomass	28
% large Cladocera (>710 μm) in total zooplankton biomass	6
% large Copepoda (>420 μm) in total zooplankton biomass	22

Table E.9 Llyn Penrhyn littoral invertebrate data

Macro-invertebrate species present and mean number per one minute kick/sweep sample in autumn (October 1993) and spring (April 1994).

code	Taxon	mean no.	
		autumn	spring
	TURBELLARIA		
03 12 00 00	Tricladida	86.7	28.0
	MOLLUSCA		
13 03 01 03	*Valvata piscinalis* (Müller)	16.7	
13 07 01 01	*Lymnaea truncatula* (Müller)	0.7	2.0
13 07 01 07	*Lymnaea peregra* (Müller)	1.3	0.8
13 08 02 01	*Physa fontinalis* (L.)	107.3	5.6
13 09 03 01	*Planorbis carinatus* (Müller)	13.3	
13 09 03 04	*Planorbis vortex* (L.)	58.7	3.2
13 09 03 07	*Planorbis albus* Müller	10.0	7.2
13 09 03 09	*Planorbis crista* (L.)	2.0	1.2
13 09 03 10	*Planorbis contortus* (L.)	25.3	1.6
13 09 04 01	*Segmentia complanata* (L.)	177.3	11.2
13 10 01 01	*Acroloxus lacustris* (L.)	28.7	31.6
	BIVALVIA		
14 03 02 00	*Pisidium* spp.	22.7	0.8
	HIRUDINIA		
17 02 01 01	*Theromyzon tessulatum* (Müller)	5.3	2.8
17 02 03 01	*Glossiphonia heteroclita* (L.)	56.0	0.4
17 02 03 02	*Glossiphonia complanata* (L.)	8.0	0.8
17 02 05 01	*Helobdella stagnalis* (L.)	10.7	0.4
17 04 01 02	*Erpobdella octoculata*	2.0	0.4
	MALACOSTRACA		
28 03 01 01	*Asellus aquaticus* (L.)	146.0	29.2
28 07 03 05	*Gammarus pulex* (L.)	130.7	272.8
30 08 02 04	*Caenis horaria* (L.)		0.8
30 08 02 06	*Caenis luctuosa* (Burmeister)		0.8
	ODONATA		
32 02 02 01	*Ischnura elegans* (Linden)	15.3	
32 02 03 01	*Enallagma cyathigerum* (Charpentier)		3.2
	HEMIPTERA		
33 11 00 00	Corixidae sp. - immatures	28.0	
33 11 03 01	*Glaenocorisa propinqua* (Fieber)	0.7	0.4
33 11 04 01	*Callicorixa praeusta* (Fieber)	96.0	9.2
33 11 05 02	*Corixa punctata* (Illinger)	9.3	
33 11 07 02	*Arctocorisa germari* (Fieber)	64.7	
33 11 08 01	*Sigara dorsalis* (Leach)	15.3	10.4

	contd.		
33 11 08 04	*Sigara falleni* (Fieber)	73.3	12.0
	COLEOPTERA		
35 01 00 00	Haliplidae sp. - larvae	14.0	2.0
35 01 03 04	*Haliplus ruficollis* group	13.3	13.6
35 03 00 00	Dytiscidae - larvae	0.7	
35 03 10 01	*Noterus clavicornis* (DeGeer)	0.7	0.8
	TRICHOPTERA		
38 06 01 01	*Agraylea multipunctata* Curtis	30.0	3.2
38 08 05 05	*Limnephilus marmoratus* Curtis		4.4
38 12 02 03	*Mystacides longicornis* (L.)		0.4
	DIPTERA		
40 01 00 00	Tipulidae		0.4
40 09 00 00	Chironomidae	120.0	932.0
	Total invertebrates	1390.7	1393.6
	Species richness (minimum)[1]	32	32
	Minimum richness (both seasons)	35	

Notes

1 to avoid duplication, this measure of species richness does not include unidentified immatures where more mature specimens in the same group were present

