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# *The Anglesey lakes, Wales, UK—A conservation resource*

C. A. DUIGAN[a], T. E. H. ALLOTT[b], H. BENNION[b], J. LANCASTER[c], D. T. MONTEITH[b], S. T. PATRICK[b], J. RATCLIFFE[a] and J. M. SEDA[d]

[a]*Cyngor Cefn Gwlad Cymru/Countryside Council for Wales, Plas Penrhos, Ffordd Penrhos, Bangor, Gwynedd LL57 2LQ, UK*

[b]*Environmental Change Research Centre, Department of Geography, University College London, 26 Bedford Way, London WC1H 0AP, UK*

[c]*Institute of Ecology and Resource Management, The University of Edinburgh, Darwin Building, Mayfield Road, Edinburgh EH9 3JU, UK*

[d]*Royal Holloway Institute for Environmental Research, University of London, Huntersdale, Callow Hill, Virginia Water, Surrey GU25 4LN, UK*

ABSTRACT

1. The environment of the island of Anglesey, North Wales, UK, is described and related to the ecology of the lake systems present.

2. Estimates are given of the number and types of lakes present on the island. Sixteen biological Sites of Special Scientific Interest (SSSIs) have standing water as a recognized habitat feature and their reasons for receiving a conservation designation are discussed.

3. Brief reviews are given of the lacustrine flora, invertebrates, fish and aquatic bird populations of Anglesey and their importance in assessing the conservation value of a site.

4. These reviews are followed by detailed accounts of the current ecology of three of the island's lake systems—Llyn Coron, Llyn Dinam and Llyn Penrhyn—which occur within biological Sites of Special Scientific Interest. Original data are presented on their physical and chemical characteristics, diatom assemblages, macrophyte communities, littoral and open water zooplankton communities and macroinvertebrate assemblages.

5. Artificial enrichment, the introduction of alien species, the legacy of metal mining operations and recreational pressures are identified as the main threats to lake conservation on Anglesey.

6. The Anglesey Wetland Strategy, an informal operational level liaison procedure, is described. Using this mechanism, broad targets and indicative strategies are highlighted by the partner organizations active in wetland conservation on the island, and opportunities for collaboration are developed.

## INTRODUCTION

The distinct nature of the lakes on the island of Anglesey, North Wales, has been alluded to by a large number of naturalists and scientific researchers. In many studies the flora and fauna of the lowland Anglesey lakes are contrasted with those found in upland lakes in nearby Snowdonia (e.g. Griffiths, 1926; Brown, 1948; Reynoldson, 1956a, 1958; Priddle and Happey-Wood, 1983). This has led to the development of references to the 'Anglesey Meres' or 'Welsh Meres'. However, no comprehensive attempt has been made to characterize the ecology of the island's standing waters.

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The objectives of this paper are (i) to provide a general description of the Anglesey lake systems and their ecology, (ii) to provide an overview of current knowledge of the island's lacustrine flora and fauna, (iii) to describe the conservation resources within the island's lake systems, (iv) to give up-to-date descriptions of three Anglesey standing waters located within biological Sites of Special Scientific Interest (SSSIs) and thereby provide descriptions against which any future environmental changes can be assessed, (v) to provide an environmental setting for two related palaeolimnological studies of these three sites (Haworth *et al.*, 1994; Haworth *et al.*, in preparation; Bennion, 1995; Bennion *et al.*, in preparation), (vi) to analyze the potential threats to the freshwater systems on the island and (vii) to describe a local conservation strategy.

## Anglesey — the island environment

The island of Anglesey is a productive agricultural region on the western margins of Britain (Figure 1A). It has an area of 720 km$^2$, which is virtually all lowland (i.e. < 100 m altitude). Three major rock series provide a foundation for the island — Pre-Cambrian, Ordovician and Carboniferous (Jago, 1990). The undulating surface of the island is created by shallow northeast–southwest trending valleys, reflecting an underlying series of Caledonian fault lines. Pleistocene ice sheets, moving largely in a southwesterly direction, accentuated this topography but also left a veneer of boulder clay and other glacial relics (Jago, 1990), including extensive drumlin fields in the north of the island. The gentle gradients and frequently dammed valleys produced numerous shallow lakes and marshes. A number of studies have been carried out to describe the Quaternary history of the Anglesey lake basins (Seddon, 1958; Botterill, 1988; Watkins, 1991; Watkins and Scourse, 1995).

Anglesey's climate is determined by three major factors (Buchan, 1990). As no part of the island is more than 12 km from the sea, there are cool summers and mild winters, with few extreme temperatures. Its

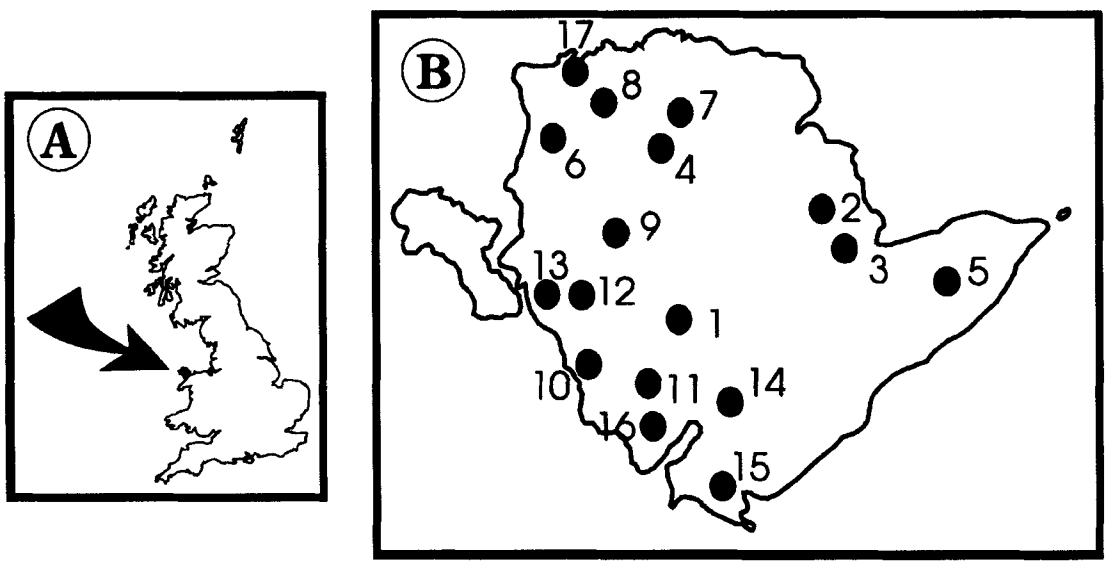


Figure 1. The Anglesey lakes (A) Map showing location of Anglesey on the western margins of Britain; (B) Location of biological Sites of Special Scientific Interest with standing water on Anglesey; 1. Cors Bodwrog (Llyn Hendref); 2. Cors Erddreiniog (Llyn Yr Wyth Eidion); 3. Cors Goch (Llyn Cadarn); 4. Llyn Alaw; 5. Llyn Bodgylched; 6. Llyn Garreg-Lwyd; 7. Llyn Hafadol & Cors Clegyrog; 8. Llyn Llygeirian; 9. Llyn Llywenan; 10. Llyn Maelog; 11. Llyn Padrig; 12. Llyn Traffwll; 13. Llynnau Y Fali (Llyn Dinam, Llyn Penrhyn and other smaller waterbodies); 14. Malltraeth Marsh (Llynnau Gwaith-glo; Cefni relict meanders; Cob Pools); 15. Newborough Warren–Ynys Llanddwyn (Llyn Rhos-Ddu); 16. Tywyn Aberffraw (Llyn Coron); 17. Cemlyn Bay.

low relief allows moisture-laden air from the west to pass over the island subsequently producing rain in Snowdonia. The mountains of Snowdonia shelter the island from southern winds, contribute a mountain-induced component to the rainfall and influence the sunshine. Rainfall averages between 900 and 1025 mm per annum.

Land use of the island is predominantly agricultural, reflecting its low topography, equable climate and fertile soils. Of Anglesey's 72 000 ha, only 14% can be classed as natural or semi-natural wildlife habitat (Williams *et al.*, 1993), and much of this is under some degree of agricultural management. Some 52 000 ha (72%) of the island is classed as arable or managed grassland though the proportion has been higher in the past reaching 61 000 ha (83%) at the turn of the century. In former times, the proportion of arable was high enough to earn Anglesey the epithet 'Mon mam Cymru', the breadbasket of Wales, but in recent years there has been a steep decline in cereal production to less than 3000 ha (2316 ha in 1993), mostly as a break crop before reseeding pasture (P. Olsen, Welsh Office, Statistical Directorate, personal communication, 1995).

Today, Anglesey is almost exclusively a stock rearing area, with around 400 000 sheep (augmented with substantial numbers of mountain sheep in winter), 65 000 cattle and normally up to 1.9 million chickens, the latter mostly in intensive rearing. There are more than 80 major dairy units on the island, often with intensive feed requirements and consequential nutrient outputs. Widespread use of silage and big bale feeding has enabled higher stocking rates to be held through the winter (e.g. a 470% increase in indigenous sheep numbers since the war). Pig production has diminished in recent years but still presents localized effluent problems and approximately 5200 pigs are believed to occur on the island. All the livestock figures are based on 1993 estimates provided by the Welsh Office (P. Olsen, personal communication, 1995).

## The lakes — a resource

The island's geology, relief and climatic regime influences the character of the lakes found on the island. Rain is fed over relatively short distances into lake basins by low gradient streams and small rivers running along shallow valleys trending north-east to south-west. In general, the lakes are less than 10 m deep. Unlike the lakes in Snowdonia, there is little significant ice cover during the winter. Lakes in exposed coastal locations along the south-western margin are subjected to onshore winds which influence their hydro- and thermal dynamics. Some tentative generalization can be made from the restricted pH and conductivity data set available for the Anglesey lakes. They are alkaline, generally occurring within the pH range of 7–8.5. Conductivity values are usually in the 200–450 $\mu S\,cm^{-1}$ range. These chemical characteristics are largely a product of the presence of extensive tracts of base-rich rocks and Carboniferous Limestone.

