

Research Papers

No. 19

PALAEOECOLOGICAL EVALUATION OF THE RECENT ACIDIFICATION OF WELSH LAKES

**3. Llyns Conwy and Gamallt, Gwynedd
(Site descriptions, fishing and land use/management histories)**

S. T. Patrick and A. C. Stevenson

Editors: A.C. Stevenson & S.T. Patrick

**Palaeoecology Research Unit
Department of Geography
University College London
26 Bedford Way
London WC1H 0AP**

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Explanation of Abbreviations

ADAS	Agricultural and Development Advisory Service.
BGS	British Geological Survey.
MAFF	Ministry of Agriculture, Fisheries and Food.
NLW	National Library of Wales.
PRO	Public Record Office.
WWA	Welsh Water Authority.
SSSI	Site of Special Scientific Interest.

1.0 Introduction

Surface water acidification is recognised as one of the most important environmental problems in Europe and North America, yet despite the pioneering work of Gorham on precipitation chemistry in Cumbria (Gorham 1958) the full extent of acidification in the UK is still not known. In earlier papers (Flower and Battarbee 1983, Battarbee *et al.* 1985 and Jones *et al.* 1986) we established that both non-afforested and afforested lakes on granitic rocks in Galloway, south-west Scotland, were strongly acidified, and that the most likely cause of the acidification in the non-afforested lakes was acid deposition. We have now extended our enquiry to non-afforested acid lakes in Wales and other parts of Scotland to test the general hypothesis that non-afforested clearwater lakes with pH values less than 5.5 occurring within areas of high acid deposition are acidified owing to an increase in acid deposition over recent decades.

This paper presents lake/catchment descriptions, fishing histories and land use/management histories of Llyn Conwy and Gamallt, two acid lakes in north Wales (Fig. 1). Sediment cores were taken from these lakes in May 1985. However, the material recovered proved inadequate for diatom and associated sediment analyses (to reconstruct past pH values and illustrate past atmospheric inputs) (eg. Battarbee *et al.* 1985, Anderson *et al.* 1986, Fritz *et al.* 1986a, Kreiser *et al.* 1986).

It is proposed to re-core these lakes in the future and negotiations are in progress to secure funds for such a project. Evidence presented in this paper suggests that these lakes are particularly worthy of further palaeoenvironmental investigation.

2.0 Site details

2.1 Llyn Conwy

2.1.1 The lake

Llyn Conwy lies at an altitude of 450 m on the north of the Migneint Plateau, some 8 km north-west of Ffestiniog, an area which receives a rainfall of over 2000 mm yr⁻¹. The lake has a surface area of 40.1 ha. The detailed bathymetry demonstrates that away from the shallow embayments the lake is dominated by a relatively uniform basin (Fig. 2). The lake has a mean depth of 7.66 m and a volume of 3,073,846 m³ (Table 1). The lake is used for potable water supply and is subject to water level fluctuations as a result of artificial drawdown, particularly in summer.

The drainage network is poorly formed. One rather indistinct inflow drains into the north and one to the north-east of the lake (Fig. 3). Most of the water input is by groundwater flow and by flow within and over the blanket peats. A single outflow (Afon Conwy) drains from the southern end of the lake (Fig. 3) over a weir constructed by the WWA.

Water quality of the lake is monitored by the WWA. A preliminary report (Milner and Jones 1985) indicated a pH of 4.6 with an alkalinity of 8.2 ueq l⁻¹. Dissolved calcium levels averaged 42 ueq l⁻¹ and dissolved aluminium 8.2 ueq l⁻¹.

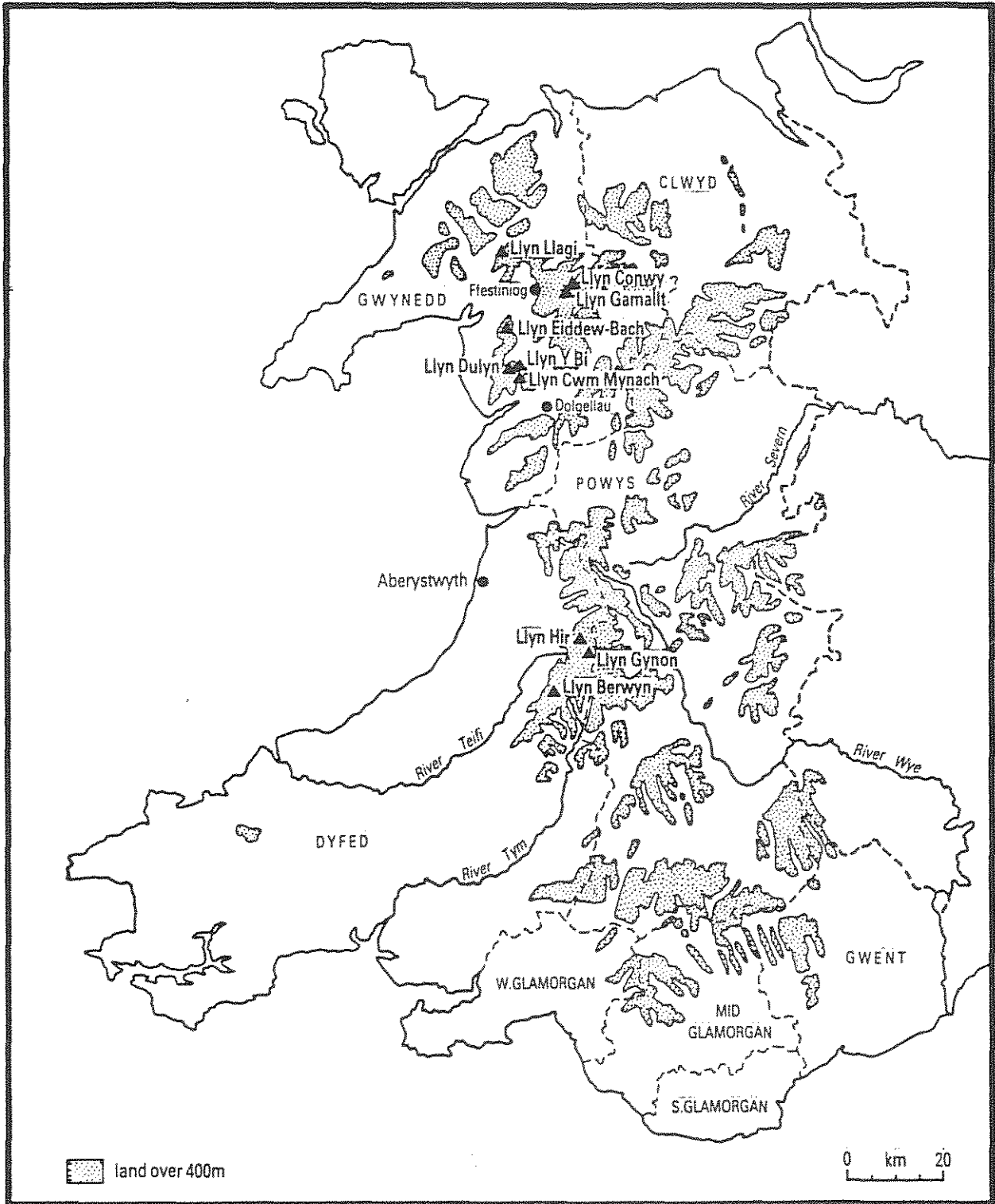


Fig. 1. WELSH LAKES STUDIED UNDER DOE CONTRACT

An assessment of lake vegetation was made in May 1895 (P. Raven pers. comm.). Plant life in the lake is not abundant. Juncus acutifloris and Juncus articulatus are locally plentiful in sheltered embayments and surround the small island off the central eastern shore. Littorella uniflora is scarce while Lobelia dortmanna and Isoetes lacustris were only recovered from the strandline indicating their presence in the sublittoral. A previous survey (Rose 1984) indicated that Isoetes lacustris, Lobelia dortmanna and Juncus bulbosus dominated the flora of the lake.

2.1.2 The catchment

Llyn Conwy has a relatively small catchment area of 95.9 ha (excluding the lake), giving a lake catchment:lake ratio of 2.39. The catchment is of only moderate relief reaching a maximum altitude of 526 m (some 75 m above the lake water surface) to the north (Table 1, Fig. 3).

Detailed geological mapping of the catchment is not yet available but surveying is in progress nearby (R. Bazely pers. comm.). In general, thinly bedded Ordovician and Silurian mudstones and shales dominate the catchment geology with occasional outcrops of Ordovician volcanics. Drift geology is almost entirely absent (Milner and Jones 1985).

Soils of the catchment are dominated by blanket peats belonging to the Crowdy 2 peat series (1013b). To the north-east a small area of wet loamy soils overlain by peat belonging to the Wilcox 2 series (721d) occurs.

Mature Calluna vulgaris dominates the catchment vegetation with Eriophorum vaginatum occupying a secondary position. Areas of eroding blanket peat characterised by Sphagnum recurvum and S. cuspidatum occur to the east of the lake (Fig. 4).

