ENVIRONMENTAL ASPECTS OF PLANTATION FORESTRY IN WALES

INSTITUTE of TERRESTRIAL ECOLOGY

NATURAL ENVIRONMENT RESEARCH COUNCIL

Natural Environment Research Council

Environmental aspects of plantation forestry in Wales

ITE symposium no. 22

Proceedings of a symposium
held at the Snowdonia National Park Study Centre,
Plas Tan-y-Bwlch, Maentwrog, Gwynedd, north Wales
20-21 November 1986

Edited by

J E G GOOD

ITE, Bangor Research Station

INSTITUTE OF TERRESTRIAL ECOLOGY

Printed in Great Britain by
Cambrian News (Aberystwyth) Ltd

Published in 1987 by
Institute of Terrestrial Ecology
Merlewood Research Station
GRANGE-OVER-SANDS
Cumbria LA11 6JU

BRITISH LIBRARY CATALOGUING-IN-PUBLICATION DATA
Environmental aspects of plantation forestry in Wales
ISSN 0263-8614; no. 22)
1. Forests and forestry—Environmental aspects—Wales
I. Good, J E G. II. Institute of Terrestrial Ecology. III. Series
634,9'09429 SD387.E58
ISBN 1 870393 02 3

COVER ILLUSTRATION
A forest trail in Tal-y-Bont Forest, south Wales (Photograph H Williams)

ACKNOWLEDGEMENTS
The symposium was organized by Dr John Good, with help throughout from Mr Alastair Scott, Private Forestry and Environment Officer for the Wales Conservancy of the Forestry Commission. Dr Don Harding of the Department of Forestry and Wood Science, University College of North Wales, Bangor, and Dr Mike Hornung, of ITE Bangor, also gave frequent support. Mrs Janet Pritchard, ITE Bangor, dealt with all the routine administration calmly and efficiently, while her colleague, Miss Heather Jones, typed these proceedings and helped the editor generally. Mrs Penelope Ward, of ITE Merlewood, saw the completed typescript safely through to publication. The editor thanks them all for their efforts.

The *Institute of Terrestrial Ecology (ITE)* was established in 1973, from the former Nature Conservancy's research stations and staff, joined later by the Institute of Tree Biology and the Culture Centre of Algae and Protozoa. ITE contributes to, and draws upon, the collective knowledge of the 14 sister institutes which make up the *Natural Environment Research Council*, spanning all the environmental sciences. The Institute studies the factors determining the structure, composition and processes of land and freshwater systems, and of individual plant and animal species. It is developing a sounder scientific basis for predicting and modelling environmental trends arising from natural or man-made change. The results of this research are available to those responsible for the protection, management and wise use of our natural resources. One quarter of ITE's work is research commissioned by customers, such as the Department of Environment, the European Economic Community, the Nature Conservancy Council and the Overseas Development Administration. The remainder is fundamental research supported by NERC.

ITE's expertise is widely used by international organizations in overseas projects and programmes of research.

Dr J E G Good
Institute of Terrestrial Ecology
Bangor Research Station
Ffordd Penrhos
BANGOR
Gwynedd LL57 2LQ
0248 (Bangor) 364001

Contents

Preface

A H A SCOTT
Private Forestry and Environment Officer Wales, Forestry Commission Wales, Victoria House, Victoria Terrace, Aberystwyth, Dyfed SY23 2DQ

Forestry in the UK has entered an intensely interesting phase in which concern for the environmental impact, although seldom entirely absent from the minds of earlier generations, has moved centre stage. Foresters and the society which they serve urgently need environmental scientists, not to define objectives or to abrogate the responsibilities of management, but to establish connections between action and environmental results.

Foresters in Wales have been particularly well served over the past period by a small band of first-rate scientists, and the primary purpose of the symposium was to seize an opportunity for them to report their work to practising foresters in Wales, both public and private. I, for one, regard this purpose as more than satisfactorily discharged. Additionally and most rewardingly, we had marvellously authoritative statements from 3 people deeply experienced in, respectively, the history of forestry, forest recreation and forest landscape in the Principality. It is most satisfactory that all papers are now bound in this volume, although mere readers cannot re-create the intellectual excitement of having been there.

The symposium had the ancillary objectives of attempting to persuade a wider range of environmental scientists in Wales to turn their minds to matters on their doorstep and to demonstrate to rural decision-makers how foresters are responding to the changing requirements of society. I believe that we were less successful in this regard simply because the response was poorer than we had hoped. This volume will demonstrate what they missed.