Figure E.1 Llyn Penrhyn: sample location & substrate map

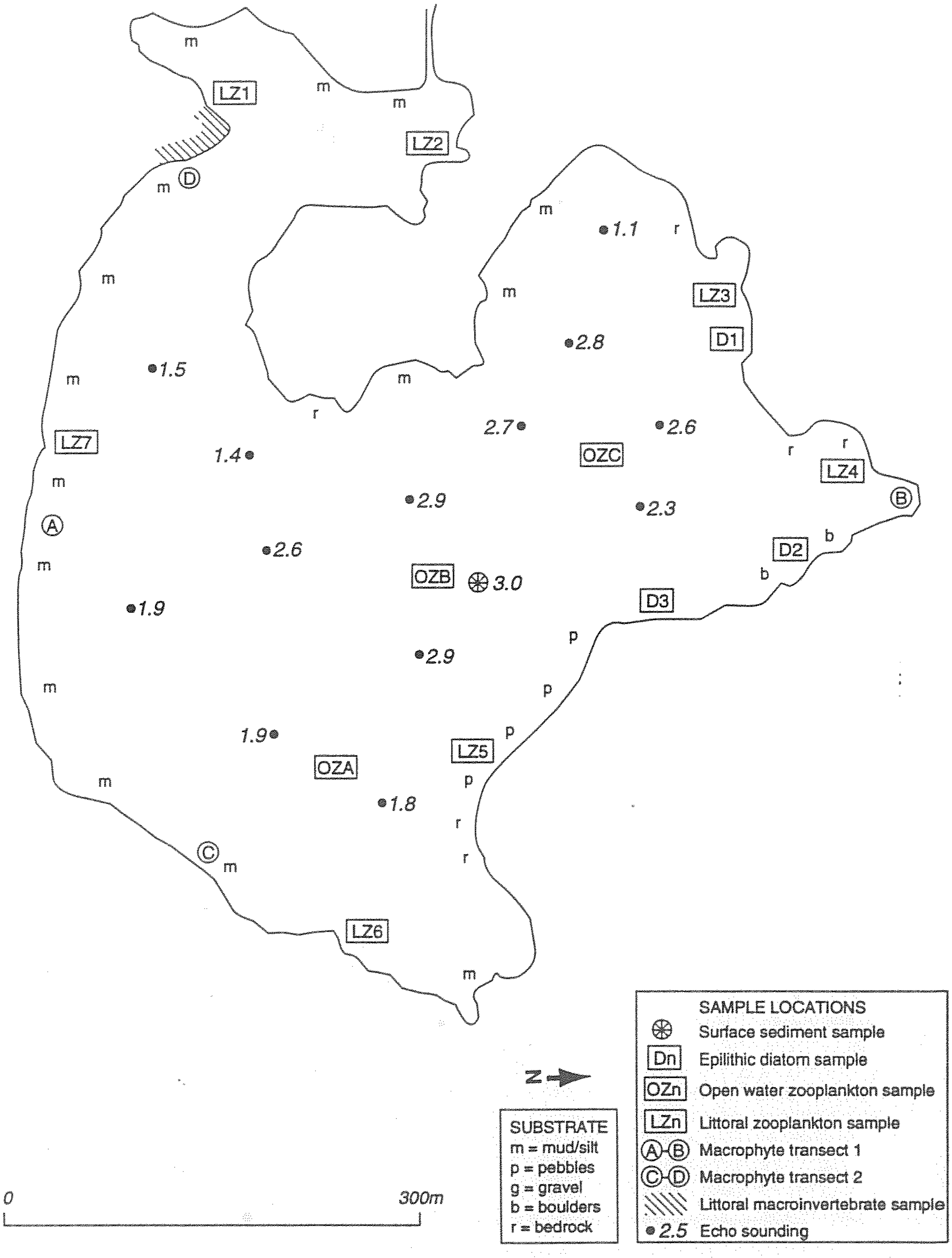


Figure E.2 Llyn Penrhyn: aquatic macrophyte distribution map

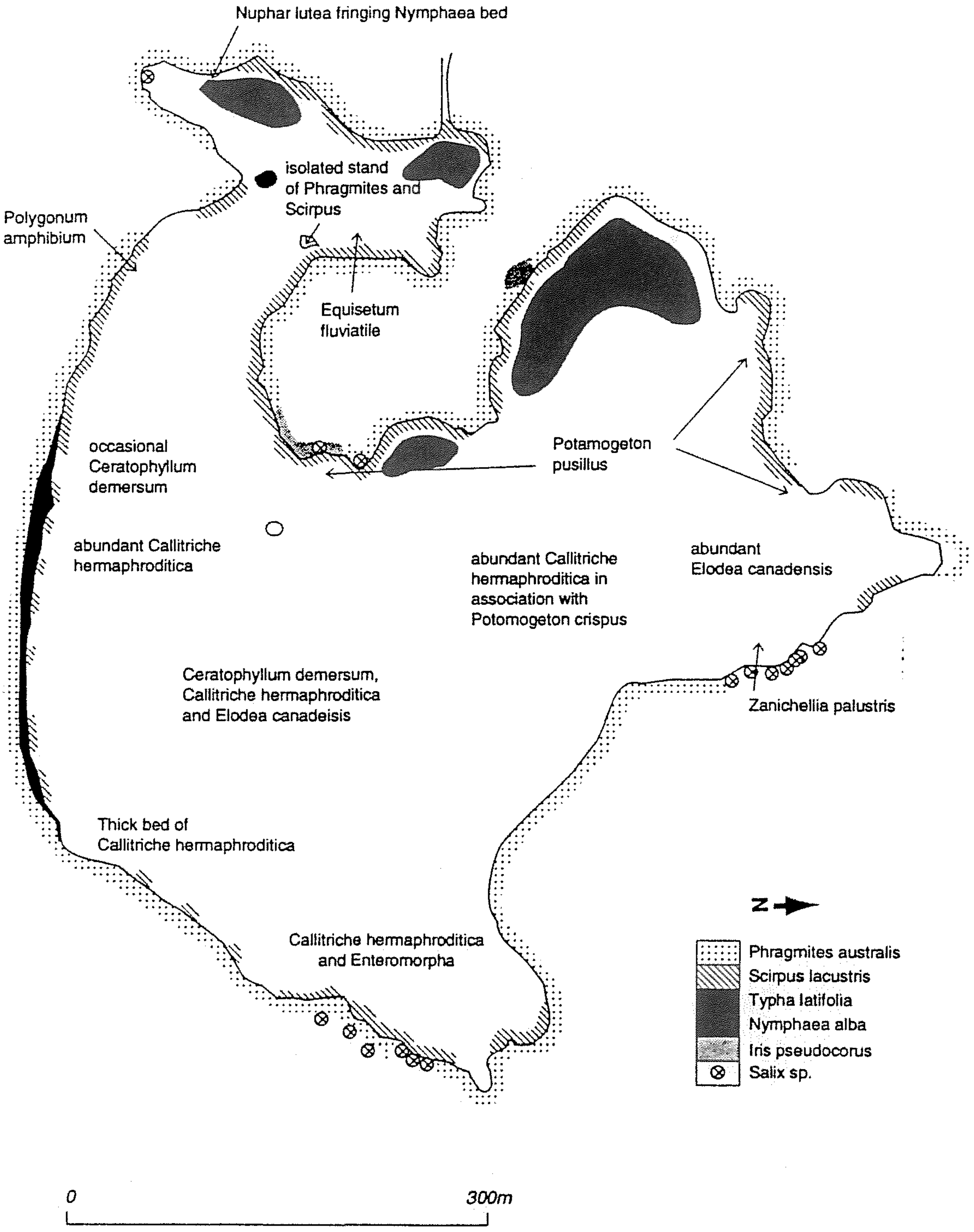


Figure E.3 Llyn Penrhyn: Temperature profiles

10 July 1993	**3 September 1993**
Air temperature = 13.0°c	Air temperature = 15.3°c
Secci disc transparency = 2.3 m	Secci disc transparency = 2.5 m