Table 1 Llyn Conwy, lake and catchment characteristics

Lake

Altitude	450 m
Surface area	40.1 ha
Maximum depth	22 m
Mean depth	7.66 m
Volume	3,073,846 m ³

Catchment

Maximum altitude	526 m
Area (excluding lake)	95.9 ha
Catchment:lake ratio	2.39

Fig. 2. LLYN CONWY, BATHYMETRY

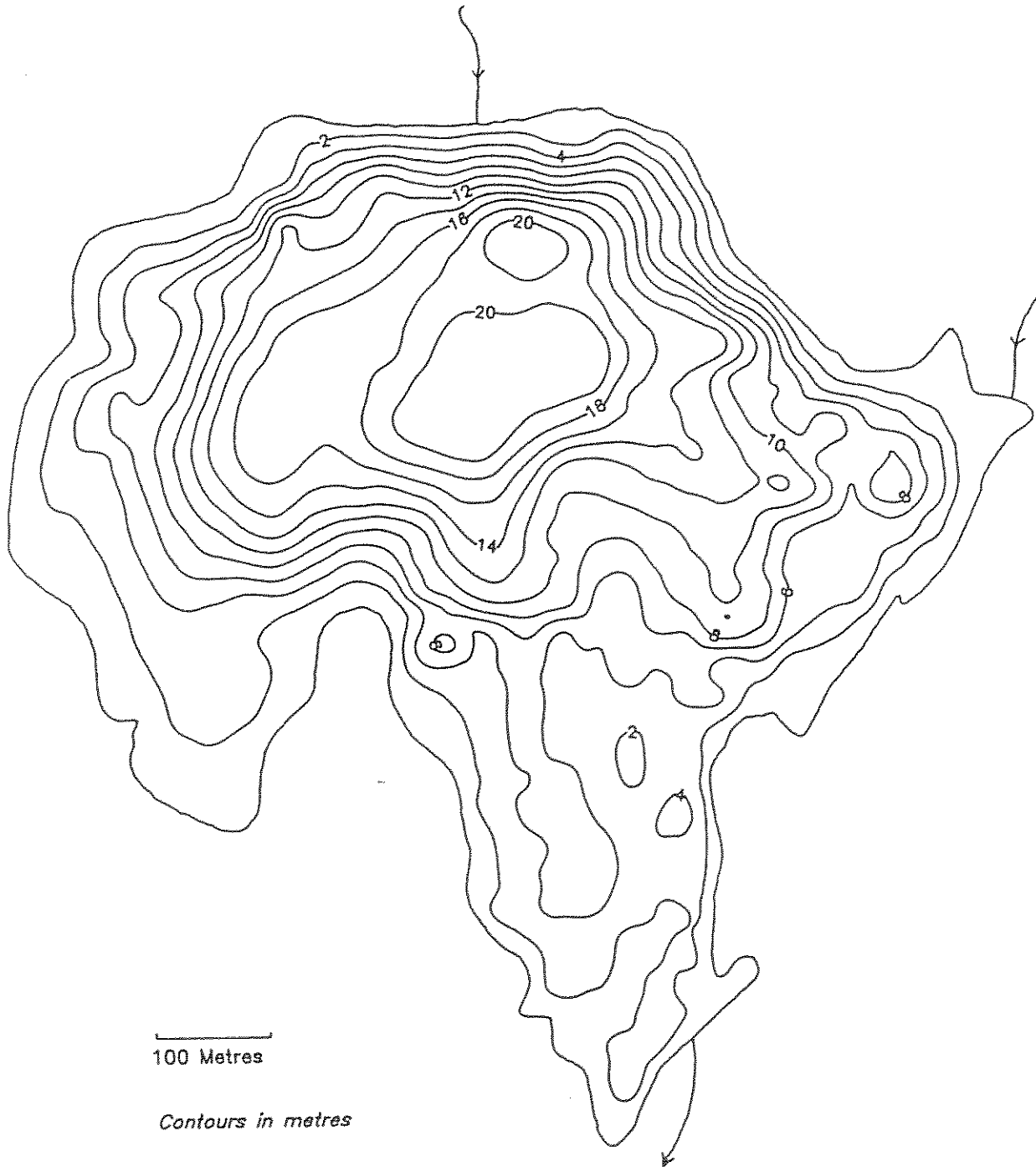


Fig. 3. LLYN CONWY, CATCHMENT

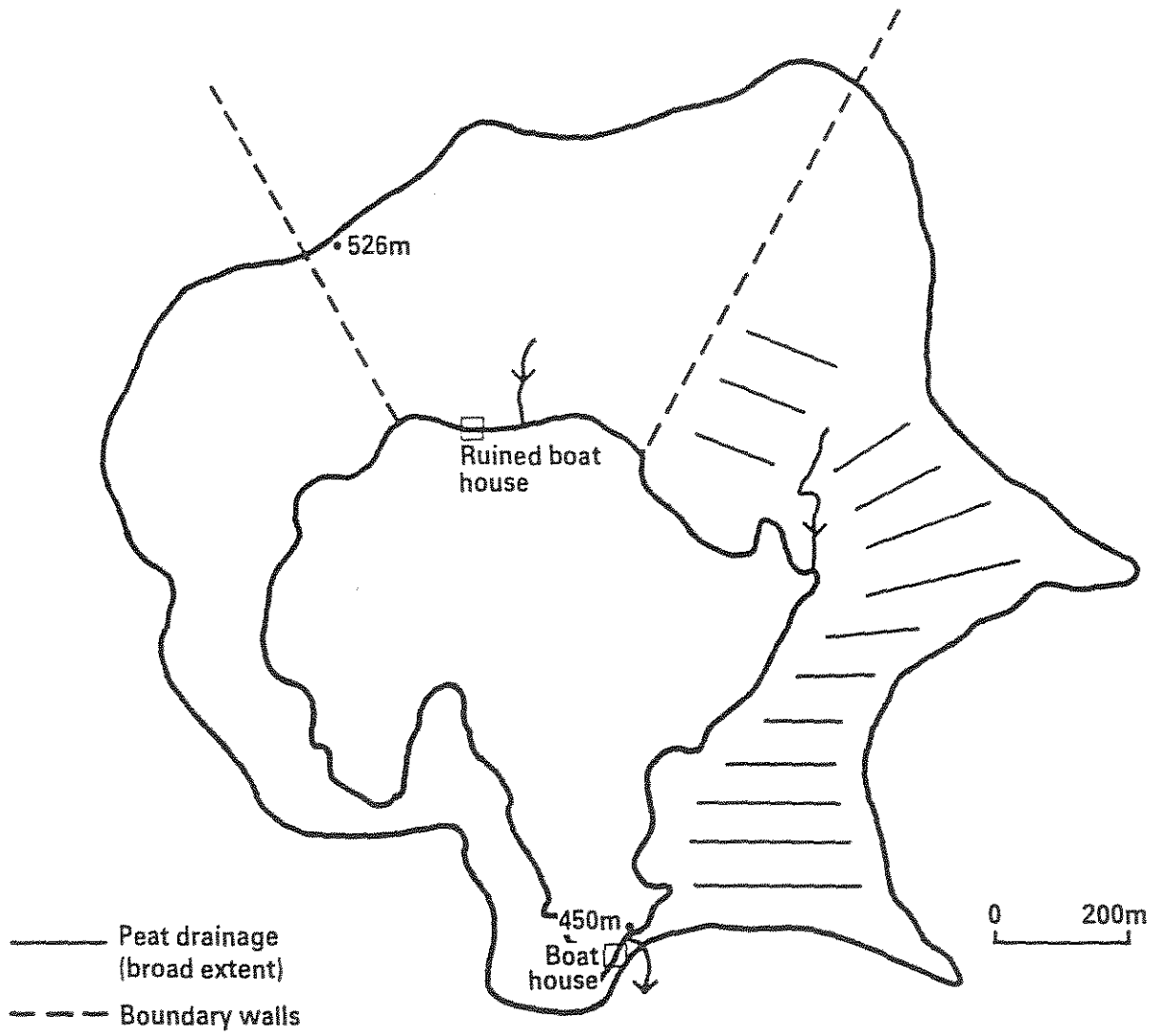
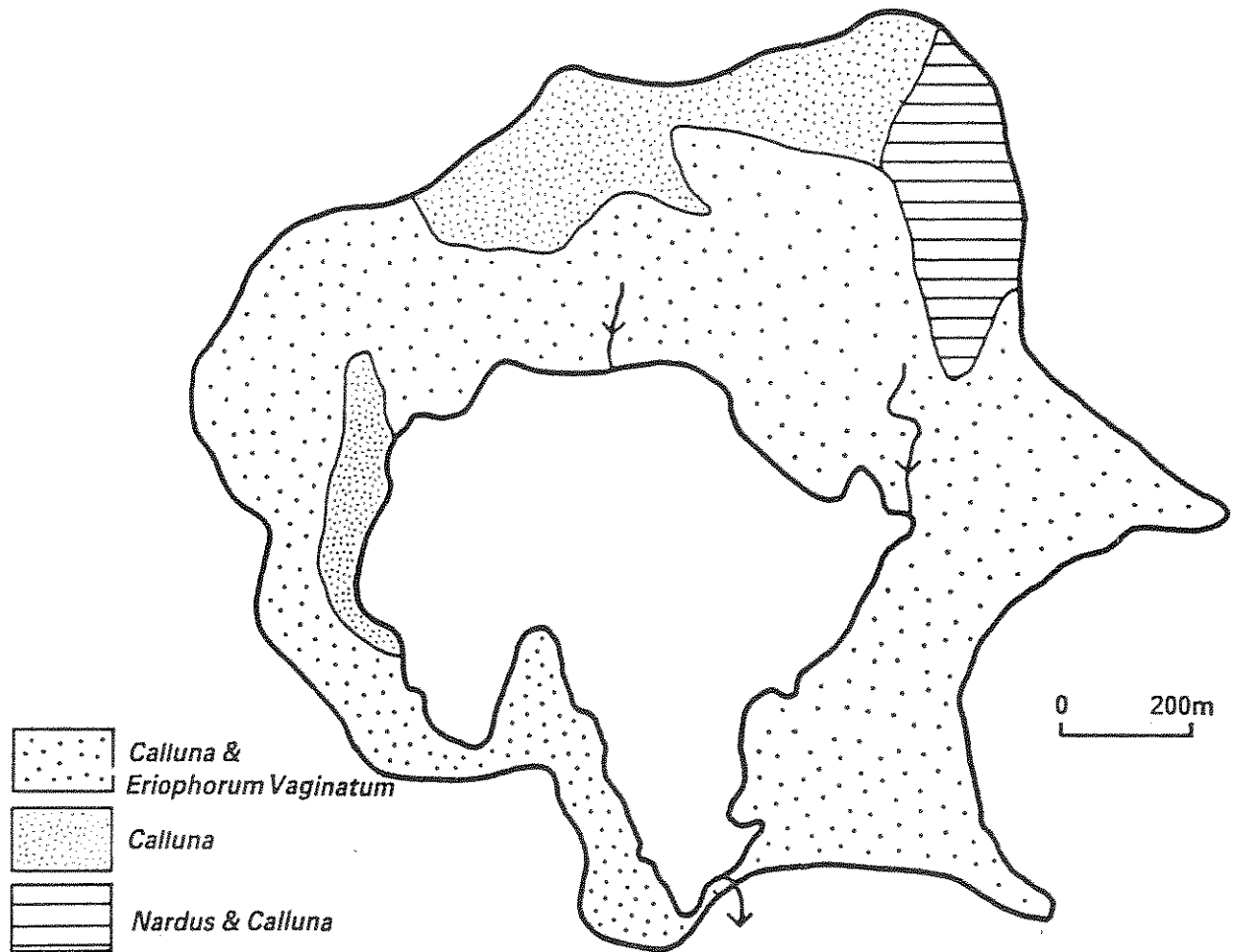