Influences shaping the development of plantation forestry in Wales

J W L ZEHETMAYR
Woodland & Wildlife Consultant, The Haven, 13 Augusta Road, Penarth, South Glamorgan CF6 2RH

1 Introduction
There are so many influences to consider that I can do so only in the broadest terms, quoting examples which I trust will ring a bell with you the reader, leaving you to fill in the picture. What has brought us to our present position, one where Wales has more forest than for about 500 years, most of it as plantations of non-native species and in a form which a vocal minority, however misguided, finds alien and unattractive? Is it just dislike of change or has the response to all the influences been misjudged? I, for one, say 'Yes' and 'No'!

We all know in outline the major factors: woodland clearance over centuries; upland areas with at best limited fertility and an uncertain climate; a growing population whose need for food took precedence over their need for wood. The ancient forest, entirely broadleaved, gradually declined and has been partially replaced by conifers introduced from Europe and America, slowly from about 1700, gaining momentum in the first half of the 20th century, with, to some, an undesirable flood in the second. The word 'plantation', suggesting coffee, sugar and spice at the start of this period, now immediately conjures up Sitka spruce (*Picea sitchensis*) in serried ranks!

I must declare my debt to 2 authors: Bill Linnard of Amgueddfa Genedlaethol Cymru for *Welsh woods and forests* (1982) and George Ryle, once Director of Forestry for Wales, for *Forest Service* (1969). They have supplied facts to support the generalizations already outlined. The former takes us to 1920 and the latter to 1965, and after that I am dependent on Forestry Commission (FC) publications and my recollections, since I have worked, albeit at first intermittently, in Wales since 1958.

I cannot add anything to your knowledge of the basic geology, climate, or soils, but their influence is, of course, over-riding and man's influence is entirely within their limitations. Soils have clearly been affected by centuries of extensive grazing and burning. If man's removal of tree cover did not directly influence climate, then his pollution of the atmosphere has done so, at least in the field of acid rain.

Plantation forestry has, I believe, made 2 starts in Wales, on each occasion from a low ebb. The first began when shortage of timber became obvious around 1500 and a slow movement towards plantations, mixed or coniferous, continued over 300 years, during which time the total woodland area continued to decline. The all-time low was reached after the devastation of 1914–18, with about 4% of the land classed as woodland, of which more than a third was scrub, devastated, or felled. From this state, of course, sprang the Forestry Commission and, not surprisingly, the emphasis was on fast-growing plantations, and the new forest service, often under threat, had little time for niceties while concentrating on getting the maximum area under trees using known techniques. Just as some amelioration was being introduced, including underplanting with beech (*Betula* spp.) and setting up the 'National' Forest Parks—with Beddgelert camp site designed by Clough Williams Ellis—World War II again led to devastation in the private woodlands. The post-War census showed that the total woodland area had risen to 6% and, while the FC's 37 kha of young coniferous high forest was virtually intact, of the private sector's 90 kha, half was now scrub, devastated or felled. This is the position from which the last 40 years' work started and, inevitably, plantation forestry on the grand scale predominated, doubling the total woodland area.

Before considering the factors I have identified by broad types, I would like to point out the great variation in the timescale over which they operate.

On the longest scale, the dominance of sheep in the uplands over centuries led to the treeless wastes of moor-grass (*Molinia*) where 'blanket afforestation' is almost the only alternative by the time Frazer Darling's 'devastation by fire and tooth' has run its course. On a moderate timescale, coal mining in the south Wales valleys led to the use of all the better lower ground for housing, railways and the pits, to the decline and collapse of farming and, in due course, to the rapid afforestation of the plateau. This pattern has only raised public opposition in the last area entered by the FC, the Rhondda. On a much shorter timescale, the decision in 1981–82 to switch from public to private sector afforestation has raised the possibility of more direct conflicts because the varied private interests are not so responsive to the pressures, eg the agricultural veto that was enforced on the FC in the 1950s and 1960s and so greatly constricted what was done. Today it is environmental pressure which limits expansion.

Table 1 shows the timescale over 5 centuries during which certain factors appear to have operated as major or lesser influences on plantation forestry in Wales. While the chronology is derived almost entirely from Linnard (1982), I cannot hold him responsible for the following observations.