It is estimated that there are 110 standing waters marked on 1 : 50 000 Ordnance Survey (OS) maps for Anglesey, with the vast majority of them being less than 10 ha in surface area. Water supplies for the island have always been an area for concern (Richards, 1972). Therefore, it is not surprising that the largest lakes on Anglesey are reservoirs — Llyn Alaw (SH 390 865), Llyn Cefni (SH 445 775). In 1905, Llyn Traffwll (SH 325 770), the largest natural lake on Anglesey, was acquired as a reservoir by the Holyhead Water Company (Richards, 1972).

Eight distinct types of standing waters can be recognized on Anglesey based on their structural origins — natural lakes, reservoirs, quarry/mine pools, relict river channels, subsidence lakes, intermittent/seasonal pools, a coastal lagoon and artificial fish ponds. The natural lakes can be further subdivided into rock basins, moraine dammed, sand dune dammed and limestone solution hollows. In Greenly's (1919) seminal study of the geology of Anglesey, he estimated that 25 of the island's lakes were of glacial origin. Lakes such as Llyn Cadarn (SH 492 812), Llyn Llwydiarth (SH 548 787) and the small tarns on Mynydd Bodafon (SH 467 851) have formed in rock basins. Llyn Llygeirian (SH 347 898) and Llyn Hafadol (SH 395 890) are retained by deposits of boulder clay, although both lakes are now controlled by sluices. Llyn Maelog (SH 325 730), Llyn Rhos Ddu (SH 425 648) and Llyn Coron (SH 378 380) are retained by an extensive sand

dune system which has developed along the south-western shores of Anglesey (Robinson, 1980). The small lake at Parciau (SH 496 843) is believed to be a limestone solution lake.

The Parys Mountain Mine in the north eastern corner of Anglesey was once the world's largest producer of copper and a legacy of mine workings and mineral tips remain (Pearce, 1993). These include a series of settling ponds and ochre precipitation ponds. The former course of the Afon Cefni is indicated by a series of relict standing waters within Malltraeth Marsh. These small lakes are the subject of active conservation management by the Countryside Council for Wales and the National Rivers Authority. Also within Malltraeth Marsh, Llynnau Gwaith-glo (SH 450 715) were formed by subsidence following coal mining operations in the mid 1800s. Cemlyn Bay (SH 330 933) is the only coastal lagoon on the island although the Cob Pools (SH 409 684) behind the flood embankment at Malltraeth have a significant tidal influence. Pools of standing water form in the sand dune systems at Newborough Warren and Aberffraw on an intermittent basis. This phenomenon last occurred in the springs of 1994 and 1995 and it has previously been recorded in 1987.

The Nature Conservancy Council (and subsequently the Countryside Council for Wales (CCW)) recognized the conservation importance of the Anglesey lakes. This led to the designation of 17 sites, with standing water as a recognized habitat feature, as biological SSSIs (Figure 1B; Table 1). An SSSI is the term used to denote an area of land or water notified under the Wildlife and Countryside Act 1981 (as amended) as being, in the opinion of the CCW, of nature conservation importance. The special conservation interest of each site is described on a site 'citation'. Most of the Anglesey sites qualified with reference to the *Guidelines for Selection of Biological SSSIs* (Nature Conservancy Council, 1989) on the basis of important aquatic macrophyte communities and bird populations (Table 1). A number were also chosen as particular habitat examples for the area. For example, Llyn Llygeirian was selected as an example of a moderate base-rich lake in the West Gwynedd site selection area. Components of the freshwater flora and fauna of Anglesey are listed under three major pieces of conservation legislation — the Wildlife and Countryside Act, the EC Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora, and the Convention on the Conservation of European Wildlife and Natural Habitats (known as the 'Bern Convention') (Table 2).

Table 1. Analysis of Anglesey biological Sites of Special Scientific Interest citations for features associated with standing waters.

| | Habitat | Aquatic Macrophytes | Birds | Invertebrates |
|---|---|---|---|---|
| Cors Bodwrog | | • | • | • |
| Cors Erddreiniog | | • | | • |
| Cors Goch | | • | | • |
| Llyn Alaw | | • | • | |
| Llyn Bodgylched | | • | • | |
| Llyn Garreg-lwyd | | • | • | |
| Llyn Hafadol | | • | | |
| Llyn Llygeirian | • | • | • | |
| Llyn Llywenan | • | • | • | |
| Llyn Maelog | • | • | • | • |
| Llyn Padrig | | • | | |
| Llyn Traffwll | • | • | • | |
| Llynnau y Fali | | • | • | |
| Malltraeth Marsh | | • | • | • |
| Newborough Warren | | No aquatic feature cited | | |
| Tywyn Aberffraw | | • | | • |
| Cemlyn Bay | | • | • | |

Table 2. Freshwater biota recorded on Anglesey and listed under conservation legislation: WCA, Wildlife and Countryside Act; EC, EC Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora; Bern, Convention on the Conservation of European Wildlife and Natural Habitats.

| Common name | Scientific name | WCA | EC | Bern |
|---|---|---|---|---|
| Southern damselfly | *Coenagrion mercuriale* | | + | |
| Medicinal leech | *Hirudo medicinalis* | + | + | + |
| Common frog | *Rana temporaria* | + | + | + |
| Common toad | *Bufo bufo* | + | | + |
| Natterjack toad[a] | *Bufo calamita* | + | + | + |
| Great crested newt | *Triturus cristatus* | + | + | + |
| Palmate newt | *Triturus helveticus* | + | | + |
| Smooth newt[b] | *Triturus vulgaris* | + | | + |
| River lamprey | *Lampetra fluviatilis* | | + | + |
| Brook lamprey | *Lampetra planeri* | | + | + |
| Sea lamprey | *Petromyzon marinus* | | + | + |
| Atlantic salmon | *Salmo salar* | | + | + |
| Otter[c] | *Lutra lutra* | + | + | + |
| Bog moss | *Sphagnum* | | + | |
| Water plantain[d] | *Luronium natans* | + | + | + |

[a]A doubtful 1960s record for the natterjack toad exists for the north-west coast of Anglesey (Howe, 1990); [b]There is a single record for the smooth newt from an unspecified location in south-east Anglesey (Howe, 1990); [c]There are no confirmed records of otter on Anglesey for the last 20 years; [d]Roberts (1982) remarked that the water plantain is now probably extinct on the island.

**Lacustrine flora**

There is a long history of the occurrence of algal blooms on the Anglesey lakes and a realization of their potential impact on water quality. West (1890) reviewed all the previous collections of freshwater algae in North Wales. The samples from Llyn Coron were considered 'richest in diatoms'. Griffiths (1926) characterized four Anglesey lakes as 'far from being "desmid" in type in that they show an alga-flora in which Myxophyceae, the diatom *Asterionella*, and the Peridinian *Ceratium hirundinella*, are dominant to a degree sufficient to cause conspicuous water-blooms'. He related differences in the algal flora of the Anglesey lakes and Llyn Ogwen (an oligotrophic lake in Snowdonia) to basin contour and topography of the catchments. Woodhead (1937) described how *Botryococcus braunii* formed a yellow water-bloom in Llyn Maelog which lasted several weeks and imparted an oiliness to the water in late summer 1934. Several species of *Microcystis* were also recorded from Maelog and they were reported as occurring in other Anglesey lakes. The presence of the Myxophyceae species (*Microcystis* sp., *Aphanocapsa* sp.) was causing problems in relation to the use of the water from Llyn Maelog to supply the neighbouring village of Rhosneigr (Woodhead, 1938). Preparatory algal surveys of the island's lakes were also undertaken prior to the construction of Llyn Cefni reservoir (Woodhead, 1968) and the results contributed to the monograph on the algal flora of Anglesey and Caernarvonshire (Woodhead and Tweed, 1954–1955). Woodhead (1968) described the seasonal succession of algae in a typical Anglesey lake (Llyn Traffwll) throughout a year and reported that *Chara* was widespread in the shallows of many of the island's lakes.

More recently Happey-Wood (1995) described the phytoplankton of the Anglesey lakes as typical of eutrophic waters: diatoms in spring, followed by green algae and blue-green algae often forming visible blooms in summer, with diatom populations appearing again in autumn. Relationships between species' composition and the relatively high algal standing crops have been correlated with nutrient and silica concentrations (Priddle and Happey-Wood, 1983; Happey-Wood and Priddle, 1984). The diverse flagellate-dominated algal population of Llyn Rhos Ddu has been described and accounted for by the species' contrasting diurnal patterns of movement on to the surface of the sediment (Happey-Wood, 1988).

The Nature Conservancy Council and its successor organizations (The Countryside Council for Wales, English Nature and Scottish Natural Heritage) have a long history of higher plant survey work in Britain. This extensive data base is used to assess the botanical resource of standing waters in Britain and to identify areas worthy of protection as SSSIs. An analysis of this data set led to the development of a lake classification scheme representing a transition from oligotrophic to eutrophic sites (Palmer *et al.*, 1992). The Anglesey lakes classified using this scheme are confined mainly to types 8, 9, 10A or 10B and therefore considered eutrophic or base-rich. Type 8 sites are rich in emergent species and are characterized by the occurrence of *Lemna minor*, *Callitriche stagnalis* and *Polygonum amphibium*. Type 9 sites have well developed stands of *Nuphar lutea* and *Nymphaea alba*. *Myriophyllum spicatum* and *Potamogeton pectinatus* occur at type 10 sites. The sub-types are delineated by a dominance of *Elodea canadensis* and *Lemna minor* at type 10A sites and *Chara* at type 10B sites.