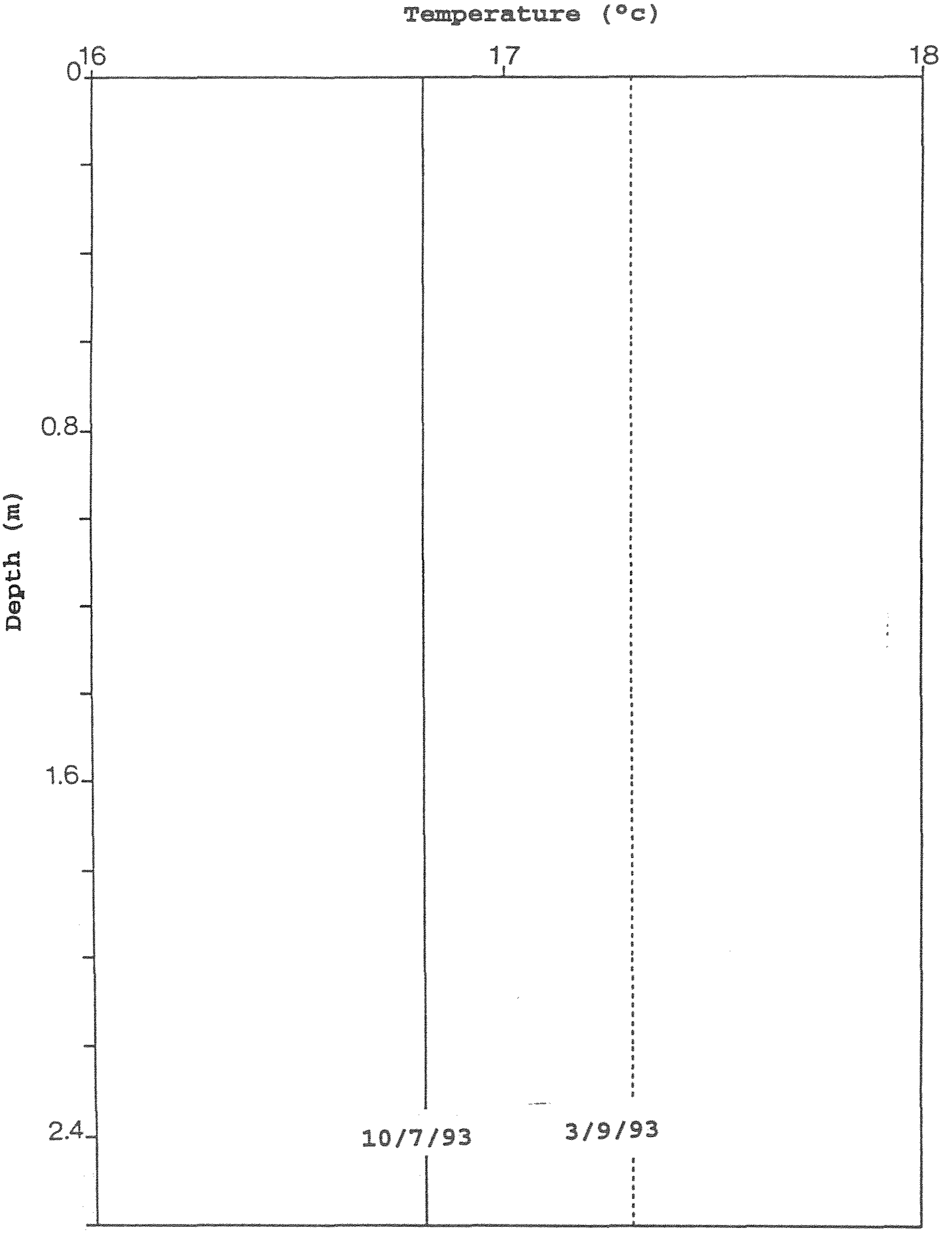
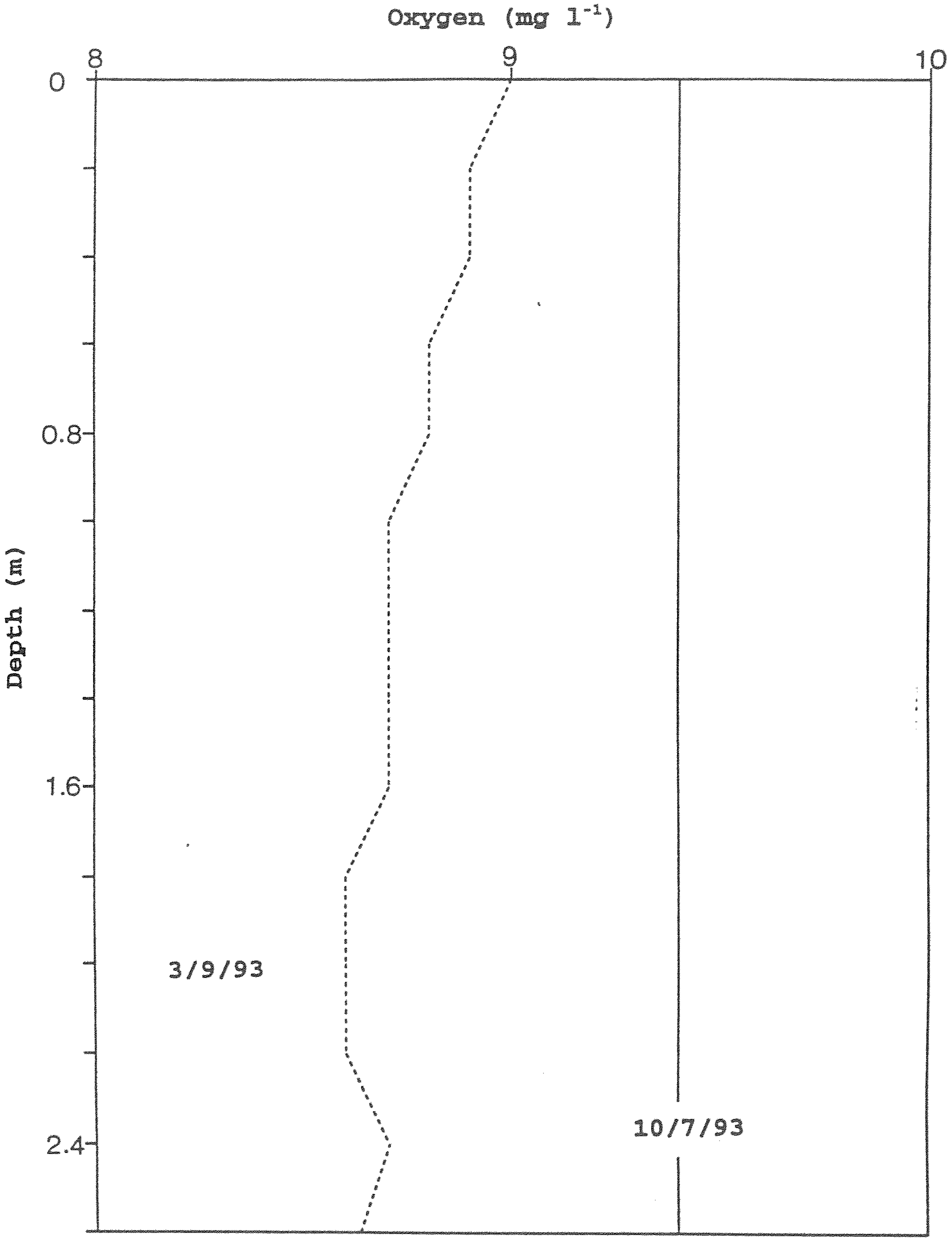