Table 1. Activities of man influencing plantation forestry in Wales from 1500 AD; those of lesser importance indicated ( ) or — — —

Factor	16th	17th	Century 18th	19th	20th
Land use	◀ ———	———	Sheep farming ——— Enclosures ◀— Game ◀— — — —	——— ——— — —▶ ◀—Water ◀— — — — — — — ———	——— ▶ ——— ▶ — — — —Landscape▶ Conservation Recreation —(Coal mining)— —▶
Wood used for	◀— — ——— ◀— — —	—— Charcoal —— — ——— Naval—	——— — — — — ——— Pitwood (coppice)—	—▶ —▶ — — — — — Pitwood (conifer) —	— — —▶ ——— — — —▶ Pulpwood Structural
People		J Evelyn *et al.*	Pioneer landowners Thomas Johnes	Scots foresters	Professional foresters FC
Species available.— native oak ash birch (beech lime yew)	Sweet chestnut Sycamore		N European conifers SP EL NS (SF)	N American conifers DF JL SS	
Technical	Limited ability to cut/transport ∴ Coppice working			Powered transport and cutting ∴ High forest	
Government policy	Protection and exhortation		Laissez-faire ———	———▶Enquiry	Forestry school(s) Forest Policy FC PW/Tax
Outcome:— % woodland Wales	c. 10%	Slow decline to:—		4% ———	4% ———▶ 12% 1/5 coppice — no coppice

Key: SP = Scots pine; EL = European larch; NS = Norway spruce; SF = silver fir; DF = Douglas fir; JL = Japanese larch
SS = Sitka spruce
FC = Forestry Commission; PW = private woodland

2 Land use

From the time of the Cistercian clearances, sheep farming has been the main industry and land use on the uplands of Wales and, indeed, dominated them completely almost into the present century when water, forestry, recreation and conservation, in turn, started to play a part.

The enclosures of the 17th century facilitated not only the segregation of intensive/extensive agriculture, freehold and common, hendre and hafod, but also enclosure for planting. This practice physically separated forestry and agriculture, as it did the roles and interests of landlord and tenant.

In Wales, the conserving of game was paramount only in the 19th century, when timber prices fell after the Napoleonic wars, free trade encouraged imports, and such planting as was done was often directed to improve hunting or shooting.

The building of reservoirs from the middle of the 19th century set the scene for the later planting of catchments, first as a barrier against sheep and then as a sensible use of the catchment once the lower land was flooded. The later reaction has had little impact so far on the formation of plantations, but is clearly likely to be of great importance in the second rotation of existing forest, or indeed any extension.

3 Timber use

The combination of widespread metal mining and smelting, availability of native broadleaved species and the difficulties of transport made coppice working for charcoal common until about 1800. When smelting with coal began, the coppice could supply the props, but conifers—available by then in small quantities—were as good or better. Hardwood props were used only in the south Wales coalfield well into the present century, being finally banned by the National Coal Board (NCB) on its creation after World War II.

Linnard stresses 2 points. The old silviculture of coppice for charcoal did not destroy such forest as remained; its survival within reach of the hearths was in everyone's interests. Also, the new plantations were made by Scots foresters trained in the silviculture of conifers. However, by the time Government forest policy emerged in the present century, the overwhelming demand was for softwood timber for mining or structural use.

4 People

In the change-over to coniferous high forest, certain names stand out for initiating or demonstrating that major change was desirable or possible. Evelyn had little impact in Wales but a century later Johnes, at Hafod, used conifers on some scale and showed concern for landscape, as did others at this time, at least for the policies round the great houses. The Scots foresters already cited introduced management as we know it, while in this century first Lord Robinson for the FC and later Kenneth Rankin for the Economic Forestry Group/private woodland (EFG/PW) favoured large-scale coniferous plantations.

5 Use of species and technical developments

Table 1 shows the use of species, technical developments and introductions of policies in relation to plantation forestry in Wales from 1500 AD to the present time. Those activities of lesser importance are shown in parentheses.

6 Government policy

Government played its part, viz the first Elizabeth's 'Act that Timber shall not be felled to make coals for burning of Iron' in 1558, but the fact that there were no Crown Forests in Wales meant that the Act had even less impact than in England, and by the end of the last century Government had done no more than set the scene for education in forestry and experimental forests at Hafod Fawr and Tintern/High Meadow.

Clearly, the interactions of the factors set out in Table 1 are innumerable, and it is almost impossible to determine cause and effect or to separate 'chicken' and 'egg'.

Table 2 shows the last 2 centuries in more detail, the 19th by quarters, the 20th by decades, and attempts to show the factors and pressures that influenced the planners and planters of the forests we know today.

Economics and the state of forestry are clearly dominated by 3 periods of World War, with intervening periods of empire which did not long survive World War II. Policies of great importance in one period, eg land settlement and employment between World Wars I and II, have little impact today, but left their mark particularly in the intensive care of plantations in which no weed tree was allowed its head and every blank was to be filled. From this time date our most productive forests, which are now largely accepted: Coed y Brenin, Dovey and Brechfa.