Assessments of the nature conservation interest of the standing waters of Anglesey have also taken into account the presence of rare plant species. The Red Data Book plant species *Elatine hydropiper* has been reported from a number of sites on Anglesey (Preston *et al.*, 1991). Plant species or hybrids recorded as native in 16–100 10 km squares are considered nationally scarce and those recorded on Anglesey include *Luronium natans*, *Potamogeton coloratus*, *Potamogeton filiformis*, *Potamogeton trichoides*, *Potamogeton* × *zizzii*, *Ranunculus tripartitus* and *Isoetes echinospora* (Preston *et al.*, 1991).

Components of the lacustrine flora have also been reported in the floras produced for the island (Griffith, 1895; Roberts, 1982). In addition, species lists for several Anglesey standing waters were used in Seddon's (1972) study of aquatic macrophytes as limnological indicators.

Many of the lakes on Anglesey are in natural transition to fens or mires. These wetlands are recognized in their own right as areas of outstanding conservation importance and a number of them have been designated as SSSIs (e.g. Cors Goch and Cors Erddreiniog).

**Aquatic invertebrates**

Fowles (1994) remarked that neither the river systems nor the lakes of North Wales region are particularly well recorded for invertebrates but Anglesey's lowland freshwater bodies were acknowledged for their rich dragonfly fauna. Fifteen open water and wetland sites on Anglesey are included in the *Invertebrate Site Register* (Rees, 1983) which is used for the recording and assessment of sites in Britain with invertebrate conservation interest. In general, the conservation assessment of aquatic invertebrate species in Britain is confined to a number of well studied groups—Gastropoda, Bivalvia, Coleoptera, Diptera, Trichoptera, Plecoptera, Ephemeroptera, Odonata. In the past the Anglesey lakes have been fortunate to attract attention from a number of specialist recorders (e.g. Rotifera and Cladocera: Galliford, 1953; aquatic Coleoptera: Balfour-Browne, 1942, 1949; Foster and Lazell, 1967, 1968; Foster, 1971; Hemiptera-Heteroptera: Popham, 1951; Odonata: Matthews, 1969; Morgan, 1970). In addition, the staff and students at the nearby University College of North Wales have made significant contributions to the knowledge of aquatic fauna of Anglesey (e.g. Reynoldson, 1956a, 1966; Reynoldson and Jacques, 1976; Taylor, 1960; Morgan, 1987a,b).

The freshwater invertebrate interest cited in the SSSI descriptions is frequently restricted to notable dragonfly populations, e.g. the presence of the nationally scarce variable damselfly *Coenagrion pulchellum* and the scarce blue-tailed damselfly *Ischnura pumilio* on Cors Bodwrog SSSI. Llyn Cerrig Bach is noted for its scarce water beetles, including the whirligig *Gyrinus paykulli* in its only known Welsh site (Fowles, 1994). Swan mussels *Anodonta cygnea* have a restricted distribution in Wales as they require calcium-rich waters. On Anglesey, they are known to occur in Llyn Maelog, Llyn Traffwll, Llyn Cefni, Llyn Yr Wyth Eidion (SH 475 818) and Llyn Coron. Their survival is intimately linked with the availability of a fish host for the larval phase of their life cycle. In 1956, the medicinal leech, *Hirudo medicinalis*, was first recorded on

Anglesey from Beaumaris Reservoir (Reynoldson, 1956b). It was later recorded on two occasions from Cors Goch (Morgan, 1987b) and more recently from sandy pools in Newborough Forest (Evans, 1993).

### Fish and birds

Ward's (1931) guide to the fisheries of Wales described Llyn Maelog as an excellent trout lake years ago but as was the case with other good lakes in this part of Anglesey, it was unfortunately stocked with coarse fish, which multiplied greatly at the expense of the trout. A collation of the data available for all the freshwater fish recorded on Anglesey reveals that the native species are almost matched by an equal number of introduced species (Table 3) and it seems unlikely that a native fish population has survived in any of the lakes. Further surveys are required to assess the fish communities at individual sites. However, it is considered unlikely that many would pass the procedure for the selection of important sites for freshwater

Table 3. Freshwater fish species recorded on Anglesey. Data sources are Forrest (1907), Maitland (1972), Shaw (1977), Clarke (1990), Maitland and Campbell (1992) and CCW records. No attempt was made to distinguish between riverine and lacustrine species.

| | Native | Introduced |
|---|---|---|
| LAMPREYS Family PETROMYZONIDAE | | |
| Sea lamprey *Petromyzon marinus* | + | |
| River lamprey *Lampetra fluviatilis* | + | |
| Brook lamprey *Lampetra planeri* | + | |
| SALMON AND TROUT Family SALMONIDAE | | |
| Atlantic salmon *Salmo salar* | + | |
| Brown trout *Salmo trutta* | + | |
| Rainbow trout *Oncorhynchus mykiss* | | + |
| Brook trout *Salvelinus fontinalis* | | + |
| SMELT Family OSMERIDAE | | |
| Smelt *Osmerus eperlanus* | + | |
| PIKE Family ESOCIDAE | | |
| Pike *Esox lucius* | | + |
| CARP Family CYPRINIDAE | | |
| Common carp *Cyprinus carpio* | | + |
| Crucian carp *Carassius carassius* | | + |
| Tench *Tinca tinca* | | + |
| Common bream *Abramis brama* | | + |
| Minnow *Phoxinus phoxinus* | | + |
| Rudd *Scardinus erythrophthalmus* | | +[a] |
| Roach *Rutilus rutilus* | | +[a] |
| EELS Family ANGUILLIDAE | | |
| European eel *Anguilla anguilla* | + | |
| STICKLEBACKS Family GASTEROSTEIDAE | | |
| Three-spined stickleback *Gasterosteus aculeatus* | + | |
| Ten-spined stickleback *Pungitius pungitius* | + | |
| PERCH Family PERCIDAE | | |
| Perch *Perca fluviatilis* | | + |
| MULLET Family MUGILIDAE | | |
| Thick-lipped mullet *Mugil chelo* | + | |
| FLATFISH Family Pleuronectidae | | |
| Flounder *Platichthys flesus* | + | |

[a]Refer to text for discussion of status.

fish in the British Isles (Maitland, 1985), with the possible exception of sites which could be considered useful local representatives of a fish community.

The family Cyprinidae is the most well represented on Anglesey. In general, the species found on Anglesey could be considered typical of lowland lake and river systems with abundant plant growth and muddy substrates. Clarke (1990) considered trout, rudd, three-spined stickleback and eel to be the most widespread native species on Anglesey. Four other native species—ten-spined stickleback, salmon, flounder and mullet—were thought to have a more limited distribution, with all other fish found on the island away from the coast probably the result of introductions. However, Maitland and Campbell (1992) considered rudd, tench, common bream and minnow as native only to south-east England with introductions in Wales. Records for rudd and roach are further complicated by their ability to hybridize. Forrest (1907) reported perch as a recent introduction to Anglesey, following the introductions of pike to Pen-y-parc (SH 586 751) and roach to 'Gwalchmai Lake' (probably Llyn Hendref SH 397 765).

It is likely that the smelt population is extinct but it was reported from the Crigyll river and as being sometimes taken about May when running down to the sea at low water (Forrest, 1907).

Brown trout populations on the island are supplemented by stocking (e.g. Llyn Coron). Rainbow trout have also been released into Llyn Alaw, Llyn Cefni and Llyn Llywenan (Clarke, 1990). Morphological variability in brown trout populations led to the recognition of separate species in the 19th century, and the presence of Loch Leven's *Salmo levenensis* in Llyn Traffwll and the 'Dinam lakes' has been reported (Forrest, 1907; Ward, 1931). Ward (1931) refers to *Salmo fontinalis* on Anglesey and presumably this is what is now known as *Salvelinus fontinalis* or American brook trout.

The commercial put-and-take fisheries on the island are believed to hold a number of exotic carp species. Recently an application was made to introduce *Silurus glanis* or wels to an artificial pond as a means of carp population control.

Eels are found in virtually all the Anglesey lakes. As they are the main food of the bittern they can hardly be a limiting factor for this rare bird, last recorded breeding here in 1986. Other water birds are more successful, with several lakes supporting nationally (GB) significant numbers of breeding tufted duck, gadwall and pochard and Anglesey supporting almost the whole Welsh breeding population of shoveler and gadwall and pochard. In a Welsh context many of the individual lakes are significant for wintering gadwall, shoveler, tufted duck, coot and pochard, with Llyn Alaw in particular also supporting large numbers of teal, and whooper swans (Royal Society for the Protection of Birds, 1993).

## CASE STUDIES—LLYNNAU CORON, DINAM AND PENRHYN

### Study site designations

In 1993–94 Llynnau Coron, Dinam and Penrhyn, three standing waters within biological SSSIs on Anglesey, were included in a larger research project designed to record the range of major physical, chemical and biological variables exhibited by Welsh lakes (Allott *et al.*, 1994). These three Anglesey lakes are considered good examples of the type of natural lake system found on the island and it is hoped that the ecological descriptions included here will provide a basis for monitoring any future environmental change.

Llyn Coron and its outflow, the Afon Ffraw, form the Tywyn Aberffraw SSSI. The site was recognized in the *Nature Conservation Review* (Ratcliffe, 1977) as a key conservation site in a British context and an account was given of its biological and environmental features of nature conservation value. Ratcliffe (1977) acknowledged that the descriptions of many of the sites included in the review were 'dated' and would require future revision. Llyn Dinam and Llyn Penrhyn lie within the Llynnau y Fali: Valley Lakes SSSI. Llyn Penrhyn is also part of a Royal Society for the Protection of Birds reserve and it is an important wildfowl sanctuary.

## Catchments

The catchment of Llyn Coron has a low relief with a maximum altitude of 65 m. Drainage is by one major stream, the Afon Gwna, supplemented in places by 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 appears only as outcrops. The extensive overlying glacial drift, when drained, produces relatively fertile land on which large areas of improved pasture have been developed. 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.