Figure E.4 Llyn Dinam: Oxygen profiles



Appendix F Notes on substrate of Cladocera sampling sites

F.1 Llyn Idwal, Snowdonia, 05-09-93.

Samples taken while wading along shoreline.

SITE 1: At outflow; sand-rock substrate; abundant filamentous algae, *Juncus* sp., *Littorella* and *Callitriche* sp.
SITE 2 (replicate samples A & B): Inflowing stream; *Lobelia*, *Littorella* and *Myriophyllum*.
SITE 3: Rock-stone-boulder substrate; *Lobelia*, *Sparganium* and *Juncus bulbosus*
SITE 4: Mud-vegetation substrate; *Equisetum* dominant; some *Littorella* and *Lobelia*.
SITE 5: Mud-vegetation substrate; peat seepage; *Phragmites* stand and *Juncus bulbosus*.
SITE 6: Rock-stone substrate; *Eriophorum angustifolium*, floating *Potamogeton* sp. *Lobelia* and *Littorella*.
SITE 7: Sand-stone substrate; *Callitriche* dominant; *Littorella*, *Equisetum*, *Lobelia* and *Juncus bulbosus*.

F.2 Llyn Cwellyn, Snowdonia, 04-09-93.

Samples taken while wading along shoreline.

SITE 1 (replicate samples A & B): Sand-rock substrate; *Juncus bulbosus*, *Littorella*, *Lobelia*, *Sparganium*.
SITE 2: Sandy beach, rocky offshore; Submerged grass, *Fontinalis*, *Juncus bulbosus*, *Lobelia* and *Isoetes*.
SITE 3: Sand-rock substrate, *Fontinalis*, *Lobelia*, *Juncus bulbosus*, emergent *Juncus*.
SITE 4: Stones and boulders; *Fontinalis*, *Juncus bulbosus* and much filamentous algae.
SITE 5: Sand-rock-boulders; *Juncus bulbosus*, *Fontinalis*, *Littorella* and much filamentous algae.
SITE 6: Bare rock/boulder substrate devoid of plant growth.

F.3 Llyn Coron, Anglesey, 01-09-93.

Samples taken while walking around the shore.

SITE 1: *Eleocharis*, *Nympheae*, *Polygonum amphibium* present.
SITE 2: Floating *Polygonum amphibium*, but mainly *Scirpus*.
SITE 3: Stony substrate devoid of plant growth.
SITE 4: Rocky substrate; sample taken through base of *Phragmites* stand.
SITE 5: Rocky substrate; *Scirpus* stand.
SITE 6: Rocky shore devoid of plant growth.
SITE 7: Rocky shore with little plant growth.

F.4 Llyn Dinam, Anglesey, 02-09-93.

All samples taken from boat.

SITE 1: Scirpus with floating mass of *Callitriche* sp.
SITE 2: *Nymphaea* stand.
SITE 3: *Phragmites* stand with *Mentha aquatica* and some *Nymphaea* and *Scirpus*.
SITE 4: *Solanum*, *Iris*, *Scirpus*, *Nymphaea* and *Callitriche* sp.
SITE 5: *Veronica beccabunga* and *Callitriche* at base of *Phragmites* stand.
SITE 6: *Menyanthes*, *Callitriche* and *Ceratophyllum*.