Fig. 4. LLYN CONWY, CATCHMENT VEGETATION



2.2 Llyn Gamallt

2.2.1 The lake

Llyn Gamallt comprises two rock basin lakes - Gamallt Fawr (lower lake) and Gamallt Bach (Upper lake) linked by a short connecting stream (Fig. 6). The lakes lie to the west of the Migneint plateau immediately below the Graig Goch Ridge, some 5 km north-west of Ffestiniog. The lake system lies at an altitude of 465 m in an area which receives an annual rainfall in excess of 2000 mm. The combined lake surface area is 13 ha (Table 2). The bathymetry of the lower lake (Fig. 5) must be considered only an approximation owing to technical problems encountered in the field. The upper lake comprises four small sub-basins in excess of 3 m offset to the east of centre (Fig. 5). The upper lake has a maximum depth of 5.3 m, a mean depth of 1.5 m and a volume of 41.694 m³ (Table 2).

Apart from the connecting stream no discrete streams enter the lake system. Afferent drainage comprises many channels some of which are supplied by natural pipe formations in the peat, some are spring-fed channels flowing mainly through boulder scree and others are artificial (see Section 4.2.1) (Milner and Jones 1985). The lower lake is drained by a single outflow (Afon Gamallt) at its south-western extremity (Fig. 6).

The water quality of Llyn Gamallt is monitored by the WWA. The lakes are very acid (pH 4.5) with an alkalinity of 6.3 ueq l⁻¹. Calcium levels averaged 40 ueq l⁻¹ and aluminium 16.0 ueq l⁻¹ (Milner and Jones 1985).

Aquatic vegetation is not well developed in the lakes. The clear water and stoney substrate supports Nardia compressa, Littorella uniflora and Lobelia dortmanna. There is no emergent vegetation in Gamallt Bach but along the shore of Gamallt Fawr small areas of Carex rostrata and Glyceria sp. occur in the bays (Alexander and Lutley 1981).

2.2.2 The catchment

Llyn Gamallt has a catchment of 55.47 ha (excluding the lake) giving a lake catchment:lake ratio of 4.26 (Table 2). The high craggy ridge and screes of Graig Goch (Maximum altitude 588 m) dominate the north and east of the catchment, with less rugged peat covered terrain to the west.

Detailed geological mapping of the catchment is not yet available but surveying is in progress nearby (R. Bazely pers. comm.). In general, thinly bedded Ordovician and Silurian mudstones and shales dominate the catchment geology with occasional outcrops of Ordovician volcanics. A well defined exposure of these volcanics runs along the south shore of the upper lake (Alexander and Lutley 1981). Drift geology is almost entirely absent (Milner and Jones 1985).

Soils of the catchment are dominated by acid humic rankers belonging to the Bangor association (311e). In addition, large areas of the lake catchment are covered in deep blanket peat belonging to the Winterhill soil association series.

The vegetation of the area has been well mapped (Alexander and Lutley 1981). Briefly, Calluna vulgaris dominates the catchment (Fig. 7) often overlying

the deep blanket peats. There is a partial understorey of Vaccinium myrtillus and Empetrum nigrum. Interspersed tussocks of Eriophorum vaginatum and Juncus squarrosus form ca. 25% of the cover and create a hummocky structure. A luxuriant Sphagnum lawn acts as an understorey to most of these communities. To the south of the lakes the heath vegetation grades into a grassy heath dominated by Festuca ovina and Deschampsia flexuosa.

Table 2 Llyn Gamallt, lake and catchment characteristics

Lake

Altitude 465 m
 Surface area (combined) 13 ha
 Maximum depth (upper lake) 5.3 m
 Mean depth (upper lake) 1.5 m
 Volume (upper lake) 41,694 m³

Bathymetry of the lower lake is considered unreliable (see Section 2.2.1)

Catchment

Maximum altitude 588 m
 Area (excluding lakes) 55.47 ha
 Catchment:lake ratio 4.26