Llyn Penrhyn and Llyn Dinam lie 0.5 km apart, approximately 1.5 km from the coast of western Anglesey. Their catchments are difficult to distinguish topographically and have a maximum altitude of 25 m. Ordovician sedimentary rocks underlie most of the catchments, but sedimentary rocks of the Pre-Cambrian occur at the extreme western edge. Soils are exclusively cambric stagnogley soils of the Brickfield 2 association as described above.

The Dinam catchment is dominated by agricultural land used for arable and better quality rough grazing 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 Penrhyn are the residential and operational facilities of Valley Royal Airforce Base, 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 lies within the catchment. At the time of the current survey, secondary treated effluent from this plant was discharged directly into Llyn Penrhyn but from May 1994 a phosphate stripping plant has become operational. A further potential impact may come from the exhaust plumes of low altitude incoming and outgoing aircraft.

A summary of the physical characteristics of each site is given in Table 4.

Table 4. The physical characteristics of Llynnau Coron, Dinam and Penrhyn, Anglesey.

| | Llyn Coron | Llyn Dinam | Llyn Penrhyn |
|---|---|---|---|
| Grid reference | SH 378 380 | SH 311 775 | SH 315 770 |
| Lake altitude (m) | 10 | 4 | 4 |
| Maximum depth (m) | 2.8 | 1.8 | 3.0 |
| Mean depth (m) | 1.8 | 1.4 | 2.2 |
| Volume ($\times 10^6 m^3$) | 0.47 | 0.13 | 0.42 |
| Lake area (ha) | 26 | 9 | 19 |
| Shoreline development index[a] | 1.46 | 2.09 | 2.08 |
| Estimated hydraulic residence time (days) | 18 | 20 | 690 |
| Catchment area (excluding lake) (ha) | 1717 | 648 | 43 |
| Catchment : lake ratio | 66.0 | 72.0 | 2.3 |
| Net relief (m) | 55 | 21 | 21 |
| Mean annual rainfall (1988) (mm) | c. 1020 | c. 880 | c. 880 |
| Total S deposition (keq $H^+ ha^{-1} yr^{-1}$) | 1.58 | 0.57 | 0.57 |
| Total N deposition (keq $H^+ ha^{-1} yr^{-1}$) | 1.58 | 0.47 | 0.47 |

[a]This index represents the ratio of the length of shoreline to the circumference of a circle of area equal to that of the lake; it reflects the potential for the development of littoral communities in proportion to the area of the lake (Wetzel, 1983).

**Fieldwork and methods**

A full account of the survey and analytical methods used can be found in Allott *et al.* (1994). They include a number of standard methodologies devised and utilized by other freshwater research projects (Battarbee, 1986; Harriman *et al.*, 1987; Bell, 1990; Patrick *et al.*, 1991; Wolfe-Murphy *et al.*, 1991; Palmer *et al.*, 1992).

The study sites were visited on 10 July 1993 for the purpose of collecting the first of a quarterly series of water samples and the establishment of summer oxygen and temperature profiles. However, the majority of the fieldwork was carried out at all three sites during 1–3 September 1994. This fieldwork period included a further determination of oxygen and temperature profiles, collection of water samples, epilithic and surface diatom sampling, recording and mapping aquatic macrophytes and collection of littoral and open water zooplankton samples.

The water chemistry data presented are the annual means, with the addition of measurements made on samples collected on 6 December 1993 and 29 March 1994. The water samples were taken using the standard sampling and analytical methodology adopted by the Acid Waters Monitoring Network (Patrick *et al.*, 1991).

Ten cobble size stones from each site were brushed to obtain a representative sample of the epilithic diatom communities. Surface sediments were sampled for diatoms using a Glew gravity corer (Glew, 1989). The diatom samples were prepared using standard techniques and examined by light microscopy at × 1000. The 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, personal communication, 1993).

The methodology adopted for the recording and mapping of the aquatic macrophytes broadly followed that of the Northern Ireland Lake Survey (Wolfe-Murphy *et al.*, 1991) and the Nature Conservancy Council (Bell, 1990; Palmer *et al.*, 1992). The perimeter of the lake was inspected in a shoreline walk and a boat and grapnels were used to sample the offshore species. Following the key devised by Palmer (1989), each site was classified as a lake 'type' using the relative abundance of the macrophyte species recorded. In addition, a 'Trophic Ranking Score' (Palmer, 1989; Palmer *et al.*, 1992) for each site was calculated. This value indicates site nutrient status and has been used to monitor changes in water quality (Palmer *et al.*, 1992).

The littoral Cladoceran populations were sampled at six or seven sites chosen around each lake in a range of vegetation communities and substrate types. The technique follows that described in Duigan (1992). The open water zooplankton communities were sampled using an Apstein plankton net for vertical hauls from bottom to surface at three different stations within each lake.

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 study the three sites were sampled during two seasons, April and October 1993, to obtain the fullest range of species. 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 was feasible to collect replicate kick/sweep samples.

**Physical and chemical data**

The water chemistry of Llyn Coron and Llyn Penrhyn are typical of alkaline, nutrient-rich lakes (Table 5). In Coron, alkalinity values exceed 2000 $\mu eq\,L^{-1}$ over the summer period and mean total phosphorus $> 150\,\mu g\,L^{-1}$. Nitrate values show significant seasonal variation ranging from $14\,\mu g\,L^{-1}$ in late summer to exceptionally high levels of $1400\,\mu g\,L^{-1}$ in the late winter period. Chlorophyll *a* values are high in the September 1993 sample ($56\,\mu g\,L^{-1}$), emphasizing the productive nature of this site. In Dinam, total phosphorus concentrations are consistently above $100\,\mu g\,L^{-1}$ and alkalinity above $1500\,\mu eg\,L^{-1}$. Values of TOC are generally high ($> 8\,mg\,L^{-1}$).

Table 5. The water chemistry of Llynnau Coron, Dinam and Penrhyn, Anglesey.

| Determinand | | 1993–1994 Annual mean chemistry ($n=4$) | | |
|---|---|---|---|---|
| | | Llyn Coron | Llyn Dinam | Llyn Penrhyn |
| pH | | 8.61 | 7.84 | 8.07 |
| Alkalinity[a] | $\mu eq\,L^{-1}$ | 1869 | 1533 | 2153 |
| Alkalinity 2[a] | $\mu eq\,L^{-1}$ | 1878 | 1552 | 2178 |
| Conductivity | $\mu S\,cm^{-1}$ | 322 | 335 | 442 |
| Sodium | $\mu eq\,L^{-1}$ | 1050 | 1341 | 1846 |
| Potassium | $\mu eq\,L^{-1}$ | 70 | 65 | 134 |
| Magnesium | $\mu eq\,L^{-1}$ | 634 | 567 | 524 |
| Calcium | $\mu eq\,L^{-1}$ | 1988 | 1516 | 2202 |
| Chloride | $\mu eq\,L^{-1}$ | 957 | 1497 | 1824 |
| Aluminium–total monomeric | $\mu g\,L^{-1}$ | 7 | 1 | 1 |
| Aluminium–non-labile | $\mu g\,L^{-1}$ | 3 | 1 | 1 |
| Aluminium–labile | $\mu g\,L^{-1}$ | 4 | 0.3 | 0.3 |
| Absorption | (250 nm) | 0.262 | 0.378 | 0.242 |
| Carbon–total organic | $mg\,L^{-1}$ | 6.8 | 10.3 | 8.8 |
| Phosphorus–total | $\mu gP\,L^{-1}$ | 156.1 | 111.9 | 1085 |
| Phosphorus–total soluble | $\mu gP\,L^{-1}$ | 99.4 | 87.1 | 1038 |
| Phosphorus–soluble reactive | $\mu gP\,L^{-1}$ | 73.8 | 65.3 | 1016 |
| Nitrate | $\mu g\,L^{-1}$ | 700 | 68 | 142 |
| Silica–total | $mg\,L^{-1}$ | 10.4 | 2.82 | 3.39 |
| Silica–soluble reactive | $\mu g\,L^{-1}$ | 7.79 | 2.99 | 2.22 |
| Chlorophyll *a* | $\mu g\,L^{-1}$ | 21.2 | 7.8 | 4.3 |
| Sulphate | $\mu eq\,L^{-1}$ | 393 | 256 | 449 |
| Copper–total soluble[b] | $\mu g\,L^{-1}$ | <1 | <1 | <1 |
| Iron–total soluble[b] | $\mu g\,L^{-1}$ | 279 | 237 | 151 |
| Lead–total soluble[b] | $\mu g\,L^{-1}$ | <1 | <1 | <1 |
| Manganese–total soluble[b] | $\mu g\,L^{-1}$ | 53 | 161 | 174 |
| Zinc–total soluble[b] | $\mu g\,L^{-1}$ | <5 | <5 | <5 |

[a]Alkalinity was measured using two techniques; a standard titration of pH 5.0 (alkalinity 1) and a Gran titration (alkalinity 2).
[b]Only one sample taken in late March 1994.

The water chemistry characteristics of Llyn Penrhyn are quite distinct from the previous two sites and are suggestive of a higher level of productivity. Alkalinity is consistently above $2000\,\mu g\,L^{-1}$ and shows relatively little seasonal variation. Phosphorus concentrations are particularly high, with total phosphorus falling below $1000\,\mu g\,L^{-1}$ only in the March sample. Nitrate levels are also very high, reaching a marked peak of $413\,\mu g\,L^{-1}$ in winter 1993.

Chloride levels are high throughout the year at all three sites and are suggestive of a significant marine influence. The considerable fluctuation in nutrient and, to a lesser extent, pH levels indicates the importance of biological processes in determining annual variation in water chemistry at these sites. Based on oxygen and temperature data collected during the summer/autumn, there is no evidence of water column stratification, with the possible exception of Llyn Coron which exhibited a tendency towards stratification in September 1993.