F.5 Llyn Penrhyn, Anglesey, 03-09-93.

All samples taken from boat.

SITE 1: *Iris*, *Ceratophyllum* and *Phragmites*.
SITE 2: *Nymphaea* and *Ceratophyllum* only.
SITE 3: *Scirpus*, *Phragmites*, *Callitriche* and *Ceratophyllum*.
SITE 4: Rocky substrate; *Phragmites*, *Ceratophyllum* and *Iris*.
SITE 5: Rocky substrate; *Phragmites* and *Ceratophyllum*.
SITE 6: Rocky substrate; *Scirpus* and *Ceratophyllum*.
SITE 7: *Scirpus* and *Ceratophyllum*.

Appendix G Notes on substrates of littoral macroinvertebrate sampling sites

G.1 Llyn Idwal, Snowdonia

- small bay, protected from wind
- sandy substrate, some cobbles, fine layer of silt
- sparse macrophytes: a few emergent, a few submerged
- no emergent macrophytes during spring sampling

G.2 Llyn Cwellyn, Snowdonia

- wave washed shore
- rocky substrate: mostly pebbles, some cobbles
- a few submerged macrophytes (both seasons)

G.3 Llyn Coron, Anglesey

- sand/gravel substrate, some boulders, overlain by a layer of organic material
- extensive stands of emergent macrophytes, some floating forms

G.4 Llyn Dinam, Anglesey

- sand/gravel substrate, overlain by a layer of organic material
- extensive stands of emergent macrophytes, some floating and submerged forms

G.5 Llyn Penrhyn, Anglesey

- sand/gravel substrate, overlain by a layer of organic material
- extensive stands of emergent macrophytes, some floating and submerged forms

Appendix H Macrophyte records for Llyn Idwal used by Garnett and Blackstock (1983) and stored in table form in the CCW North Wales Region office.

Table H.1

Callitriche brutia - Seddon (1972),Wade & Beresford (1976), Wade (1976)
Callitriche hamulata - Griffiths (1895)
Caltha palustris - Seddon (1972)
Carex rostrata - Seddon (1972), Wade & Beresford (1976), Wade (1976)
Elatine hexandra - Seddon (1972), Wade & Beresford (1976), Wade (1976)
Equisetum fluviatile - Wade & Beresford 1976), Wade (1976), Woodhead (1926), Seddon (1972)
Eriphorum angustifolium - Anon. (CCW files)
Hydrocotyle vulgaris - Seddon (1976)
Isoetes setacea - Seddon (1976)
Isoetes lacustris - Seddon (1972), Wade & Beresford (1976), Wade (1976)
Juncus bulbosus - Seddon (1972), Wade & Beresford (1976), Wade (1976)
Juncus effusus - Wade & Beresford (1976), Wade (1976)
Littorella uniflora - Griffiths (1895), Wade & Beresford (1976), Wade (1976), Seddon (1976)
Lobelia dortmanna - Griffiths (1895), Hyde & Wade (1957), Wade & Beresford (1976), Wade (1976), Seddon (1976)
Menyanthes trifoliata - Seddon (1972), Wade & Beresford (1976), Wade (1976)
Myosotis secunda - Seddon (1976)
Phragmites australis - Seddon (1972), Wade & Beresford (1976), Wade (1976)
Pilularia globulifera - Benoit, William & Parker (1979, CCW files)
Potamogeton berchtoldii - Wade & Beresford (1976), Wade (1976)
Potamogeton polygonifolius - Wade & Beresford (1976), Wade & Beresford (1976), Wade (1976), Seddon (1972)
Ranunculus flammula - Griffiths (1895), Seddon (1972), Wade & Beresford (1976), Wade (1976)
Scirpus lacustris - Wade & Beresford (1976), Wade (1976)
Sparganium angustifolium - Griffiths (1895), Hyde & Wade (1957), Wade & Beresford (1976), Wade (1976), Seddon (1972)
Sparganium erectum - Wade & Beresford (1976), Wade (1976)
Sparganium minimum - Newbold & Palmer (1980, CCW files)
Subularia aquatica - Seddon (1972), Wade & Beresford (1976), Wade (1976)

Table H.2

Juncus articulatus - Wade & Beresford (1976), Wade (1976)
Sphagnum auriculatum - Wade & Beresford (1976), Wade (1976)
Nitella fexilis/opaca - Wade & Beresford (1976), Wade (1976)

Appendix I Plant records for Llyn Cwellyn used by Garnett and Blackstock (1983) and stored in table form in the CCW North Wales Region office.

Table I.1

Callitriche brutia - Seddon (1972)
Callitriche hamulata - Loughborough University (1980)
Callitriche stagnalis - Loughborough University (1980)
Caltha palustris - Seddon (1972)
Elatine hexandra - Loughborough University (1980)
Equisetum fluviatile - Seddon (1972), Loughborough University (1980)
Isoetes setacea - Loughborough University (1980)
Isoetes lacustris - Seddon (1972)
Lobelia dortmanna - Seddon (1972)
Luronium natans - Griffiths (1895), Loughborough University (1980), Seddon (1972)
Phalaris arundinacea - Griffiths (1895), Seddon (1972)
Phragmites australis - Griffiths (1895), Seddon (1972)
Potamogeton polygonifolius - Griffiths (1895), Seddon (1972)
Potentilla palustris - Seddon (1972)
Ranunculus flammula - Seddon (1972)
Scirpus fluitans - NCR Site Description
Subularia aquatica - Loughborough University (1980), "SW" possible erroneous record

Table I.2

Achillea ptarmica - Loughborough University (1980)
Crepis paludosa - Griffiths (1895)
Deschampsia caespitosa - Griffiths (1895)
Fontinalis antipyretica - Loughborough University (1980)
Sphagnum subsecundum - Loughborough University (1980)

Appendix J Macrophyte records for Llyn Coron used by Garnett and Blackstock (1983) and stored in table form in the CCW North Wales Region office.