Fig. 5. LLYN GAMALLT, BATHYMETRY

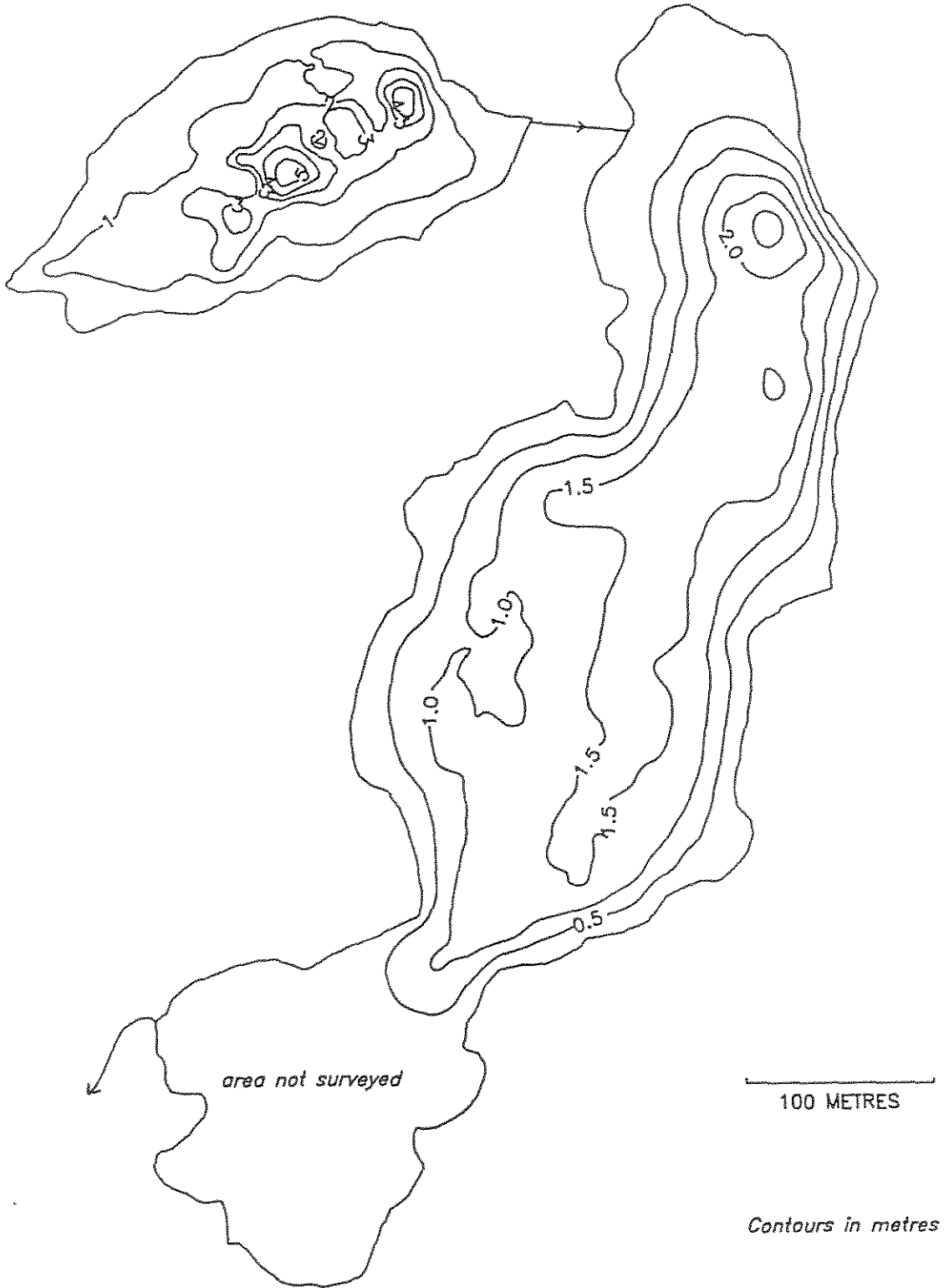


Fig. 6. LLYN GAMALLT, CATCHMENT

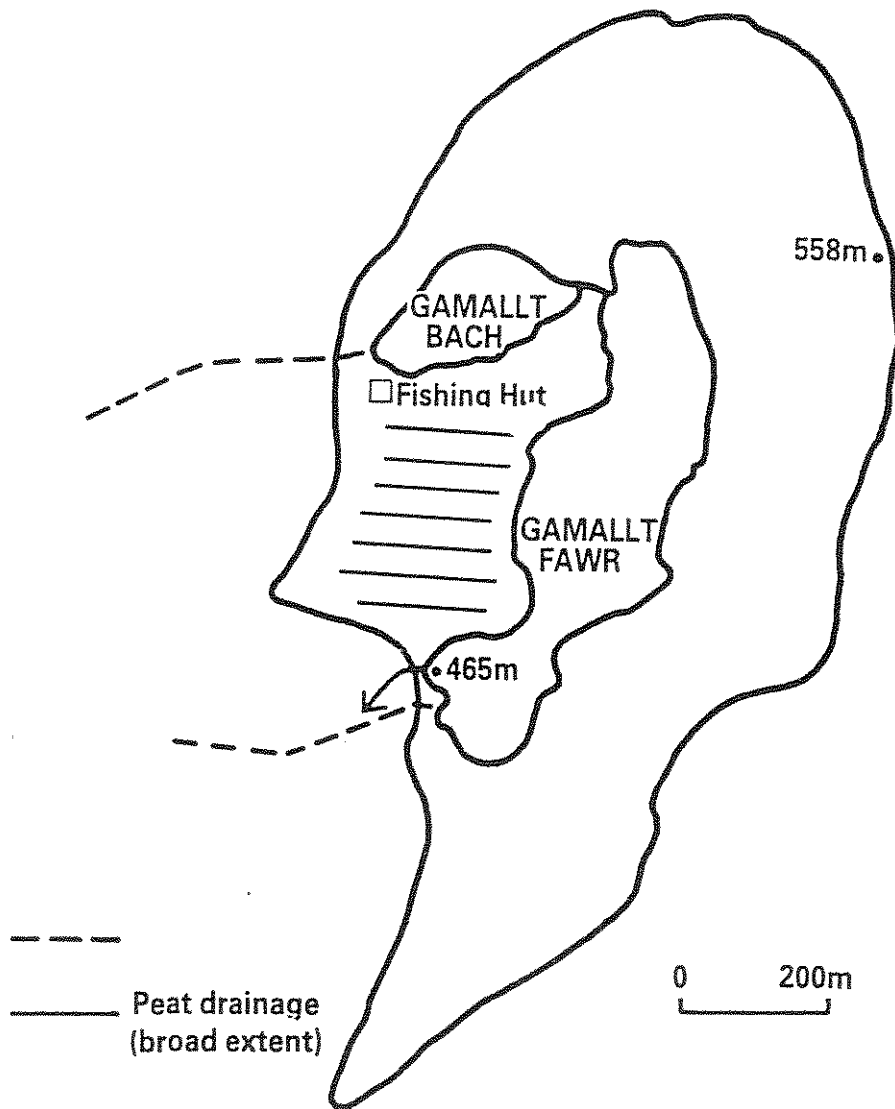
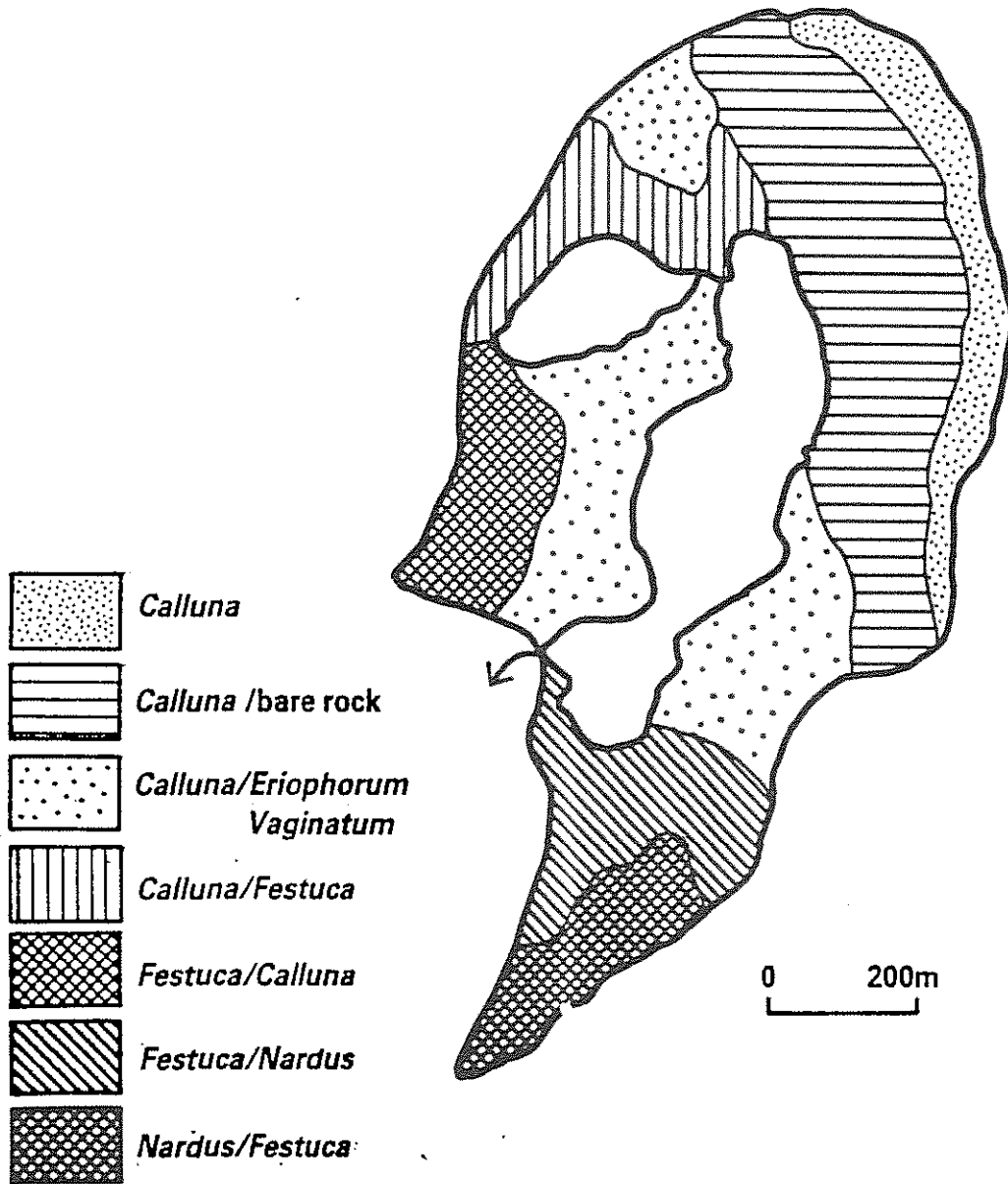


Fig. 7. LLYN GAMALLT, CATCHMENT VEGETATION,



3.0 Fishing Histories

3.1 Llyn Conwy

In the 1950s Llyn Conwy was regarded as the best brown trout lake in Snowdonia (Jones 1984). Since the early 1960s a major decline in the natural population has been observed to the extent where fishing is now only maintained by stocking with adult brown trout (Jones 1984, Milner and Jones 1985).