In contrast, after 1945, the prevention of almost any inbye agricultural land being planted by FC by the need for 'clearance by MAFF' pushed forestry up the hills on to ever higher and poorer land only plantable through the coming to fruition of the pre-War research programmes, involving ploughing, draining, new species and fertilization. Only the arrival of the Economic Forestry Group in the late 1950s, and perhaps that of the Welsh Office 10 years later, helped to break the pattern.

This agricultural pressure together with the forest economic disciplines of Net Discounted Revenue (NDR) and the need for chipwood and pulpwood all

Table 2. Factors influencing plantation forestry from 1800 to 1990

Factor	19th century — quarters 1st	2nd	3rd	4th	1900s	10s	20s	30s	40s	50s	60s	70s	80s
Economic state of forestry	Napoleonic wars Boom	Free trade and decline		Forestry at low ebb		War Boom Heavy cut	Depression FC afforestation		War Heavy-cut in PW	Steady growth FC afforestation →	PW afforestation →		
Forest policies subject to							Timber reserve Employment Land settlement Economic crises		Maximize agricultural production →		Timber for industry → Economic NDR → Multiple land use Other pressures →		
Education and technical progress		New species		(EL dieback)	Dean Forestry School → Flat or pit planting	UCNW Bangor, University Forestry School →			Turf planting	Gwydyr FS Ploughing and fertilizers →			
Forests started on land type				Vyrnwy catchment	Hafod Fawr experiment		Coed Morgannwg Gwydyr Brechfa Old Estate/Agric.		Hafren Upland	Tywi High plateaux	Rhondda		
Pressures					←		Filter for catchments ← Fire & frost	← Recreation Forest parks ← Landscape		Agricultural → ? ? Sheep & wind → National parks	Water quantity/quality →	Nature conservation B L revival	

Key: FC = Forestry Commission; PW = private woodland; FS = Forest School; BL = broadleaved woodland; NDR = Net Discounted Revenue served to promote Sitka spruce as the universal species. Fire, frost, sheep and wind all played their part, largely in promoting simple planting and management prescriptions.

There was little pressure in Wales from recreation and landscape interests pre-War; National Parks did not come till the 1950s and we happily planted in huge SSSIs into the 1970s, but the pressures were building up. Fortunately, there were lower rainfall areas, skeletal soils and the threat of fire, which made us continue to use pine (*Pinus* spp.) and particularly Japanese larch (*Larix leptolepis*) in some quantity. The responses of FC to the pressures were by no means insignificant:

— Forest Parks (one and a bit in Wales) date from the late 1930's
— The 'open forest' policy for walkers and recreation was developed from 1961 onwards
— Sylvia Crowe was appointed as consultant landscape architect in 1964, one of the most far-sighted and successful moves ever made
— A Broadleaved Policy, enunciated in 1970, mainly prescribed a *status quo*. No further conversions were to be made by FC, but private woodlands were not brought into line until 1985.

Two quotations are, however, apt at this point. Linnard (1982) relates: 'Wyndham stressed (in 1770) not only the vigour, beauty and profitability of this large conifer plantation ... "in country where the soil and climate seem averse to the production of all other kinds of forest trees"', and Ryle (1969) writes, 'Today few in the Forest Service would ever concentrate on main-crop broadleaf trees or advise private owners to do so. Whether for the production of wood or for the improvement of the country scene it is too much of a risk to plant squirrel fodder'. So, what has changed and why the broadleaved revival: my final entry in Table 2? I believe that it is still quite unrealistic for the public, planners and self-styled 'greens' to call on us for large-scale planting of broadleaves in new plantations or, indeed, for the conversion of existing conifer plantations in the second rotation.

On the other hand, there is immense scope for planting small new broadleaved woods, for conversion of small coniferous blocks, for accepting natural broadleaves in the second rotation, and for planting strategic margins, riversides and areas difficult to extract. Indeed, we in Wales persuaded FC to recognize 'scrub' as a crop type and a permanent non-productive land use category some 15 years ago, and to accept the large area in aggregate of broadleaves not identified by standard stock records and forest survey.

What other factors play a part?

— *Squirrel control*? Perhaps? Are small owners either aware of it or confident in the prescription?
— *Tree shelters/Tuley tubes*. I believe these devices are the most important factor in establishing broadleaves since labour for years of hand weeding became prohibitive in cost.
— *Rise of the firewood market*. Again, this increase has been a most important change in the last decade. The woodburning stove, while never a solution to our energy needs, can and should perpetuate farm woods, revive coppice and enhance wildlife variety. I hope to see firewood promoted in the present state of agriculture as a valuable diversification for anyone with 5 acres or so of woodland, and the broadleaves grant should help anyone with less.