Table J.1

Agrostis stolonifera - Day (1983)
Alisma plantago aquatica - Day (1983)
Apium inundatum - Roberts (1982)
Apium nodiflorum - Day (1983)
Baldellia ranunculoides - Day (1983), Griffiths (1895), Hyde & Wade (1957)
Callitriche hermaphroditica - Day (1983), Roberts (1982)
Carex elata - "near Llyn Coron" Roberts (1982)
Carex rostrata - Day (1983)
Ceratophyllum demersum - Griffiths (1895), Roberts (1982)
Elatine hexandra - Roberts (1982)
Elatine hydropiper - Hyde & Wade (1957), Roberts (1982), Day (1983)
Eleocharis acicularis - Day (1983), Griffiths (1895), Hyde & Wade (1957), Roberts (1982)
Eleocharis palustris - NCR Site Description, Day (1983)
Elodea canadensis - "inflow" Day (1983)
Equisetum fluviatile - Day (1983)
Equisetum palustre - Griffiths (1895)
Hydrocotyle vulgaris - Day (1983)
Iris pseudacorus - Day (1983)
Juncus bulbosus - Day (1983)
Juncus effusus - Day (1983)
Lemna minor - Anon. (CCW files)
Lemna triscula - Roberts (1982) "Valley Lakes"
Littorella uniflora - Day (1983), Griffiths (1895), Roberts (1982)
Luronium natans - Griffiths (1895), Roberts (1982) "Now probably extinct", not recorded by Day (1983)
Mentha aquatica - Day (1983)
Myosotis laxa - Griffiths (1895), Roberts (1982), Day (1983)
Myriophyllum alterniflorum - Griffiths (1895), Hyde & Wade (1957), Anon. (CCW files)
Myriophyllum spicatum - Roberts (1982), Day (1983)
Nymphaea alba - Day (1983)
Oenanthe fistulosa - Griffiths (1895), Roberts (1982)
Phalaris arundinacea - Day (1983)
Phragmites australis - Day (1983)
Polygonum amphibium - Day (1983), NCR Site Description
Potamogeton crispus - Day (1983)
Potamogeton pectinatus - Griffiths (1895), Anon. (CCW files)
Potamogeton perfoliatus - Day (1983), Griffiths (1895), Hyde & Wade (1957), Roberts (1982)
Potamogeton pusillus - Griffiths (1895), Hyde & Wade (1957), Roberts (1982)
Potamogeton trichoides - NCR Site Description
Ranunculus circinatus - Day (1983), Griffiths (1895), Hyde & Wade (1957), Roberts (1982)
Ranunculus flammula - Griffiths (1895), Day (1983)
Ranunculus fluitans - "outlet" Hyde & Wade (1957)
Rumex hydrolapathum - Roberts (1982)
Scirpus lacustris - Griffiths (1895), Roberts (1982)
Scirpus tabernaemontani - Roberts (1982), Day (1983)
Sparganium minimum - "Not in fruit ?" Day (1983)
Veronica anagallis-aquatica - "near Llyn Coron" Roberts (1982)
Veronica catenata - Day (1983)
Veronica scutellata - Roberts (1982)
Zannichellia palustris - Roberts (1982), Day (1983)

Table J.2

Anagallis minima - Griffiths (1895)
Bidens tripartita - Roberts (1982)
Carex curta - Roberts (1982)
Carex disticha - "Border of Llyn Coron" Roberts (1982), "G+H" source unknown

Carex serotina - Griffiths (1895)
Deschampsia caespitosa - Day (1983)
Eleocharis uniglumis - Griffiths (1895)
Epilobium palustre - Griffiths (1895)
Eriophorum latifolium - Griffiths (1895)
Filipendula ulmaria - Day (1983)
Galium palustre - Day (1983)
Galium uliginosum - Roberts (1982)
Juncus articulatus - Day (1983)
Juncus conglomeratus - Day (1983)
Lotus uliginosus - Day (1983)
Lychnis flos-cuculi - Day (1983)
Lycopus europaeus - Roberts (1982)
Lysimachia vulgaris - Griffiths (1895), Roberts (1982)
Lythrum salicaria - Day (1983)
Myosotis laxa x scorpioides - Roberts (1982)
Oenanthe crocata - Day (1983)
Ruppia maritima - Roberts (1982)
Scutellaria galericulata - Roberts (1982)
Stellaria palustris - Day (1983), Roberts (1982)
Chara aspera - Griffiths (1895)
Chara fragilis - Griffiths (1895)
Chara contraria - Griffiths (1895)
Chara vulgaris - Griffiths (1895)
Tolypella glomerata - Griffiths (1895)

Appendix K Macrophyte records for Llyn Dinam used by Garnett and Blackstock (1983) and stored in table form in the CCW North Wales Region office.