### Epilithic and surface sediment diatom communities

The epilithic diatom communities of the three lakes are quite distinctive (Table 6). In Llyn Coron, the epilithic flora is dominated by two forms of *Fragilaria vaucheriae*, in association with *Nitzschia fonticola* and *Navicula tripunctata*. *Nitzschia* species—*N. inconspicua* and *N. palea* var. *debilis*—dominate in Llyn

Table 6. The epilithic and surface sediment diatom species composition and relative abundance (%) for Llynnau Coron, Dinam and Penrhyn, Anglesey, September 1993.

| Taxon | Surface sediment | | | Epilithon | | |
|---|---|---|---|---|---|---|
| | Coron | Dinam | Penrhyn | Coron | Dinam | Penrhyn |
| *Achnanthes lanceolata* | | 2.1 | | | | |
| *Achnanthes clevei* | | | 2.3 | | | |
| *Achnanthes peragalli* | | | 3.1 | | | |
| *Achnanthes minutissima* | 2.3 | 2.1 | | | | 4.9 |
| *Amphora lybica* | | | 3.1 | | | |
| *Amphora pediculus* | | | 2.0 | 4.3 | 7.8 | 4.9 |
| *Aulacoseira granulata* var. *angustissima* | 11.6 | | | 5.2 | | |
| *Cyclostephanos invisitatus* | 2.4 | 2.1 | | | | |
| *Cyclostephanos* [cf. *tholioformis*] | 7.5 | 6.2 | | | | |
| *Cocconeis placentula* | 2.1 | | 3.3 | | 3.2 | 3.0 |
| *Cocconeis placentula* var. *euglypta* | | | | | 2.7 | 2.6 |
| *Cocconeis placentula* var. *lineata* | | 2.6 | 2.6 | | 2.7 | 3.6 |
| *Cocconeis pediculus* | | | 2.0 | | | 3.0 |
| *Cyclotella meneghiniana* | | 2.1 | | | | |
| *Cymbella sinuata* | | | | | | |
| *Diatoma vulgaris* | | | | 2.2 | | |
| *Epithemia sorex* | | | | | 5.2 | |
| *Fragilaria pinnata* | | 6.7 | 2.0 | | | |
| *Fragilaria construens* | | 5.3 | | | | |
| *Fragilaria construens* var. *venter* | | 15.4 | 6.6 | | | 2.0 |
| *Fragilaria capucina* var. *mesolepta* | 4.9 | | 3.6 | | | |
| *Fragilaria virescens* var. *exigua* | | 3.1 | | | | |
| *Fragilaria brevistriata* | | | 11.6 | | | |
| *Fragilaria vaucheriae* | 2.9 | | | 31.2 | | |
| *Fragilaria capucina* | | | | 5.6 | | 2.0 |
| *Fragilaria exigua* | | | 3.1 | | | |
| *Navicula menisculus* | | | 14.0 | | | |
| *Navicula cryptotenella* | | | | | | 9.8 |
| *Navicula tripunctata* | | | | 7.7 | | 6.2 |
| *Navicula trivialis* | | | 2.8 | | | |
| *Navicula vitabunda* | | | | | | 3.4 |
| *Nitzschia* sp. | | | | 3.9 | 3.9 | 3.1 |
| *Nitzschia amphibia* | | | 2.6 | 3.6 | | 7.0 |
| *Nitzschia dissipata* | | 2.6 | | | | |
| *Nitzschia fonticola* | | | | 13.4 | 5.3 | 3.6 |
| *Nitzschia frustulum* | | | | 2.6 | | 2.8 |
| *Nitzschia gracilis* | | | | | 4.8 | |
| *Nitzschia inconspicua* | | | | | 15.9 | |
| *Nitzschia intermedia* | 3.1 | | | | | |
| *Nitzschia palea* | | | | | 5.5 | 5.2 |
| *Nitzschia paleacea* | | | | | | 2.1 |
| *Nitzschia palaeo* var. *debilis* | | | | | 9.1 | |
| *Nitzschia silesiaca* | | | | | | 2.1 |
| *Nitzschia tripunctata* | | | | 7.7 | | |
| *Rhoicosphenia curvata* | | 4.8 | 3.3 | 3.2 | 12.8 | 15.9 |
| *Stephanodiscus hantzschii* | 5.9 | | | | | |
| *Stephanodiscus parvus* | 24.4 | 14.2 | 22.6 | | | |

All data presented as percentages of a total count of 500–600 valves. Epilithon samples are derived from aggregating samples taken from three points around the lake shore. All taxa with greater than 2% relative abundance in either surface sediment or epilithon samples in any lake are recorded.

Dinam. *Rhoicosphenia curvata* and *Amphora pediculus* are also abundant at this site. The Llyn Penrhyn epilithic flora is dominated by *R. curvata* with *Navicula cryptotenella, Nitzschia amphibia* and *Navicula tripunctata* also common.

The surface sediment diatom assemblage of Llyn Coron is dominated by the planktonic taxa *Stephanodiscus parvus, Aulacoseira granulata* var. *angustissima* and *Cyclostephanos* [cf. *tholiformis*]. In Llyn Dinam, the sedimentary diatom assemblage is dominated by the planktonic *S. parvus* and the periphytic *Fragilaria construens* var. *venter*, with high abundances of *Cyclostephanos* [cf. *tholiformis*] and *Fragilaria pinnata*. 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, which indicate that the lake bottom is periodically within the photic zone. In Llyn Penrhyn, the surface sediment diatom assemblage is dominated by the planktonic *Stephanodiscus parvus* with the periphytic *Navicula menisculus*, the non-planktonic *Fragilaria* species and *Cocconeis* species also common. The high proportions of *Cocconeis* types indicates the importance of epiphytic habitats at this site. All these epilithic and surface sediment diatom species are characteristic of alkaline waters with intermediate to high nutrient values.

**Aquatic macrophytes**

Table 7 lists the aquatic macrophytes recorded at Llynnau Coron, Dinam and Penrhyn in September 1993. Macrophyte distribution maps have also been produced (Figures 2–4). During the period of the survey at Llyn Coron, the lake was covered by a bloom of the alga *Microcystis aeruginosa* which made the survey work difficult. *Enteromorpha* sp. was also present 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 *Polygonum 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, with *C. 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 this 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. Due to the presence of *Littorella uniflora* and a single specimen of *M. alterniflorum* Llyn Coron is typed as 5A (mesotrophic) after Palmer *et al.* (1992), with a trophic ranking score of 8.59. Without the presence of *Myriophyllum* the site would be typed as 8 (eutrophic).

Llyn Dinam has a shoreline dominated by *Phragmites australis* and to a lesser extent *Scirpus lacustris* ssp. *lacustris*. In the north there is a limited stretch of open shoreline, maintained by cattle grazing, where *Elatine hydropiper, Callitriche hermaphroditica* and *Littorella uniflora* occur. *Ceratophyllum demersum* occurs in abundance in the shallow (<1.5 m) open water habitat, often in association with *C. hermaphroditica* and *Lemna triscula*. The charophyte *Nitella* sp. and the moss *Fontinalis antipyretica* thrive at the far eastern end. A second charophyte species (*Chara* sp.) was found close to the shore at the western end. *Nymphaea alba* and *Nuphar lutea* dominate in a sheltered arm of the lake in the west. Three species of *Potamogeton, P. pectinatus, P. perfoliatus* and *P. pusillus* were found, the last of these being the most frequent and occurring mainly close to the shore in the eastern half of the lake. Llyn Dinam is typed as 10B (eutrophic) with a trophic ranking score of 8.59, after Palmer *et al.* (1992).

Being deeper than Llyn Dinam, Llyn Penrhyn (max. depth = 3 m) has a significantly deeper water zone where submerged vegetation is either sparse or absent. Its margin is also dominated by *Phragmites australis*, often fringed on the open water side by *Scirpus lacustris* spp. *lacustris*. A few large stands of *Nymphaea*

Table 7. A list of the aquatic macrophyte species and their relative abundance recorded at Llynnau Coron, Dinam and Penrhyn, September 1993.

| Taxon | DAFOR relative abundance score | | |
|---|---|---|---|
| | Coron | Dinam | Penrhyn |
| **Emergent** | | | |
| *Caltha palustris* | O | R | |
| *Eleocharis acicularis* | O | O | R |
| *Alisma plantago-aquatica* | O | | O |
| *Eleocharis palustris* | O | | |
| *Equisetum fluviatile* | R | | R |
| *Hydrocotyle vulgaris* | R | R | |
| *Iris pseudacorus* | O | F | O |
| *Juncus effusus* | A | F | |
| *Mentha aquatica* | R | F | |
| *Menyanthes trifoliata* | | F | R |
| *Phalaris arundinacea* | O | F | O |
| *Phragmites australis* | R | A | D |
| *Polygonum hydropiper* | | R | |
| *Rumex hydrolapathum* | | | |
| *Scirpus lacustris* ssp. *tabernaemontani* | A | | |
| *Scirpus lacustris* ssp. *lacustris* | | F | F |
| *Sparganium erectum* | O | | O |
| *Typha latifolia* | | O | O |
| *Veronica beccabunga* | | O | R |
| **Floating or floating leaved** | | | |
| *Glyceria fluitans* | | | O |
| *Lemna minor* | | R | R |
| *Lemna trisulca* | | F | O |
| *Nuphar lutea* | | R | O |
| *Nymphaea alba* | R | F | F |
| *Polygonum amphibium* | O | O | O |
| **Submerged** | | | |
| *Callitriche hermaphroditica* | | A | A |
| *Callitriche stagnalis* | A | | |
| *Ceratophyllum demersum* | | A | F |
| *Chara* sp. | O | R | |
| *Elatine hydropiper* | F | F | |
| *Elodea canadensis* | R | | F |
| *Fontinalis antipyretica* | | F | |
| *Littorella uniflora* | R | F | |
| *Myriophyllum alterniflorum* | R | | |
| *Myriophyllum spicatum* | | O | |
| *Nitella* sp. | | O | |
| *Potamogeton crispus* | | | O |
| *Potamogeton pectinatus* | | R | O |
| *Potamogeton perfoliatus* | O | R | |
| *Potamogeton pusillus* | | O | R |
| *Potamogeton trichoides* | R | | |
| *Ranunculus aquatilus* | | O | |
| *Ranunculus circinatus* | O | | |
| *Zannichellia palustris* | O | | R |

Scores determined qualitatively following shoreline and deeper water grapnel surveys according to the DAFOR index: D, Dominant; A, Abundant; F, Frequent; O, Occasional; R, Rare.