Let us take a final look to the plantations of the 21st century. Most of the pure coniferous plantations up to 1950 will be more attractive and diverse in their second rotation by the year 2000. For our expansion, I suggest foresters should look to the poorest 'improved' agricultural land, rather than to the moors and even higher tops, and that this better ground should be planted with Douglas fir (*Pseudotsuga menziesii*) and Corsican pine (*Pinus nigra* var. *maritima*) and even spruce (*Picea* spp.) for profit, while small areas of oak (*Quercus* spp.) and other broadleaves can be incorporated. Meanwhile, every amenity body with woods, whether National Parks, Country Parks, Nature Reserves (of all but the most primaeval or wilderness types), should be managed with wood production as one of their aims, without the constraint of maximum NDR or tax considerations. Even the motorway and trunk road plantings could play a part in more varied plantation forestry suited to multipurpose land use on a crowded island.

7 References

Linnard, W. 1982. *Welsh woods and forests: history and utilisation*. Cardiff: National Museum of Wales.

Ryle, G. 1969. *Forest Service. The first 45 years of the Forestry Commission of Great Britain*. Newton Abbott: David & Charles.

The effects of forestry on upland streams—with special reference to water quality and sediment transport

G J L LEEKS and G ROBERTS
Institute of Hydrology (Plynlimon), Staylittle, Llanbrynmair, Powys SY19 7DB

Summary
The Institute of Hydrology (IH) has been carrying out studies of the interaction between forestry and grassland practices and upland streams since 1968. Experiments using a twinned-catchment approach are described and the results of 2 current projects in mid-Wales are reported. The effects of afforestation and clearfelling on water and sediment yields, water chemistry, temperature and flow responses are discussed within the broader context of other studies. Methods to reduce the sediment outputs of forested catchments are also listed.

1 Introduction
Traditionally, water supply undertakers have favoured forestry as a cover for water gathering catchments in upland areas of Britain. Forestry was regarded as a productive use of land which otherwise would have been, at best, marginal agriculture. Also, it was thought that forestry would act as a barrier against the public and cattle around reservoirs and along feeder streams, would provide a natural filter for holding up silt and removing pollution from surface runoff, would act as a sponge to even out the flow from varying rainfall and would provide a windbreak as an aid to further land development.

The Institute of Hydrology has been investigating the interaction between upland land use and stream processes since 1968. Details of some of the current experiments are given below. In the following sections, results from these experiments, with regard to water and sediment yields, water chemistry and stream temperature, are outlined in relation to work on other forested streams.

2 Institute of Hydrology upland catchment studies
The Institute of Hydrology began catchment studies at Plynlimon in 1968 to compare the water use of established forestry and rough pasture. Other associated studies include plot-scale studies to explain the results from the catchments (Calder 1976), the comparison of nutrient losses from the 2 land uses (Roberts *et al.* 1983) and the effect of pre-afforestation ditching on sediment losses (Newson 1980b; Arkell *et al.* 1983).

As a sequel to Plynlimon, a similar study, with the same objectives, is being carried out in Balquhidder in the central Highlands of Scotland, an area receiving a greater proportion of precipitation in the form of snow than is the case at Plynlimon. A detailed description of the Balquhidder catchments and an initial appraisal of the results have been given in Blackie *et al.* (1986). More recently, the Institute has initiated a series of 3 studies in mid-Wales into the effects of upland land use change. These studies are: afforestation at Llanbrynmair, clearfelling in the Hafren Forest at Plynlimon; and upland pasture improvement at Nant-y-Moch. Each study adopts a twin-catchment approach, one being undisturbed and acting as a control and the other being subjected to the land use change following a suitable calibration period. The need to calculate nutrient losses in the streamflows as a product of streamflow total and concentration meant that reliable flow measuring structures had to be installed. As a result, the studies could be extended to look at the effects of the changes on water use and streamflow responses to storm events. Subsequently, the experiments have been further extended to study a wider range of chemical determinands, sediment losses and fish populations. More detailed descriptions are given below of the background to 2 of these current research projects as they are illustrative of the possible effects of afforestation and the end of the first rotation upon upland streams.

2.1 The afforestation study
At Llanbrynmair moor, 24 km north of the Institute of Hydrology's mid-Wales station, the Economic Forestry Group purchased a considerable amount of land for afforestation purposes, the operation being scheduled to begin in 1982. In all, a total area of 1200 ha was involved. Shortly following completion of the purchase, 2 catchments were identified, one partly within the afforestation scheme and the other totally unaffected. The catchment within the afforestation scheme, the Cwm, is about 300 ha in area, approximately 40% of which was scheduled for afforestation. The unaffected catchment, the Delyn, is approximately 100 ha in area and is used as a control. Instrumenting the 2 catchments began in the spring of 1982 and was completed in the autumn. During 1983, Fountain Forestry Limited completed the purchase of a further 150 ha of the moor for afforestation. Virtually all of this land lies within the Cwm, resulting in approximately 90% of the catchment being affected on completion of the 2 schemes.