Table K.1

Agrostis stolonifera - Day (1983), Blackstock (1982 CCW file)
Alisma plantago aquatica - Day (1983), Ward & Roberts (1977, CCW Files), Newbold & Ward (1978, CCW files)
Apium inundatum - Griffiths (1895), Hyde & Wade (1957), Seddon (1972), Roberts (1982)
Apium nodiflorum - Blackstock (1982 CCW files)
Baldellia ranunculoides - Day (1983), var. repens - Seddon (1972)
Callitriche hermaphroditica - Griffiths (1895), Seddon (1972)
Callitriche platycarpa - "Valley Lakes" Anon. (CCW files)
Caltha palustris - Ward & Roberts (1977, CCW Files)
Carex acutiformis - Day (1983), Griffiths (1895), Seddon (1972), Newbold & Ward (1978, CCW files)
Carex elata - Wade & Beresford (1976), Wade (1976), Seddon (1972), Ward & Roberts (1977, CCW Files), Blackstock (1982 CCW files)
Carex paniculata - SW, Seddon (1972), Blackstock (1982 CCW files)
Carex riparia - Blackstock (1982 CCW files), "Valley Lakes" Roberts (1982)
Carex rostrata - Ward & Roberts (1977, CCW Files), Day (1983)
Elatine hexandra - Day (1983)
Elatine hydropiper - Day (1983)
Eleocharis acicularis - Day (1983), Newbold & Ward (1978, CCW files), Ward & Roberts (1977, CCW Files), Roberts (1982)
Eleocharis palustris - Seddon (1972), Day (1983)
Elodea canadensis - Newbold & Ward (1978, CCW files), Day (1983)
Equisetum fluviatile - Day (1983)
Equisetum palustre - Griffiths (1895)
Eriophorum angustifolium - Ward & Roberts (1977, CCW Files)
Hydrocotyle vulgaris - Day (1983), Ward & Roberts (1977, CCW Files), Garnett (1982/83, CCW files)
Iris pseudacorus - Day (1983), Ward & Roberts (1977, CCW Files), Blackstock (1982 CCW files), Garnett (1982/83, CCW files)
Juncus effusus - Day (1983), "Valley Lakes" Ward & Roberts (1977, CCW Files)
Lemna minor - Day (1983)
Lemna triscula - Day (1983), "Valley Lakes" Roberts (1982)
Limosella aquatica - No record since 1910
Littorella uniflora - Day (1983)
Lobelia dortmanna - Davies (1813) but not recorded subsequently by Roberts
Luronium natans - Griffiths (1895), "Now probably extinct" Roberts (1982), Day (1983)
Lythrum portula - Roberts (1982), Ward & Roberts (1977, CCW Files), Day (1983)
Mentha aquatica - Day (1983), Ward & Roberts (1977, CCW Files)
Menyanthes trifoliata - Day (1983), Garnett (1982/83, CCW files), Blackstock (1982 CCW files), Newbold & Ward (1978, CCW files)
Myosotis laxa - Day (1983), Griffiths (1895), Seddon (1972)
Myosotis scorpioides - Day (1983)
Myriophyllum alterniflorum - Day (1983)
Nymphaea alba - Newbold & Ward (1978, CCW files), Garnett (1982/83, CCW files)
Phalaris arundinacea - Blackstock (1982 CCW files), Garnett (1982/83, CCW files), Day (1983)
Phragmites australis - Blackstock (1982 CCW files), Ward & Roberts (1977, CCW Files), Day (1983)
Polygonum amphibium - Day (1983)
Potamogeton berchtoldii - "Valley Lakes" Roberts (1982)
Potamogeton gramineus - Seddon (1972), Hyde & Wade (1957), Roberts (1982)
Potamogeton lucens - Griffiths (1895), Hyde & Wade (1957), Roberts (1982), Seddon (1972)
Potamogeton obtusifolius - "Valley Lakes" Roberts (1982), Griffiths (1895), Seddon (1972), Hyde & Wade (1957)
Potamogeton pectinatus - Day (1983), Newbold & Ward (1978, CCW files)
Potamogeton perfoliatus - "Valley Lakes" Roberts (1982)
Potentilla palustris - Day (1983)
Ranunculus aquatilis - Day (1983)
Ranunculus circinatus - Griffiths (1895), Seddon (1972)
Ranunculus flammula - Griffiths (1895), Ward & Roberts (1977, CCW Files), Seddon (1972)
Ranunculus trichophyllus - Ward & Roberts (1977, CCW Files)
Rumex hydrolapathum - Day (1983), Ward & Roberts (1977, CCW Files), Newbold & Ward (1978, CCW files), Garnett (1982/83, CCW files)

Scirpus fluitans - Seddon (1972)
Scirpus lacustris - Griffiths (1895), Seddon (1972), Newbold & Ward (1978, CCW files), Garnett (1982/83, CCW files)
Scirpus tabernaemontani - Day (1983)
Sparganium erectum - Day (1983)
Veronica scutellata - "Valley Lakes" Roberts (1982), Day (1983)
Zannichellia palustris - "Valley Lakes" Roberts (1982), Griffiths (1895)

Table K.2

Achillea ptarmica - Griffiths (1895)
Bidens cernua - Day (1983)
Bidens tripartita - Roberts (1982)
Deschampsia caespitosa - Griffiths (1895)
Eleocharis uniglumis - Roberts (1982)
Filipendula ulmaria - Day (1983)
Galium palustre - Day (1983)
Lycopus europaeus - Day (1983), Roberts (1982)
Lysimachia vulgaris 24- Day (1983), Griffiths (1895), Blackstock (1982, CCW files)
Lythrum salicaria - Day (1983)
Ranunculus lingua - Day (1983), Roberts (1982)
Rorippa islandica - Roberts (1982)
Scutellaria galericulata - Roberts (1982)
Thelypteris palustris - Day (1983)
Fontinalis antipyretica - Day (1983)
Chara aspera sp. - Roberts (1982) ?; erroneous record as Roberts did not report charophytes
Nitella opaca - Griffiths (1895)
Nitella translucens - Griffiths (1895)

Appendix L Macrophyte records for Llyn Penrhyn used by Garnett and Blackstock (1983) and stored in table form in the CCW North Wales Region office.