The lake and fishing in it were granted to the Penrhyn family by a deed from the Crown of 1686 (1). Before 1836 the fishing was not preserved and was effectively 'free'. However, when the Mostyn family obtained the fishing rights for a ten year period from 1836 they constructed a small boat house and preserved the fishing barring it to unauthorised anglers (2). The lake reverted to the Penrhyn estate in 1846 which maintained a policy of private fishing. In the 1930s Llyn Conwy was the only lake on the Penrhyn estate in Snowdonia where free fishing was not permitted (Ward 1931).

Llyn Conwy had a long established reputation as a good trout fishery. During three visits (1797, 1801, 1810) Colt Hoare reported that the lake abounded with good quality trout and reckoned it to be one of the best trout fisheries in Wales (Thompson 1983).

Cliffe (1860) recorded that Llyn Conwy was a 'fine pool' where there was sometimes 'excellent sport'. Black (1886) described the lake as being well stocked with fish. Ward (1931) reported 'large numbers of trout' that averaged 0.5 lbs in weight.

The decline in fish stock from the 1960s was accompanied by an increase in the average weight of those trout that were caught from 150-200 g in the 1950s to 500-600 g in the 1970s (Jones 1984, Milner and Jones 1985). This phenomenon is considered to be in accord with a decline in natural recruitment.

In 1978 the Llyn Conwy Flyfishers Club was established and a programme of annual stocking instigated (Table 3). Only continued stocking has maintained a viable fishery in the lake. An angling catch survey in 1984 (Milner and Jones 1985) revealed high catch rates of 4.86 and 2.74 fish per visit in the early and late seasons respectively.

A netting and electrofishing survey by the WWA confirmed the low level of natural recruitment (Milner and Jones 1985). The low pH values in association with low calcium concentrations (less than 50 $\mu\text{eq l}^{-1}$) are below the level conventionally regarded as lethal to salmonids. Jones (1984) reported that yolk sac fry and sea trout alevins soon died when introduced to the lake. Monitoring of stocked fish revealed a short term physiological response to the new environment which Milner and Jones (1985) attributed to mild acid stress.

Jones (1984) observed that the area of stream available as a nursery habitat for potential lake recruits is small (0.003 km^2) and that it is unlikely that obstruction to and from the stream, owing to lake drawdown, has been

responsible for any recruitment failure.

3.2 Llyn Gamallt

The Gamallt lakes are fished by the Cambrian Angling Association and were once considered among the best of the association's lakes (G. Williams pers. comm.). However, declining catches, first reported in 1961, have continued to the present day so that very few adult trout remain in the lake and there is no natural breeding.

In 1801 Colt Hoare drew a distinction between the larger, red fish of the upper lake and the smaller, white, 'bad' fish of the lower lake (Thompson 1983).

Ward (1931) considered Llyn Gamallt to be one of the best lakes in the region yielding fine quality trout of between 1-3 lbs. A boat was maintained on each lake and a fishing hut (still extant - Fig. 6) on the southern shore of the upper lake.

Much of the lake system was Crown property and fishing was effectively 'free' but a portion of the upper lake was privately owned. At one stage ownership was in the hands of the Casson family who had a reputation as experimental fish breeders (G. Williams pers. comm.). The first edition six inch Ordnance Survey map of 1887 (3) portrays two 'fish ponds', one between the lakes, the other at the outflow of the lower lake. The validity of this description is uncertain (it does not appear on subsequent Ordnance Survey editions). However, it is possible that these 'ponds' represented an early attempt to stock and/or manipulate the Gamallt fishery.

The first recorded stocking of the lakes was in the early 20th century when Loch Leven trout were introduced (Ward 1931). Since 1954 the lakes have been regularly stocked with brown trout (4) (Table 3). From the 1960s such stocking has met with increasingly limited success.

An angling catch survey in 1983 (Milner and Jones 1985) revealed a low catch rate in both first (0.41 fish per visit) and second (0 fish per visit) halves of the season. A similar survey in 1984 revealed no catches in 10 declared visits.

Results of the angling surveys were confirmed by a WWA netting and electrofishing exercise (Milner and Jones 1985). The few adult fish remaining were relatively large indicating an absence of natural breeding within the lake. Stocked fish were observed to experience a severe response to the acid conditions with total mortality within 48 hours.

In addition to stocking, the Cambrian Anglers Association made further (unsuccessful) attempts to improve the fishery by liming (2 tons in 1974) and fertilising (0.5 ton in 1976) the lakes (G. Williams pers. comm.).

Table 3 Stocking History of Llyns Conwy and Gamallt.
(From Milner and Jones 1985)

Year	<u>Gamallt</u>		<u>Conwy</u>	
	<u>fry</u>	<u>3-5"</u>	<u>fry</u>	<u>3-5"</u>
1950				
1951				
1952				
1953				
1954		2,000		
1955	4,000			
1956				
1957				
1958	3,000			
1959	16,000			
1960	13,000			
1961	16,000			
1962	20,000			
1963				
1964	10,000			
1965				
1966		250		
1967	12,000	4,340		
1968		186		
1969		560		
1970		576		
1971		180		
1972		80		
1973				
1974	2,000			
1975		2,920		
1976		1,820		
1977				
1978			15,000	5,000 (+1,000 6-9")
1979				5,000 (+1,000 6-9")
1980		2,500		5,000
1981				3,500
1982	25,000			3,500
1983				3,500
1984				2,000

3.3 Fishery decline: appraisal

Decline of the fisheries dates from the early 1960s in both Llyns Conwy and Gamallt. In Llyn Gamallt natural recruitment has ceased and occurs only at a very low level in Llyn Conwy. In terms of fishery status Llyn Gamallt is virtually a dead lake, while Llyn Conwy functions solely as a 'put and take' fishery.

Milner and Jones (1985) concluded that declining recruitment in these lakes has not resulted from over-exploitation by for example, angling, poaching or broodstock collection. Siltation of spawning beds has not been observed at either site.

The effect of water level drawdown in Llyn Conwy is uncertain. Reduced trout growth as a result of littoral fauna depletion consequent upon drawdown was not observed (5). However, Milner and Jones (1985) consider that the effect of drawdown on the invertebrate population of Llyn Conwy presents a potential impact that deserves further investigation.

Cage toxicity experiments with trout fry in both lakes confirmed that acid water conditions account for the low level or absence of natural recruitment. Most mortality was ascribed to pH toxicity compounded with low calcium levels rather than the action of aluminium (Milner and Jones 1985).

The history of stocking (particularly in Llyn Gamallt - Table 3) may have exacerbated the demise of natural recruitment. Milner and Jones (1985) suggest that the interbreeding of hatchery strains with wild populations could have led to a gradual loss of acid resistance and possibly other fitness traits, in subsequent generations.

4.0 Land use and management (6)

4.1 Land use

The catchments of Llyns Conwy and Gamallt lie at over 400 m on peats and acid soils that comprise unimproved moorland utilised for rough grazing and game shooting. In terms of vegetational composition (see Sections 2.1.2, 2.2.2) the catchments may be categorised as 'shrubby heath' (eg. King 1977, Ball et al. 1982).

In terms of the ADAS (7) Land Capability Classification the catchments comprise land of the categories H3 - 'improvements generally severely limited but of moderate or high grazing value' (Conwy and Gamallt) and H4 - 'generally not improvable and of low grazing value' (Gamallt) (MAFF 1980).

Both catchments are predominantly unenclosed. Two boundary walls at the north of Llyn Conwy (Fig. 3) were constructed in the 1870s to delimit local sheepwalk boundaries (8). The western side of the Llyn Gamallt catchment is broadly enclosed with stone walls (Fig. 6). This 'enclosure', set within unenclosed moorland, is of some antiquity, dating from before 1784 (9). Although enclosure allows stock numbers to be controlled within a defined area and may thus be utilised as a means towards land improvement (Patrick 1986), there is no evidence to suggest that 'enclosed' land in the Conwy and Gamallt catchments was managed so intensively as to upgrade the moorland vegetation.

Areas of artificial peat drainage exist in both catchments (see Sections 4.2.1, 4.2.2). At both sites drainage was to manipulate the quality of indigenous Calluna and did not represent an attempt to alter the vegetation type.

There is no likelihood that any attempt was made to improve the acid moorland with lime. North-west Wales is almost entirely devoid of limestone deposits and in the 19th century the high price of imported lime together with the cost of carriage over poor roads, ensured that it was rarely used in remoter areas (Davies 1813) (10).