A map of the Cwm catchment showing the timing and extent of afforestation is given in Figure 1. Air photographs of the area confirmed that the 2 areas to be afforested by the Economic Forestry Group were, in fact, completed by April 1984. Some burning of the

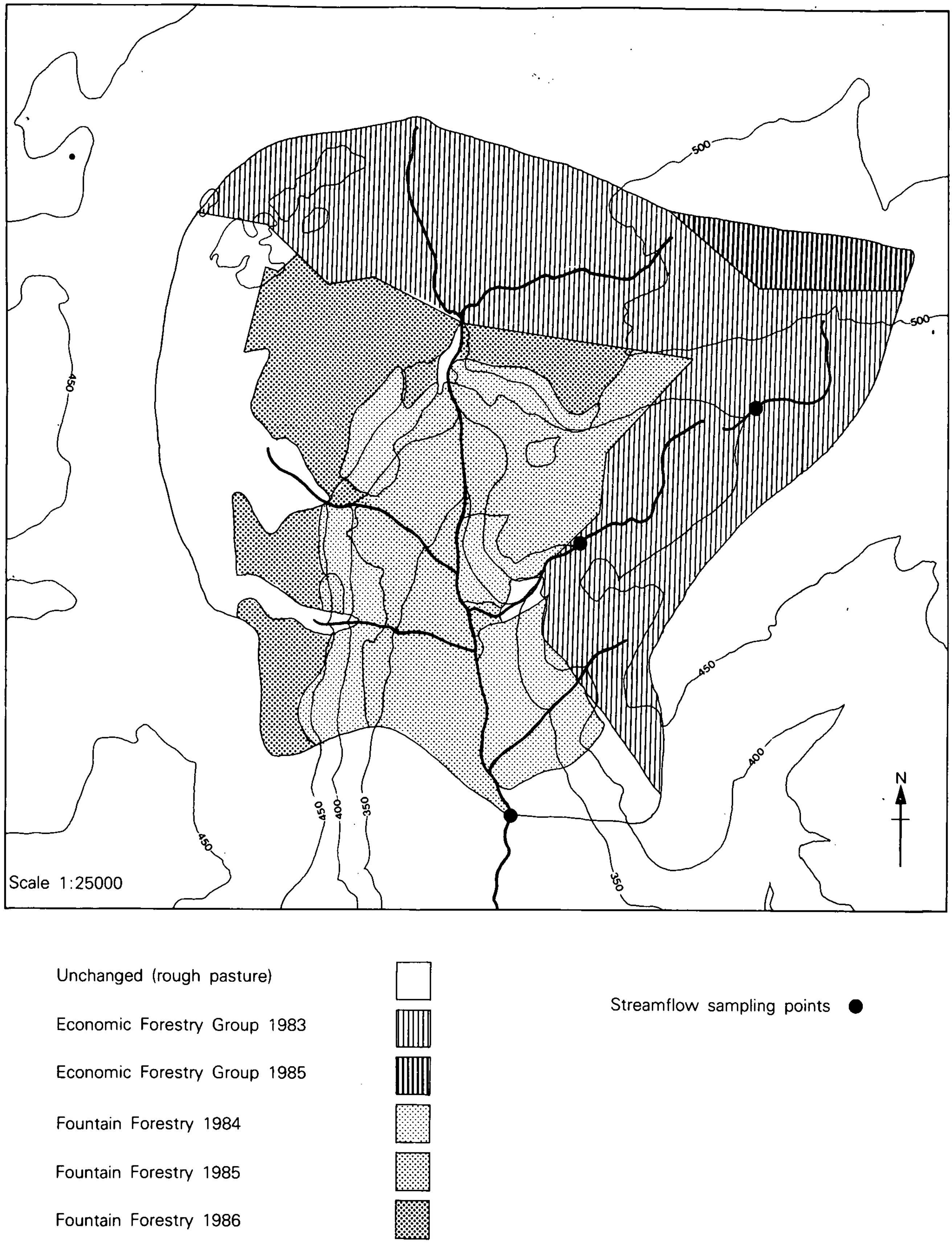

Figure 1. Llanbrynmair Cwm catchment: afforestation sequence

indigenous vegetation was involved and the whole area was ditched prior to planting. A phosphorus fertilizer was applied to all the planted areas at a rate of 181 kg ha^{-1} of P_2O_5. The area designated to be planted by Fountain Forestry in 1984 (see Figure 1) was completed during the spring of that year. This planting was mainly on steep slopes, the major species being Sitka spruce (*Picea sitchensis*), with smaller amounts of Douglas fir (*Pseudotsuga menziesii*), Japanese larch (*Larix leptolepis*) and noble fir (*Abies nobilis*), and the method used was screef planting with minimal ground disturbance. The bottom of the valley was contour ploughed in November 1984 and planted with Sitka spruce in April 1986. The only areas of the Fountain Forestry holding to receive a fertilizer dressing were 2 sites, adding up to some 10 ha, in the north-east and north-west of the plantation. These areas received an NPK dressing by hand during the spring of 1986 at a rate of 580 kg ha^{-1}. As part of their agreement with the Severn-Trent Water Authority, buffer strips, approximately 20 m wide, were left on either side of perennial streams. It was also agreed that approximately 15% of these strips were to be planted with a mixture of alder (*Alnus* spp.), birch (*Betula* spp.), oak (*Quercus* spp.) and ash (*Fraxinus excelsior*). Also, some areas above steep gullies on the western side of the catchment (see Figure 1) were left unplanted so as to minimize erosion. A number of roads to access both the top of the catchment and also the valley bottom have been constructed.

Routine monitoring at the outfalls of the 2 catchments began in July 1982. Streamflow from the Cwm catchment is measured by means of a Crump weir and from the Delyn by means of a sharp-crested weir with a V-notch.

2.2 The clearfelling study

This study is being carried out in the IH Plynlimon catchments in mid-Wales. The forested catchment, the upper Severn, has been described in some detail elsewhere (IH 1976; Newson 1976). Two subcatchments are involved: the Hafren of 358 ha which is to act as a control, and the Hore of 317 ha. Agreement was reached with the Forestry Commission that approximately 157 ha of the Hore subcatchment, amounting to almost 50% of the catchment area, would be felled over a 2 year period beginning in 1985. Two areas were to be felled, both in the lower portion of the catchment, consisting of a 90 ha area containing Norway spruce (*Picea abies*) and Sitka spruce planted in 1937–38 and a 67 ha area containing mainly Sitka spruce but also Japanese larch, Norway spruce and lodgepole pine (*Pinus contorta*) planted in 1948–50. Some thinning and clearing of windblown areas of trees had been taking place for several years, and it was agreed that this practice would be terminated in the spring of 1984, so as to allow a 12 month 