Table L.1

Agrostis stolonifera - Day (1983), Blackstock (1982 CCW files), Garnett (1982/83, CCW files)
Alisma plantago aquatica - Day (1983), Garnett (1982/83, CCW files)
Apium nodiflorum - Day (1983)
Berula erecta - Day (1983)
Butomus umbellatus - Day (1983), Newbold & Ward (1978, CCW files)
Callitriche brutia - Seddon (1972)
Callitriche hamulata - Griffiths (1895)
Callitriche hermaphroditica - Roberts (1982)
Callitriche platycarpa - "Valley Lakes" Anon. (CCW files)
Caltha palustris - Seddon (1972), Day (1983)
Carex acuta - Roberts (1982), Seddon (1972)
Carex elata - Day (1983), Griffiths (1895), Seddon (1972)
Carex nigra - Seddon (1972), Day (1983)
Carex paniculata - Day (1983)
Carex pseudocyperus - Hyde & Wade (1957), Day (1983)
Carex riparia - Seddon (1972), Day (1983)
Carex rostrata - Day (1983)
Ceratophyllum demersum - Newbold & Ward (1978, CCW files), Day (1983)
Eleocharis acicularis - Anon. (CCW files)
Eleocharis palustris - Day (1983)
Elodea canadensis - Day (1983)
Equisetum fluviatile - Blackstock (1982 CCW files), Seddon (1972), Day (1983)
Glyceria fluitans - Day (1983)
Hippuris vulgaris - Day (1983)
Hottonia palustris - Griffiths (1895)
Hydrocotyle vulgaris - Day (1983)
Iris pseudacorus - Day (1983), Seddon (1972), Newbold & Ward (1978, CCW files)
Juncus effusus - Garnett (1982/83, CCW files), Day (1983), "Valley Lakes" Ward & Roberts (1977, CCW files)
Lemna minor - Day (1983)
Lemna triscula - Day (1983), "Valley Lakes" Roberts (1982)
Lobelia dortmanna - Griffiths (1895)
Mentha aquatica - Newbold & Ward (1978, CCW files), Day (1983)
Menyanthes trifoliata - Seddon (1972), Day (1983)
Myosotis scorpioides - Roberts (1982), Day (1983)
Myriophyllum spicatum - Newbold & Ward (1978, CCW files), Roberts (1982), Seddon (1972)
Myriophyllum verticillatum - Griffiths (1895), "No recent records" Roberts (1982)
Nuphar lutea - Day (1983)
Nymphaea alba - Garnett (1982/83, CCW files), Day (1983)
Oenanthe fistulosa - "nearby" Griffiths (1895), Day (1983)
Phalaris arundinacea - Seddon (1972), Day (1983)
Phragmites australis - Day (1983), Newbold & Ward (1978, CCW files), Seddon (1972), Garnett (1982/83, CCW files)
Polygonum amphibium - Seddon (1972), Day (1983)
Potamogeton berchtoldii - Day (1983), "Valley Lakes" Roberts (1982)
Potamogeton crispus - Newbold & Ward (1978, CCW files), Day (1983)
Potamogeton lucens - Griffiths (1895), Seddon (1972)
Potamogeton obtusifolius - "Valley Lakes" Roberts (1982), Griffiths (1895), Day (1983)
Potamogeton pectinatus - Seddon (1972), Roberts (1982)
Potamogeton perfoliatus - "Valley Lakes" Roberts (1982), Griffiths (1895)
Potentilla palustris - Blackstock (1982 CCW files), Day (1983)
Ranunculus circinatus - Griffiths (1895), Hyde & Wade (1957), Seddon (1972)
Ranunculus flammula - Day (1983)
Rumex hydrolapathum - Day (1983)
Sagittaria sagittifolia - "Nr Llyn Penrhyn" Roberts (1982)
Scirpus lacustris - Seddon (1972), Newbold & Ward (1978, CCW files), Garnett (1982/83, CCW files)
Scirpus tabernaemontani - Day (1983)
Sparganium emersum - Seddon (1972)
Sparganium erectum - Seddon (1972), Day (1983)

Typha angustifolia - Garnett (1982/83, CCW files)
Typha latifolia - Newbold & Ward (1978, CCW files), Day (1983)
Utricularia australis - Griffiths (1895), Roberts (1982)
Veronica catenata - Day (1983)
Veronica scutellata - "Valley Lakes" Roberts (1982), Day (1983)
Zannichellia palustris - "Valley Lakes" Roberts (1982)

Table L.2

Bidens cernua - Griffiths (1895), Day (1983), Roberts (1982)
Bidens tripartita - Roberts (1982)
Carex disticha - Day (1983)
Epilobium hirsutum - Day (1983)
Epilobium palustre - Day (1983), Anon. (CCW files)
Equisetum telmateia - Roberts (1982)
Filipendula ulmaria - Day (1983)
Galium palustre - Day (1983)
Hypericum tetrapterum - Day (1983)
Juncus articulatus - Day (1983)
Lotus uliginosus - Day (1983)
Lycopus europaeus - Day (1983), Roberts (1982)
Lysimachia nummularia - Day (1983), Griffiths (1895), Blackstock (1982 CCW files)
Lythrum salicaria - Anon. (CCW files), Day (1983)
Ranunculus lingua - Day (1983), Anon. (CCW files)
Scutellaria galericulata - Day (1983)
Stachys palustris - Day (1983)
Triglochin palustris - Day (1983)
Thelypteris palustris - Roberts (1982)

Appendix M A biography for the study lakes

A biography for the Anglesey lakes

Papers known to refer to sites being invesitgated as part of the CCW research programme are indicated; C = Coron; D = Dinam; P = Penrhyn.

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