The Penrhyn Estate managed most of the Llyn Conwy catchment and part of the Llyn Gamallt catchment through much of the 19th and early 20th centuries. The estate was at the forefront of agricultural improvement in Wales (eg. Davies 1813, Royal Commission 1896, Williams 1941) and accounts and papers (11) indicate that lime was regularly used on arable and permanent pasture of the demesne and tenant farms (the estate possessed its own lime kiln). However, there is no evidence within the records of the Penrhyn Estate (12) to suggest that lime was used on high, rough grazing land.

Contemporary farmers (eg. G. Davies, R. Davies, P. Rowlands, T. Williams pers. comms.) and authorities (eg. J. Aylett, B. Crighton pers. comms.) confirm that agricultural lime has not been applied to the catchments in living memory.

Llyn Gamallt lies immediately east and south of an extensive slate quarrying region. The slate deposits of the catchment were mapped in the 19th century (13), but there is no evidence that slate was ever quarried within the

catchment. Similarly although there is cartographic evidence (14) of trials for lead and copper immediately to the west, but outside of, the catchment (cf. Alexander and Lutley 1981), there is no evidence of the exploitation of lead or any other mineral within the catchment.

There is no evidence for the exploitation of any mineral within the Llyn Conwy catchment. An old slate quarry and lead trials lie some 0.5 km outside the catchment to the north east.

4.1.1 Documentary sources (15)

A series of estate papers from the late 18th through the 19th centuries, relating primarily to questions of land ownership/tenure (16), grazing rights (17) and sporting rights (18), confirm (often incidentally) that during this period the Llyn Conwy and Llyn Gamallt catchments comprised unimproved moorland.

The tithe map and schedule of Ffestiniog (19) indicates that in the mid-19th century the catchment of Llyn Gamallt comprised sheepwalk land. The tithe map and schedule of Penmachno (20) distinguishes between areas of 'old pasture' (presumably rough grazing - cf. Morgan 1959, Patrick *et al.* 1986, Stevenson *et al.* 1987) and 'common'.

The immediate vicinity of Llyn Gamallt does not feature greatly in contemporary travellogues. But such works emphasise the unimproved nature of the land surrounding Llyn Conwy. Colt Hoare described the lake as lying in a "most barren and dreary waste" (1810) (Thompson 1983). In the same year Pennant (1810) recorded the "dismal" situation of the lake, "situated among rock and bog". Black (1886) noted that access to Llyn Conwy was hampered by surrounding bogs.

The first and subsequent editions of the six inch Ordnance Survey maps of the areas (21) show the catchments to consist of 'rough or heathy pasture'.

The first Land Utilisation Survey six inch manuscript maps of 1933 (22) place both catchments in the 'moorland/rough grazing category. The second Land Utilisation Survey six inch manuscript maps of 1970 (23) indicate a vegetation cover and distribution that is very similar to the present situation (see Sections 2.1.2, 2.2.2, Figs 4, 7).

A copy of the 'Grassland Survey' field map (1:63,360) of the Llyn Conwy region reproduced in Davies (1936) depicts cotton grass (Eriophorum vaginatum) as dominating the catchment. This contrasts with the dominance of Calluna as seen today and recorded in 1970 (see above). Whether this represents a regeneration of Calluna at the expense of Eriophorum vaginatum since the 1930s, or is the result of an insufficiently rigorous survey in the 1930s, is not known. However, evidence from the literature (ITE 1978, Mather 1983) suggests that where Eriophorum vaginatum succeeds Calluna as a result of decreased burning/grazing, the transition occurs over a period of centuries rather than decades.

Both catchments lie within the north Snowdonia National Park region that was studied in the Moorland Change Project of Parry *et al.* (1982). Analysis of original project data (24) confirmed that the Llyn Conwy and Gamallt catchments have experienced no change in land use since at least 1887.

4.2 Land management

4.2.1 Pastoralism

Until the mid-19th black cattle were still an important component of the pastoral economy of north Wales. Goats still ranged the hills as did young ponies (Evans 1812, Roberts 1959, Emery 1965, Hughes *et al.* 1973). The relative importance of cattle: sheep: goats is a matter of some uncertainty, but by the mid-19th century the central issues of pastoral management in moorland areas concerned their utilisation for sheep grazing (Patrick 1986).

Enclosed 'ffridd' land immediately below the open moorland often provided grazing for sheep in winter and cattle in summer. The enclosed area to the west of Llyn Gamallt (Fig. 6) is known locally as 'Ffridd Gamallt'. Surrounded by open moorland, it is doubtful whether this area functioned as true ffridd land. At an altitude in excess of 400 m, it is unlikely that a suitable habitat was available for cattle in summer (cf. Kay 1794, Williams 1932), or that it provided any great advantage over the open moorland for sheep in winter.

In the early 19th century Hyde Hall reported that cattle in Penmachno parish were sometimes grazed above the ffridd in summer (Caern. Hist. Soc. 1952). However, local farmers (eg. G. Davies, R. Davies, T. Williams *pers. comms.*) suggest that the Llyn Conwy catchment would have been too wet and exposed for cattle.

While the Penrhyn Estate had an interest in the Llyn Conwy catchment, particularly from the mid-19th - mid-20th centuries, sheep grazing was secondary to the exploitation of game (see Section 4.2.2). A sheepfold (now demolished) depicted on the Ordnance Survey six inch map of 1891 (absent on subsequent editions) at the eastern edge of the lake is evidence of the presence of sheep on the catchment in the 19th century.

For a period from the mid-1950s - mid-1960s when the active control of the Penrhyn Estate had diminished and land in the Llyn Conwy catchment was being transferred to the National Trust in lieu of death duties, continued burning of Calluna for grouse (see Section 4.2.2) encouraged tenant farmers to increase sheep numbers on the catchment (25). However, although in 1968 the Trust decided to encourage sheep at the expense of grouse on the catchment (26), an associated 'ban' on burning (see Section 4.2.2) proved a disincentive to increase sheep numbers.

Sheep grazing on the Llyn Gamallt catchment is effectively confined to the north-western - south-eastern sector. The northern and eastern slopes being too rocky and precipitous.

It is possible that a derelict structure at the outflow of the Llyn Gamallt Fawr is an old pen positioned to permit the washing of sheep in the lake prior to shearing (B. Crighton *pers. comm.*) (cf. Fritz *et al.* 1986b, Patrick *et al.* 1987). However, it is not described as such on any Ordnance Survey map.

An area immediately to the west of Llyn Gamallt Fawr was drained during the 1940s (27) to reduce the saturation of the peat and encourage healthier

stands of Calluna (B. Crighton, P. Rowlands pers. comms.) for grazing sheep. The drains were deep and narrow and although they have not been maintained they comprise an active network of drainage to the lake (see Section 2.2.1).

The Llyn Gamallt catchment was regularly burnt in broad patches by tenant farmers until the late 1960s. Aerial photographs taken in 1946 (28) clearly indicate mosaics of vegetation of different ages. National Trust policy to curtail moorland burning has resulted in the western sector of the catchment remaining unburnt for 15 years. The remainder of the catchment is now only infrequently burnt (P. Rowlands, G. Williams pers. comms.). The long and woody nature of the Calluna that dominates the catchment may be attributed to the lack of burning and concomitant low grazing pressure.

The only quantitative data relating to sheep numbers in the vicinity of the Llyns Conwy and Gamallt catchments are those of the annual parish agricultural returns of Penmachno and Ffestiniog (29) respectively. These were analysed at quinquennial intervals and are presented in Fig. 8.

Although they represent the source of information most applicable to the catchments in question, the spatial resolution of these data do not permit catchment-specific assertions to be drawn and their interpretation is hindered by several other constraints. In particular they take only a limited account of changes in sheep type and no account of changes in grazing regime (Patrick 1986).

In both parishes sheep numbers fluctuated before a general increase from the 1950s (Fig. 8). This increase has not been realised within the Llyns Conwy and Gamallt catchments where farmers have recognised a decrease (Conwy) or little change (Gamallt) (G. Davies, R. Davies P. Rowlands, T. Williams pers. comms.).

A change in grazing regime has been apparent from the second half of the 19th century. The transition from hardy wethers to ewes and lambs (cf. Fig. 8), the declining viability and eventual abandonment of many hill farms and the greater availability of winter grazing on lower land, has resulted in fewer sheep over-wintering on the high hills and a shortening of the grazing season at these altitudes (Patrick 1986).

National Trust records (30) show that by 1961 the Llyn Gamallt catchment was utilised for summer grazing only and that although grazing leases placed no limit on sheep numbers, the land would support little more than 2.5 sheep ha⁻¹. No sheep over-winter on the Llyn Conwy catchment (G. Davies, R. Davies, T. Williams pers comms.).