'settling down' period. At this time, approximately 16% of the Hafren had been affected, and 13% of the Hore, all in the lower portion of the catchment. Figure 2 shows the areas that have already been clearfelled in the first year of operation, indicating the techniques used. The rest of the enclosed area is scheduled to be felled over the next 18 months or so. Because of the uncertainties about the effects of thinning and felling already carried out, it was decided to use the upper portion, above the areas to be felled, of the Hore subcatchment to act as an additional control. Therefore, a steep streamflow measuring structure was constructed mid-way up the Hore subcatchment (Figure 2) to supplement the ones in existence at the outfalls of the Hore and Hafren. This structure was completed during the autumn of 1985 and flow recording began in October. Flow records are available from the other 2 sites since 1973.

3 Water yields

Recent research has shown that the afforestation of upland catchments is not necessarily beneficial with regard to water resources. The first experiment was conducted by the late Frank Law who, using a lysimeter situated within the forested part of the Stocks Reservoir catchment, showed that, of the 990 mm rainfall that fell during an annual study period, the loss from the forest was 290 mm greater than that from grassland (Law 1956, 1957). However, the validity of Law's results was not universally accepted. In particular, because of the small surface area of the lysimeter used (0.045 ha), doubts were expressed concerning the replicability of the experiment. More recently, the Plynlimon study conducted by the Institute of Hydrology in mid-Wales has verified Law's results for upland, high-rainfall areas. It has been found that, of the 2300 mm or so annual rainfall, approximately 17% is lost by transpiration from the Wye, grassland, catchment whilst 38% is lost from the Severn, established forestry, catchment (adjusted for 100% forest cover) (Newson 1979). Process studies have shown that the difference is due to the interception and subsequent evaporation of the incoming rainfall within the forest canopy (Calder 1976). Calder and Newson (1979), using the data from the Plynlimon study, calculated the likely losses in water supply that would occur in the major upland catchments following increased afforestation up to 50% canopy coverage. The figures vary from area to area depending on the climatological conditions, with a predicted average reduction in yield of about 10%. In contrast to the upland situation, Gash and Stewart (1977) predicted that evaporative losses from Scots pine (*Pinus sylvestris*) in Thetford Forest, a low rainfall area, would be very similar to the potential evaporation from short grass, plentifully supplied with water. The difference between the 2 situations has been attributed to differences in interception loss, this varying by a factor of more than 3 across Great Britain and in many cases being the largest component of the total evaporation (Gash *et al.* 1980). The results for Plynlimon and Thetford were obtained for established forestry. No results are available at present on the effect of plantation age on water use.