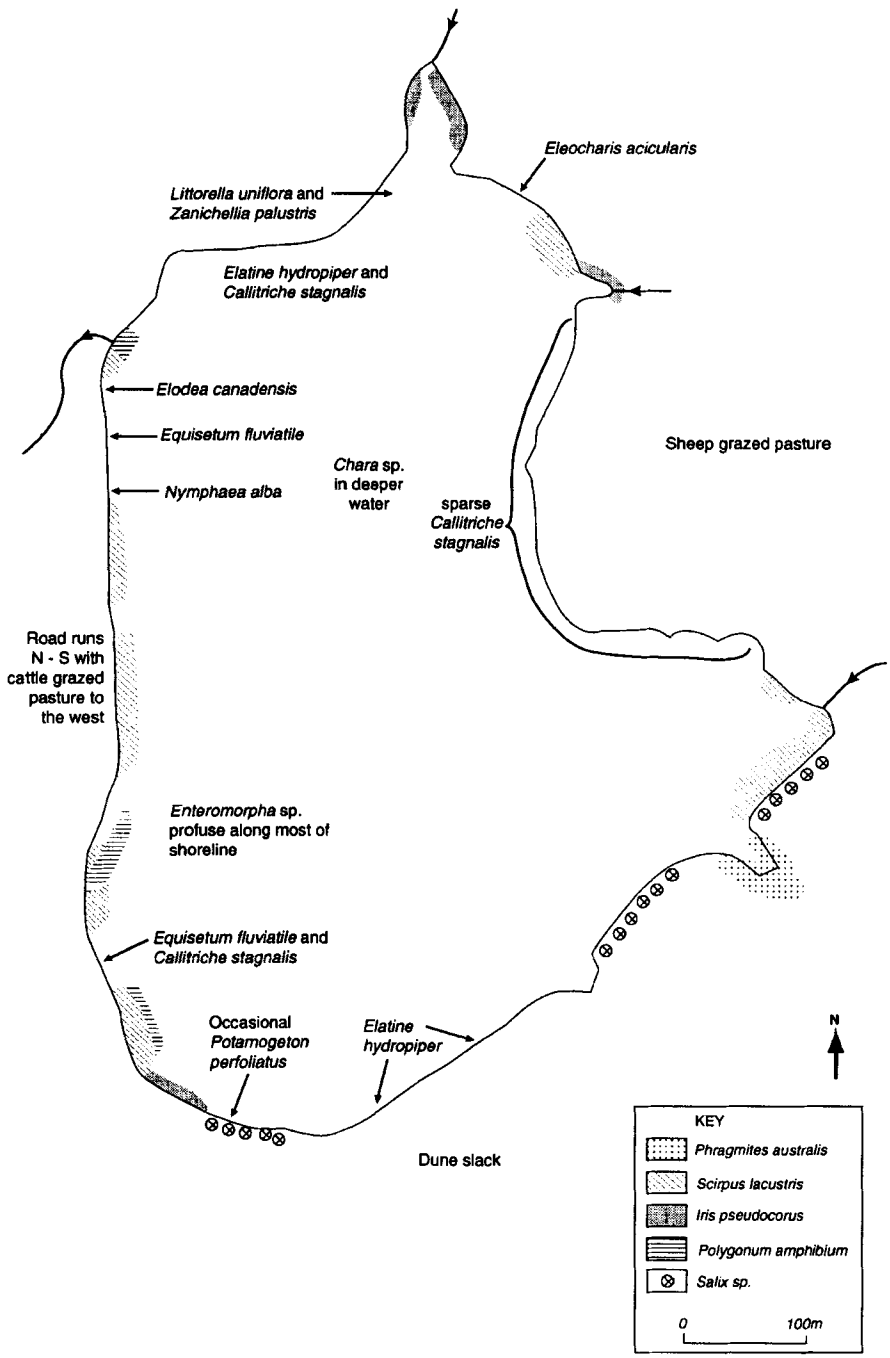


Figure 2. Macrophyte distribution map for Llyn Coron, Anglesey.

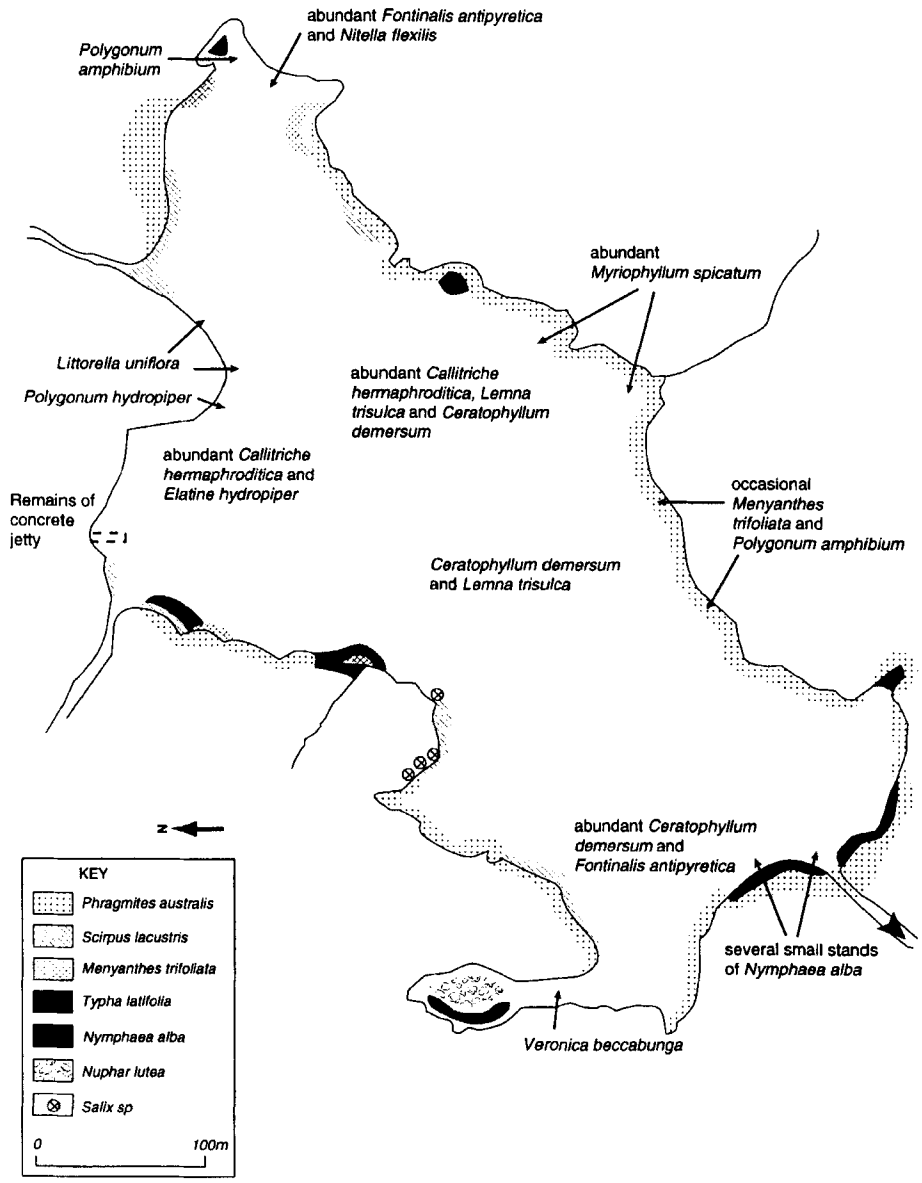


Figure 3. Macrophyte distribution map for Llyn Dinam, Anglesey.

*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 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. Llyn Penrhyn is typed as 10A (eutrophic) after Palmer *et al.* (1992), with a Trophic Ranking Score of 8.68. It differs from the typing of Llyn Dinam due to the presence of *Elodea canadensis* and *Potamogeton crispus* and the absence of *Chara* species.