Manipulation of data relating to sheep numbers (Fig. 8) and area of rough grazing from the parish statistics, permit the calculation of a crude trend of changing stocking densities on unimproved land in the Llyns Conwy and Gamallt localities (Fig. 9). These trends are not catchment specific and they assume that all sheep are turned on to the hills (not an unreasonable assumption in summer). Furthermore, they take no account of the changing impact on grazing intensity consequent upon the replacement of larger wethers by ewes and lambs.

The grazing densities indicated in Fig. 9 would appear too high for the catchments in question. Certainly there is no suggestion of an increase in stocking intensity from the 1950s in either catchment.

Fig. 8. SHEEP NUMBERS IN FFESTINIOG AND PENMACHNO 1867-1983

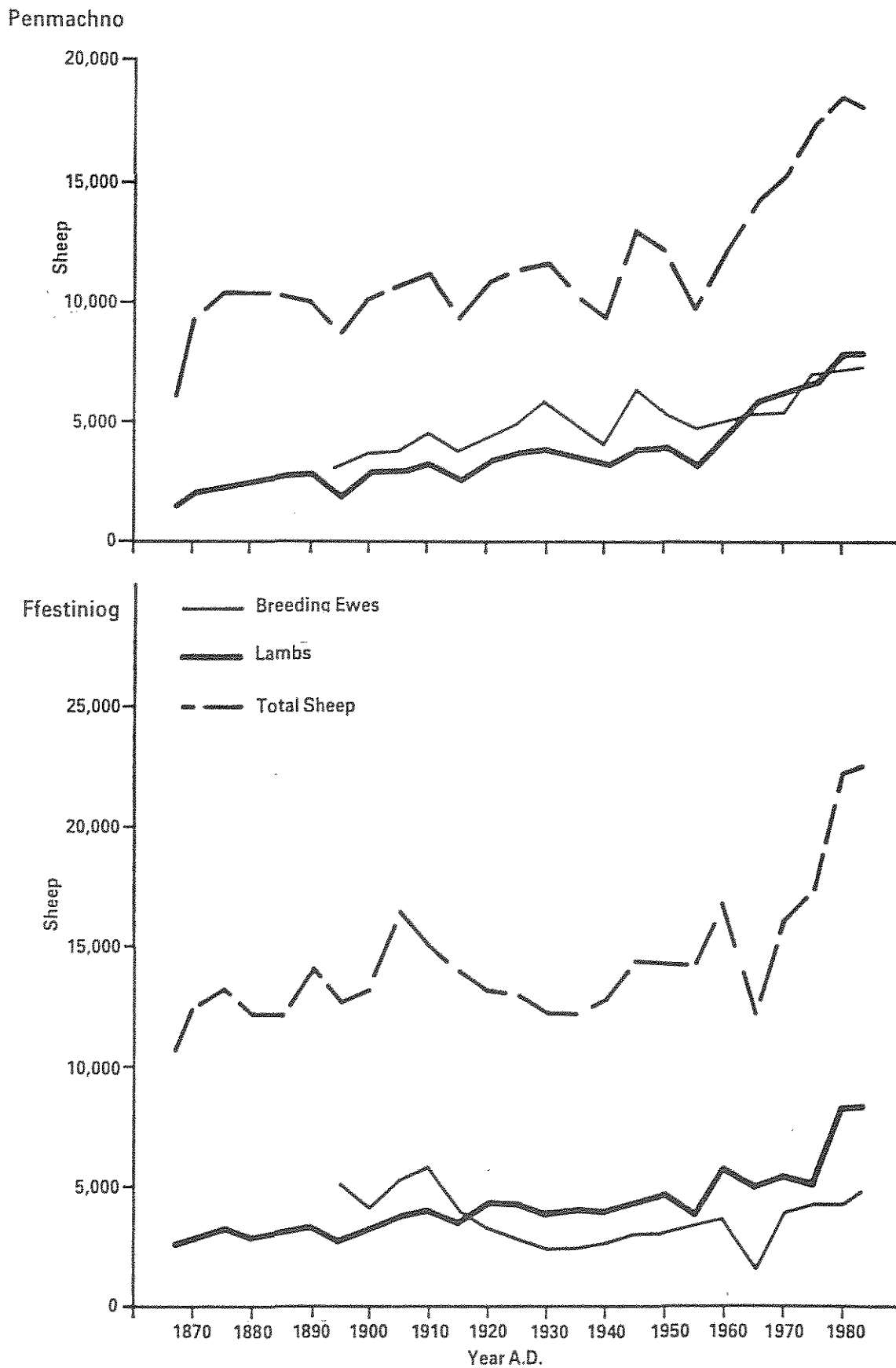
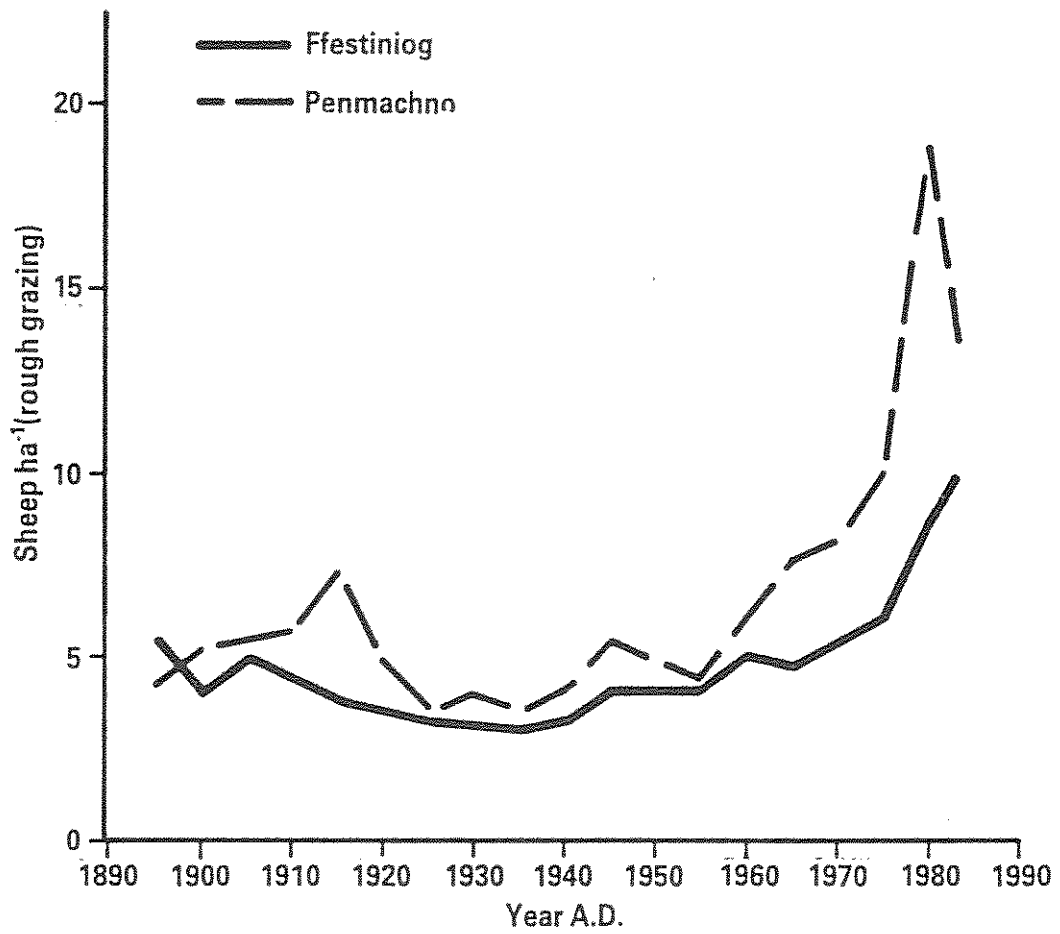


Fig. 9. CRUDE STOCKING DENSITY SHEEP HA⁻¹ ROUGH GRAZING IN FFESTINIOG AND PENMACHNO 1895-1983



4.2.2 Management for game

Llyn Conwy

The Llyn Conwy catchment was part of an area highly prized as a game moor by the Ystbytty (Penrhyn) (31) Estate and actively managed (primarily for grouse) by gamekeepers of the estate (and later the 'Ystbytty Shoot') until ca. 1970. Many of the 19th century disputes over land in the area centred upon ownership and tenancies of sporting rights (32).

The peat of the eastern slopes of the catchment was drained (Fig. 3) during the 1920s in an attempt to provide healthier Calluna stands for grouse. The drains were periodically serviced until ca. 1970 (33).

The catchment was regularly burnt in strips or small patches to yield Calluna stands of varying maturity providing both nutrition and shelter for grouse. Air photographs taken in 1946 (34) show a mosaic of burnt vegetation throughout the catchment. Burning effectively ceased in the catchment ca. 1970 as a result of National Trust policy (see Section 4.2.1), the designation of the area as part of the Migneint SSSI (1971) and the proximity of maturing forest some 1.5 km to the north-east and 1 km to the north-west.