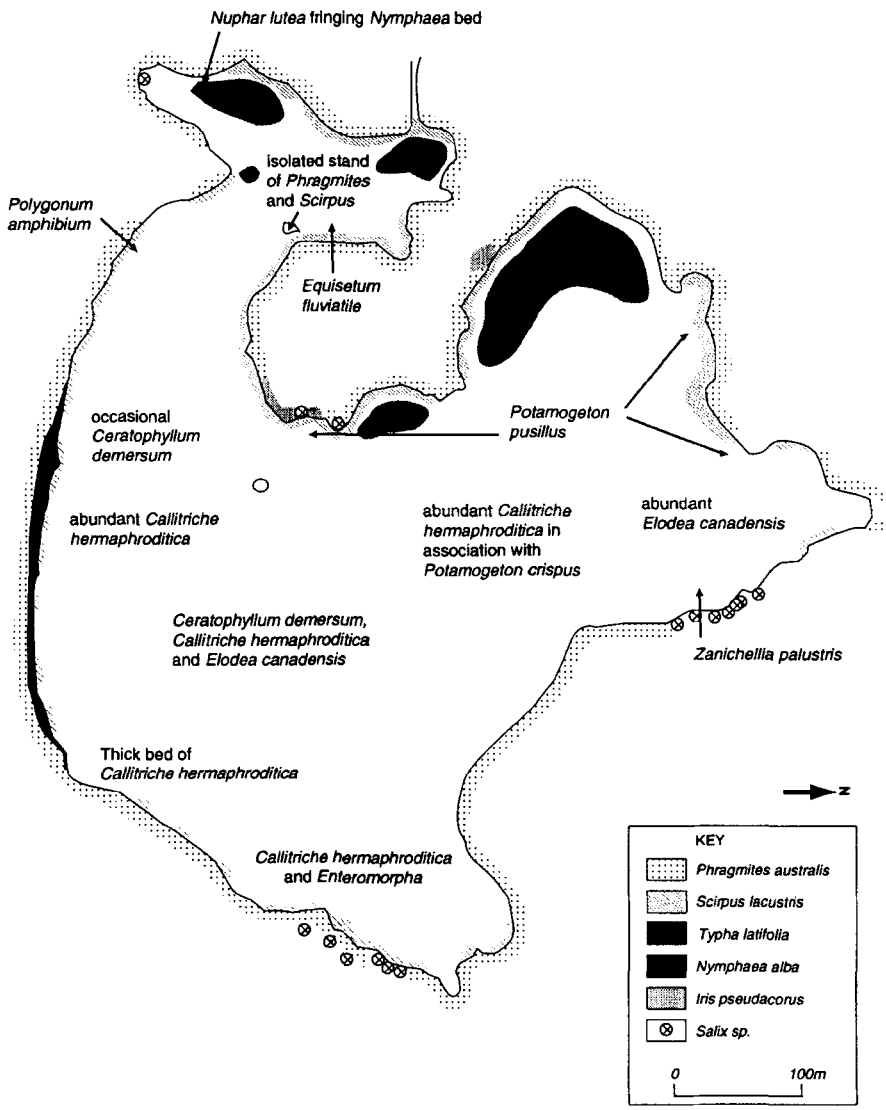


Figure 4. Macrophyte distribution map for Llyn Penrhyn, Anglesey.

## Littoral and open water zooplankton

Twenty-two taxa were identified from the littoral zooplankton samples taken from Llynnau Coron, Penrhyn and Dinam (Table 8). *Alona affinis*, *Chydorus sphaericus*, *Eurycercus lamellatus*, *Pleuroxus aduncus*, *Pseudochydorus globosus* and *Simocephalus vetulus* were the only species common to all three sites. *Pleuroxus trigonellus*, *P. aduncus* and *Daphnia hyalina* are the most common components of the littoral zooplankton of Llyn Coron. *Eurycercus lamellatus* is the dominant chydorid component of all the samples taken at Llyn Dinam. Llyn Penrhyn is characterized by the dominance of *P. aduncus* and *Ceriodaphnia dubia* and the presence of several *Daphnia* taxa.

Table 8. The littoral and open water zooplankton communities of Llynnau Coron, Dinam and Penrhyn, Anglesey, September 1993. All taxa found indicated by (+).

| Taxon | Coron | | Dinam | | Penrhyn | |
|---|---|---|---|---|---|---|
| | Littoral | Open water | Littoral | Open water | Littoral | Open water |
| *Acroperus harpae* | | | | | + | |
| *Alona affinis* | + | | + | | + | |
| *Alona rectangula* | | | + | | | |
| *Alona rustica* | | | | | + | |
| *Asplanchna* sp. | | | | | | + |
| *Bosmina longirostris* | | | + | + | | |
| *Ceriodaphnia dubia* | | | + | + | + | + |
| *Chydorus sphaericus* | + | | + | | + | |
| *Cyclops strenuus* | | + | | + | | + |
| *Cyclops vicinus* | | + | | | | |
| *Daphnia hyalina* | + | | + | | | |
| *Daphnia hyalina* var. *galeata* | | + | | + | + | + |
| *Daphnia longispina* | | | | | + | |
| *Daphnia obtusa* | | | | | + | |
| *Daphnia pulex* | | | | | + | |
| *Daphnia pulicaria* | | | | | | + |
| *Diaphanosoma brachyurum* | | | + | + | | |
| *Eubosmina longispina* | | | + | | | |
| *Eucylops serrulatus* | | + | | + | | + |
| *Eudiaptomus gracilis* | | + | | + | | + |
| *Eurycerus lamellatus* | + | | + | + | + | + |
| *Keratella cochlearis* | | + | | | | |
| *Keratella quadrata* | | + | | | | |
| *Leptodora kindti* | + | + | | | | |
| *Macrocyclops albidus* | | | | + | | + |
| *Megacylops viridis* | | + | | + | | |
| *Oxyurella tenuicaudis* | + | | | | | |
| *Pleuroxus aduncus* | + | | + | | + | |
| *Pleuroxus trigonellus* | + | | | | | |
| *Pleuroxus uncinatus* | | + | | | | |
| *Pseudochydorus globosus* | + | | + | + | + | |
| *Scapholeberis mucronata* | + | | | | | |
| *Simocephalus vetulus* | + | | + | | + | |

Llyn Coron has a relatively diverse open water zooplankton fauna with a total of 10 species identified from the samples (Table 8). Common species included *Eudiaptomus gracilis*, *Cyclops strenuus*, *Cyclops vicinus* and *Daphnia hyalina* var. *galeata*. The large body form of *D. hyalina* var. *galeata* adults indicated a reduced predation by planktivorous cyprinids, which could result from artificial stocking with predaceous trout. The most similar sites in terms of zooplankton species composition were Llyn Dinam and Llyn Penrhyn with seven species common in both lakes. Llyn Dinam was distinguished by the presence of *Eudiaptomus gracilis*, *Eucyclops serrulatus*, *Ceriodaphnia dubia*, *Macrocyclops albidus* and *Bosmina longirostris*. Llyn Penrhyn was characterized by high abundances of *Daphnia pulicaria*, *D. hyalina* var. *galeata*, *C. strenuus* and *E. gracilis*. It is considered likely that large-bodied cladocerans like *D. pulicaria* play an important role in phytoplankton growth control. The seasonal occurrence of red daphniid swarms have been remarked upon by the local fishermen.

Table 9. The macroinvertebrate communities of Llynnau Coron, Dinam and Penrhyn, Anglesey, September 1993 and April 1994. Mean number of individuals per one minute kick/sweep sample.

| | | Coron | | Dinam | | Penrhyn | |
|---|---|---|---|---|---|---|---|
| Class | Taxon | Sept 93 | April 94 | Sept 93 | April 94 | Sept 93 | April 94 |
| TURBELLARIA | Tricladida | 19.0 | 148.0 | 41.5 | 86.4 | 86.7 | 28.00 |
| MOLLUSCA | *Valvata piscinalis* | 27.5 | 120.4 | 7.5 | 61.2 | 16.7 | |
| | *Lymnaea truncatula* | 2.5 | 0.4 | | 1.6 | 0.7 | 2.0 |
| | *Lymnaea auricularia* | | 1.2 | 2.5 | 0.4 | | |
| | *Lymnaea peregra* | 14.5 | 0.4 | 2.0 | 0.4 | 1.3 | 0.8 |
| | *Physa fontinalis* | 126.5 | 19.2 | 2.5 | | 107.3 | 5.6 |
| | *Planorbis carinatus* | | | 0.5 | 0.8 | 13.3 | |
| | *Planorbis vortex* | | | | | 58.7 | 3.2 |
| | *Planorbis albus* | 5.0 | 4.4 | 59.5 | 42.8 | 10.0 | 7.2 |
| | *Planorbis crista* | | | 2.5 | 0.4 | 2.0 | 1.2 |
| | *Planorbis contortus* | 19.0 | 15.6 | 5.0 | 6.8 | 25.3 | 1.6 |
| | *Segmentina complanata* | 1.0 | | 3.0 | 19.6 | 177.3 | 11.2 |
| | *Acroloxus lacustris* | 1.5 | 0.8 | 5.0 | 17.2 | 28.7 | 31.6 |
| BIVALVIA | *Pisidium* sp. | 1.0 | 4.0 | 38.0 | 88.8 | 22.7 | 0.8 |
| HIRUDINIA | *Theromyzon tessulatum* | 6.0 | 0.4 | 1.5 | 2.4 | 5.3 | 2.8 |
| | *Glossiphonia heteroclita* | 0.5 | | 1.5 | 0.8 | 56.0 | 0.4 |
| | *Glossiphonia complanata* | 3.0 | 1.2 | 9.0 | 0.8 | 8.0 | 0.8 |
| | *Helobdella stagnalis* | | 0.4 | 6.5 | 1.6 | 10.7 | 0.4 |
| | *Erpobdella octoculata* | 1.0 | | 7.5 | | 2.0 | 0.4 |
| MALACOSTRACA | *Asellus aquaticus* | | | 2788 | 871.6 | 146.0 | 29.2 |
| | *Asellus meridianus* | 630.5 | 160.4 | | | | |
| | *Gammarus pulex* | 2.0 | 2.8 | 399.5 | 164.4 | 130.7 | 272.8 |
| EPHEMEROPTERA | *Baetis* sp. | | 2.4 | | | | |
| | *Caenis horaria* | 24.5 | 20.4 | 87.5 | 116.4 | | 0.8 |
| | *Caenis luctuosa* | | | 15.0 | 25.2 | | 0.8 |
| ODONATA | *Ischnura elegans* | 5.0 | | 130.5 | | 15.3 | |
| | *Enallagma cyathigerum* | 2.0 | 4.0 | 17.5 | 6.8 | | 3.2 |
| HEMIPTERA | Corixidae sp. | 5.0 | | 5.5 | | 28.0 | |
| | *Callicorixa praeusta* | 1.5 | 1.2 | 2.0 | | 96.0 | 9.2 |
| | *Corixa punctata* | 0.5 | 0.4 | | | 9.3 | |
| | *Arctocorisa germari* | | 0.8 | | | 64.7 | |
| | *Sigara dorsalis* | 1.0 | 11.2 | 6.0 | 3.6 | 15.3 | 10.4 |
| | *Sigara falleni* | 112.5 | 225.2 | 5.5 | 0.4 | 73.3 | 12.0 |
| COLEOPTERA | Haliplidae sp. | 38.5 | 8.4 | 3.5 | 3.6 | 14.0 | 2.0 |
| | *Haliplus confinis* | 1.0 | 0.4 | | | | |
| | *Haliplus ruficollis* group | 12.0 | 5.6 | 4.0 | 2.8 | 13.3 | 13.6 |
| | *Haliplus fluvus* | 1.0 | | | | | |
| | Dytiscidae undet. (larvae) | 3.0 | 1.2 | | | 0.7 | |
| | *Potamonectes depressus elegans* | 0.5 | 2.4 | 3.0 | 2.0 | | |
| | *Oulimnius troglodytes* | 131.5 | 10.8 | 0.5 | 0.8 | | |
| MEGALOPTERA | *Sialis lutaria* | | | 2.0 | | | |
| TRICHOPTERA | *Polycentropus flavomaculatus* | | | 12.5 | 4.4 | | |
| | *Holocentropus dubius* | | | 8.0 | | | |
| | *Ecnomus tenellus* | | | 2.5 | 0.8 | | |
| | *Tinodes waeneri* | 1.0 | 0.8 | 3.0 | 4.0 | | |
| | *Lype reducta* | | | 1.0 | 0.4 | | |
| | *Agraylea multipunctata* | | 4.8 | 7.0 | 0.8 | 30.0 | 3.2 |
| | *Oxyethira* sp. | | | 8.0 | 49.6 | | |
| | *Limnephilus* sp. | 5.5 | | | | | |
| | *Limnephilus marmoratus* | | | | 5.2 | | 4.4 |
| | *Anabolia nervosa* | | 3.2 | | 0.8 | | |
| | *Mystacides longicornis* | | | 18.5 | 14.8 | | 0.4 |
| DIPTERA | Chironomidae | 122.0 | 537.2 | 250.5 | 896.4 | 120.0 | 932.0 |

Table excludes those taxa with mean scores of $< 1$.

**Macroinvertebrates**

Llynnau Coron, Dinam and Penrhyn support dense, species-rich littoral macroinvertebrate communities. They are typified by adundant and diverse assemblages of molluscs, leeches, amphipods, isopods and various insects, all representative 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 leeches are predatory on invertebrates, and primarily those living on macrophyte surfaces, with the exception of *Theromyzon tessulatum* 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 open water.

Llynnau Penrhyn and Dinam have very similar species assemblages (Table 9). 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. Various proposals have been made to account for these differences in distribution including a differential ability to re-colonize after the last glaciation, adaptations to water sodium content and interspecific competition (Williams, 1962a,b, 1963, 1979). Williams (1963) described how *A. meridianus* was replaced by *A. aquaticus* in Llyn Llywenan (SH 347 815) between 1950 and 1962 and he proposed that *A. meridianus* was an older inhabitant of the lake which was displaced by competition with the other *Asellus* species.

The trichopteran *Ecnomus tenellus* was recorded in Llyn Dinam and it is considered locally and regionally notable (Wallace, 1991).

The most marked seasonal changes in species composition between autumn and spring in these three lakes was a decline in the abundance of *Asellus* spp. and an increase in numbers of Chironomidae. There is some suggestion of a decline in numbers of Hirudinae 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.

## CURRENT ISSUES

Ultimately lakes are temporary features in the landscape, subjected to sedimentation and hydroseral succession which will lead to their infilling. Certain actions by man may increase or retard this process. Many lakes currently have a particular balance of open water and fringing vegetation. Should the *status quo* be maintained, natural succession permitted, or changes allowed in land-use activity to alter these natural processes? Should new lakes be created for the future or old ones dredged with the loss of the valuable sediment records? There are no easy answers to these questions but perhaps the most pragmatic approach would be to attempt to retard natural succession as much as possible at natural sites and create new open water habitats. However, if these new habitats are managed as reservoirs and trout fisheries (e.g. Llyn Cefni and Llyn Alaw) will they serve as comparable replacements for natural systems? In addition, traditional management of some areas such as reedbeds for thatch, peat-cutting mires for fuel, grazing marshes with ponies, produced features of great value for nature conservation. Dereliction of these practices presents conservationists with urgent problems.

Nutrient status is central to freshwater ecology, and management of the catchment is crucial in determining the nutrient balance of waters. In view of the changes in ecology detected in the Anglesey lakes in recent years (Haworth *et al.*, 1994; Haworth *et al.*, in preparation), we need to focus on the role of changes in land management and sewage disposal on the integrity of lake ecosystems. Can half a million sheep and up to two million chickens be managed in a manner allowing their sustainable coexistence alongside a healthy aquatic environment on the island of Anglesey? How can targets be set for sustainable

agricultural production within lake catchments? The findings of palaeolimnological studies certainly help to assess the scale of nutrient enrichment problems and define targets for restoration (Haworth *et al.*, 1994; Haworth *et al.*, in preparation, Bennion, 1995; Bennion, in preparation).

Alien species are a major source of conservation problems in aquatic systems on Anglesey. Plants such as Canadian pondweed *Elodea canadensis* choke the amenity lake at Breakwater Quarry (SH 227 832) and elsewhere, and it also occurs in a number of standing waters within SSSIs (e.g. Llyn Penrhyn). Australian swamp stonecrop *Crassula helmsii*, a contaminant weed of plant pots in all the aquatic garden centres on the island, poses a threat to the pools and ditches on the island, especially Malltraeth Marsh, where it has been recorded from garden ponds adjacent to the marsh.

Aquatic invertebrates have also been introduced to water bodies on Anglesey. *Dugesia tigrina*, an American species of freshwater triclad, was accidentally introduced into a small artificial pond in Menai Bridge during stocking of the pond with plants and invertebrates from the mainland (Reynoldson, 1977). In 1985, Reynoldson reported a sudden dramatic decline in native *Polycelis* populations in Llyn Coron following the appearance of *D. tigrina*. It was concluded that this species replacement most likely resulted from interspecific competition in the absence of other more competitive British triclad species (Reynoldson, 1985). The relatively warm waters of Llyn Coron were also considered to be a contributory factor and it was suggested that the American triclad was introduced via extensive stocking with trout.

The feeding action of introduced cyprinid fish species and their excretions can be instrumental in increasing water turbidity and promoting algal blooms which can have detrimental effects on the ecology of the lake systems (Breukelaar *et al.*, 1994; Persson and Hamrin, 1994). Feral greylag geese and Canada geese populations are expanding rapidly (Delaney, 1995). Apart from the damage they may do to the neighbouring farmers' crops, they contribute to the nutrient input to lake waters with their droppings and compete with other waterfowl for nesting sites (Department of the Environment, 1994). Finally, the ruddy duck which has found a favourable habitat in Anglesey's lakes threatens to spread to the continent and to eradicate the white-headed duck by hybridization (Hughes and Grussu, 1995).

Recreational pressures are growing, although fortunately the small size and shallow weedy nature of many of the island's lakes makes them unattractive to some of the more intrusive activities. Angling is almost ubiquitous and wildfowling makes a significant contribution to the large 'sporting' industry on the island.

Mining activity at Parys Mountain has led to the oxidation of the exposed sulphide minerals producing iron-rich waters and dilute sulphuric acid, resulting in highly acid run-off (Pearce, 1993). A range of toxic metals are carried in solution and the run-off leads to the precipitation of red-orange ochre. Boult *et al.* (1994) described the Afon Goch, which drains Parys Mountain, as 'one of the most metal- and acid-contaminated streams in the UK'. It is evident that mining activity has had a serious effect on the aquatic biota within the drainage area. Ward (1931) noted that the water of Llyn Llaethdy (SH 443 917), which receives drainage from Parys Mountain, was coloured red and devoid of fish. In September 1994 this lake had pH and conductivity values of 3.22 and 438 $\mu S\,cm^{-1}$ respectively. On the same date a pond (SH 437 905) on the mountain had readings of pH 2.2 and 4170 $\mu S\,cm^{-1}$. Woodhead (1968) was surprised to find *Euglena* living in a shallow pool on Parys Mountain with a copper solution of 400 ppm. Mining operations have temporarily ceased at this site while the owners await a more financially viable climate before commencing production from a new underground lode (Pearce, 1993). A commitment has been made that future mining operations will be carried out in a sensitive manner with attention being paid to confinement of run-off.

### Anglesey wetland strategy

Cooperation between the Countryside Council for Wales (CCW), the National Rivers Authority (NRA) and the Royal Society for the Protection of Birds (RSPB) on conservation projects, particularly on

Malltraeth Marsh in 1992, led to the decision to establish regular liaison procedures. The 'Anglesey Wetland Strategy' is an informal local liaison procedure whereby broad targets and strategies are highlighted by the partner organizations. By earmarking forthcoming projects or areas of interest, each party is able to forewarn the others of their intentions and call on the expertise and resources of the other members in implementing projects.

The results of this procedure have been very encouraging. The CCW's conservation advice has helped to guide investment decisions by the other bodies. The NRA's skills in water management have been applied to sluice building and ditch maintenance. The RSPB's experience and advice in land management for birds has found wide application. The two statutory bodies have been able to coordinate their grant and research functions to greater effect. For instance, in assisting the establishment of a new RSPB reserve on Malltraeth Marsh, the NRA provided detailed topographic survey and subsequently major earthworks while CCW provided a hydrological investigation and grant aid for land purchase. In response to the need for detailed monitoring of water quality at a number of Anglesey lakes, RSPB and CCW staff are collecting much of the material whilst the NRA has undertaken analysis of samples. The group has expanded to include other wetland managers such as the Agricultural Development and Advisory Service (which operates the Environmentally Sensitive Areas Scheme) and the North Wales Wildlife Trust (which has important wetland reserve interests on the island). Networking at operational level enables opportunities to be seized and local initiatives to be undertaken more efficiently. Contacts are regular and often informal, building on trust and enabling advice and expertise to pass between the officers concerned. The future of the Anglesey lakes is seen to lie with the partnership approach.

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