Game bags (particularly grouse) declined steadily in the area from ca. 1940. Gamekeepers no longer regularly patrolled the moor so vermin increased and burning became less frequent. With the cessation of burning and active management from ca. 1970 shooting over the catchment has become very infrequent (35).

Llyn Gamallt

The Ystbytty Estate had direct control over game in the western sector of the catchment (until the area was transferred to the National Trust in the early 1960s) and leased the sporting rights on the Crown common that comprises the remainder of the catchment (36).

Editions of the Ordnance Survey six inch map of the catchment describe the fishing hut on the shore of the upper lake as a 'shooting box'. Milner and Jones (1985) suggest that the catchment was burnt for grouse. However, there is no evidence to suggest that the Llyn Gamallt catchment was managed for game as intensively as that of Llyn Conwy.

4.2.3 Subsidiary management practices

There is documented evidence of peat cutting on sheepwalks and common land in Penmachno (37) and on moorland on the Ystbytty Estate (38). However, there is no indication from documentary sources, or on the ground, that peat in the Llyn Conwy and Gamallt catchments was ever exploited as a turbarry.

5.0 Discussion

It has been conclusively shown that the acidification of Llyns Conwy and Gamallt cannot be accounted for by any change in land use within their catchments. Potentially significant land management changes have, however, occurred in both catchments.

Both catchments had a history of regular burning of their moorland vegetation (primarily for grouse at Llyn Conwy and sheep at Llyn Gamallt). In both catchments burning practically ceased from ca. 1970 with the result that the dominant Calluna vegetation has developed into mature, woody stands. The regeneration of acidic heathland species such as Calluna is a cornerstone of Rosenqvist's (1978, et al. 1980) explanation of acidification through changing 'land use'. However, as Milner and Jones (1985) observe, the acidifying effects of Calluna growth are uncertain and in any case Calluna 'regeneration' through the cessation of burning occurred some years after fishery decline was well established.

Potential acidifying effects may stem from excessive as opposed to a cessation of burning. Rose (1984) observed that several areas of surface-crusted (and potentially erodible) peat on the Migneint Plateau (including areas in the Llyn Conwy catchment) may have resulted from a history of over-burning. Peat erosion is apparent within the Llyns Conwy and Gamallt catchments.

Both catchments include areas of peat drainage. Gorham et al. (1984) and Hornung (1984) have shown that the washout of sulphate that is formed by oxidation in dry weather, is a natural acidification mechanism in peatlands. Milner and Jones (1985) demonstrated that the process was operative in the Llyn Gamallt catchment. However, while recognising that artificial drainage could enhance this process, Milner and Jones (1985) were uncertain that the small-scale drainage to the west of Llyn Gamallt Fawr was sufficient to cause a significant pH change in the lake. They further observed that Llyn Gamallt Bach which receives no artificial peat drainage, has a chemistry similar to the lower lake.

Milner and Jones (1985) consider it unlikely that artificial drawdown of Llyn Conwy and resultant redox reactions in the exposed peat has been responsible for the acidification of the lake. However, the temporal coincidence between reservoiring the lake (1957) and the onset of fishery decline (ca. 1960) may indicate a causal relationship.

The subjective observation of fishery decline is not a suitably stringent measure of the onset and development of acidification. If it were, the drainage of peat around Llyns Conwy and Gamallt Fawr and the reservoiring of Llyn Conwy could not be totally dismissed as insignificant to the acidification process.

For a full assessment of the significance of the changing management practices observed in both catchments it is necessary to assemble a more rigorous reconstruction of lake water quality through time. The palaeolimnological techniques of diatom, metals, soot particle and magnetic analyses performed on dated lake sediment cores provide that rigour.

Of the 10 lakes in Wales studied under DOE contract PECD 7/7/139 none possess such well documented and potentially significant catchment history

as Llyns Conwy and Gamallt. Unfortunately the sediments of these lakes are distributed in a complex manner and defy simple single core analysis. A programme of sediment mapping and subsequent (multi) coring is required to furnish a suitable palaeoenvironmental record.

Notes

1. NLW, Penrhyn papers, 2495. Correspondence.
2. NLW, Penrhyn papers, 2930. Papers relating to sporting rights in Ffestiniog and Penmachno, ca. 1830-1860.
3. Ordnance Survey six inch, first edition. Surveyed 1887, published 1891.
4. 1000 rainbow trout were introduced in 1964 (Milner and Jones 1985).
5. Drawdown typically takes the form of a single gradual summer lowering of water level, rather than periodic fluctuations throughout the year (Milner and Jones 1985).
6. For a definition of these terms see Patrick (1986).
7. ADAS: Agricultural Development Advisory Service (MAFF).
8. NLW, Penrhyn papers, 1806. Letter book.
9. Caernarvon Record Office, XDB/4/1290. Map of an estate belonging to Mr John Williams situated in the parish of Ffestiniog, surveyed by J. Griffith 1784.
10. The lack of improvement of land in Penmachno was partly attributed to the expense of lime in the mid-19th century by the tithe commissioners. (Penmachno tithe file, PRO (Kew), IR 18 14152).
11. eg. NLW, Penrhyn papers, 1961. Accounts for 1865.
NLW, Penrhyn papers, 2321. Articles of agreement relating to the tenancy of Penbedw, 1833.
12. Held at NLW, Bangor.
13. Caernarvon Record Office, X/BJC/1, X/BJC/6. Plans and sections of Gamallt slate property in the parish of Ffestiniog (undated).
14. eg. NLW, Penrhyn papers, 2917-2922. Maps of common and sheepwalks in the parishes of Penmachno and Ffestiniog, 1855.

NLW, Penrhyn papers, 2935. Map of Crown sporting rights in Ffestiniog, 1862.

Ordnance Survey six inch, first edition. Surveyed 1887, published 1891.
15. See Patrick (1986) with regard to sources and their interpretation utilised in documenting land use and management history.
16. eg. NLW, Penrhyn papers, 2383-2395. Papers relating to the conveyancing of Pen y Bont and Oernant properties to the Penrhyn Estate, 1867-1868.

NLW, Penrhyn papers, 2360-2361. Papers relating to the sale of Carrog farm, 1862.

NLW, Penrhyn papers, 2323. Papers relating to the conveyance of Penbedw, 1846.

Caernarvon Record Office, XDB/4/1290. See note 9.

17. eg. NLW, Penrhyn papers, 2917-2922. See note 14.

NLW, Penrhyn papers, 2916. Map of Crown waste lands in the parishes of Beddgelert, Llanfrothen, Ffestiniog and Penmachno, 1855.

NLW, Mostyn papers, 8518. Map of part of Eidda Manor (undated).

18. eg. NLW, Penrhyn papers, 2374. Lease of game and shooting rights in or on lands including Pen y Bont and Oernant, 1858.

NLW, Penrhyn papers, 2344. Lease of sporting rights on or over Carrog (and other farms), 1856.

NLW, Penrhyn papers, 2930. See note 2.

NLW, Penrhyn papers, 2935. See note 14.

19. NLW. Tithe map and schedule of Ffestiniog, 1842.

20. PRO (Kew), IR 30/46/61. Tithe map and schedule of Penmachno, 1839.

21. Llyn Conwy: First edition surveyed 1887, published 1891.
Second edition revised 1899, published 1901.
Third edition revised 1910, published 1920.
Provisional edition revised 1949, published 1953.

Llyn Gamallt: First edition surveyed 1887, published 1891.
Second edition revised 1899, published 1901.
Third edition revised 1912, published 1920.
Provisional edition revised 1949, published 1953.

There has been no 25 inch survey in either area.

22. Held at the London School of Economics archive.

23. Held at King's College London, Geography Department. Sheet no. 552 (both catchments).

24. Field data accessed on computer files and 1:25,000 maps at University of Birmingham, Geography Department.

25. National Trust, Llandudno, correspondence file YSB/ES/2.

26. See note 25.

27. The precise date of drainage is unknown. Milner and Jones (1985) suggest it occurred between 1939-1945. However, the drains do not appear on aerial photographs taken in 1946 (see note 28). B. Crighton (pers. comm.) suggests that the drains were excavated after 1945.

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28. Air Photograph Office, Welsh Office, Cardiff. 1:10,000, 279/3187, 279/3188, May 7th 1946.
 29. PRO (Kew), Class MAF 68.
 30. National Trust Llandudno, correspondence file 2344.
 31. The Penrhyn Estate obtained the Ystbytty Estate, which included the western sector of the Llyn Gamallt catchment, in the mid-19th century.
 32. eg. see Note 18.
 33. See note 25.
 34. Air Photograph Office, Welsh Office, Cardiff. 1:10,000, 279/3301, 279/3302, 279/3303, May 7th 1946.
 35. See note 25.
 36. NLW, Penrhyn papers, 2935. See note 14.
 37. NLW, Penrhyn papers, 2921. See note 14.
NLW, Penrhyn papers, 2930. See note 2.
 38. NLW, Penrhyn papers, 784. Letter book, correspondence of August 29th 1854.

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