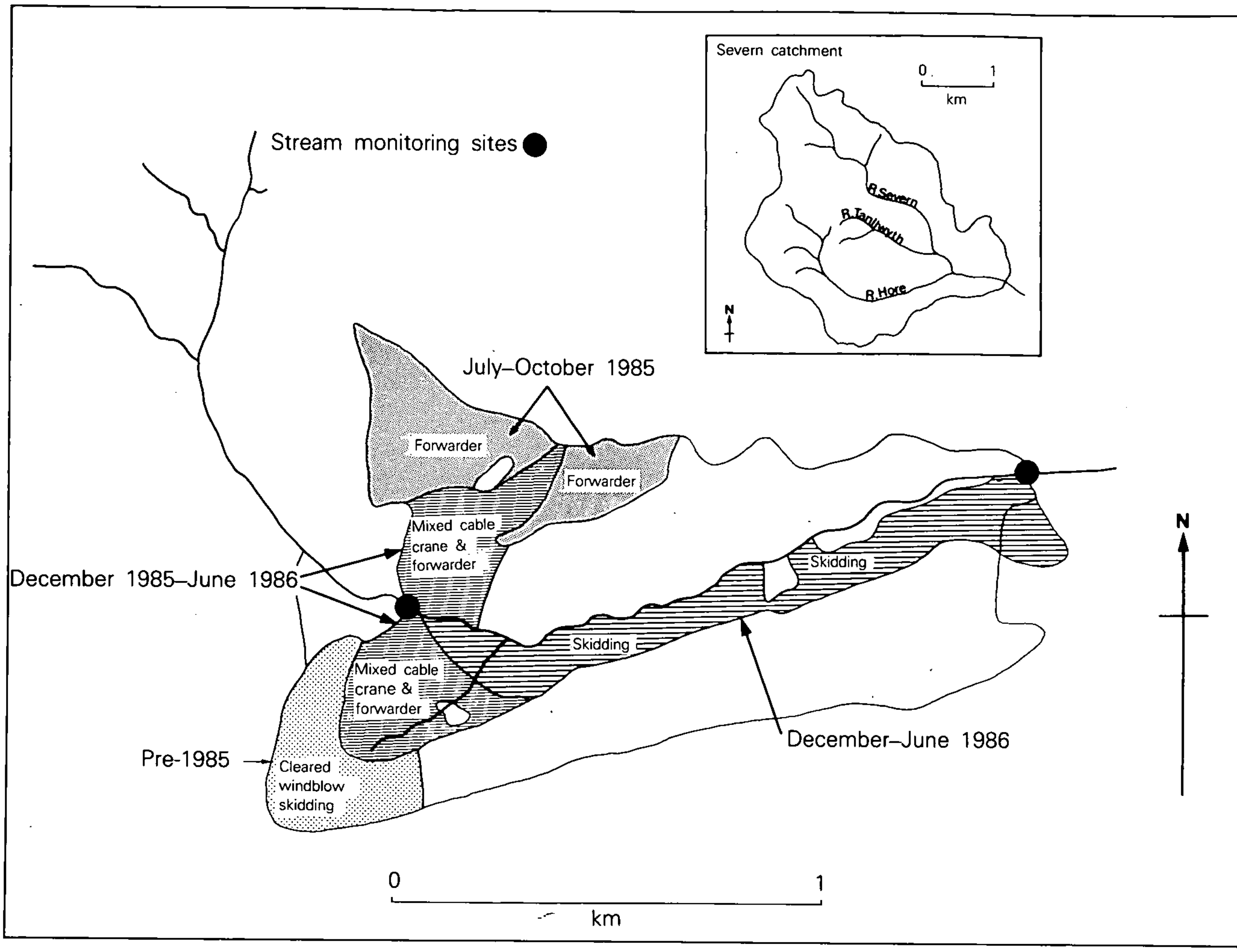

Figure 2. Hore felling project: techniques and dates

4 Flow response

The effect of forestry on stream response to rainfall, particularly the initial drainage required to produce conditions conducive for sapling development (Taylor 1970), on the timing and magnitude of peak flows has been of interest. Robinson (1980), in his study of the afforestation of the 152 ha Coalburn catchment, found that pre-afforestation drainage produced a much peakier storm response, with higher flood flows and a reduction of 50% in the time to peak. Similar results were found by Conway and Millar (1960), at Moor House in the northern Pennines, where a burnt and drained catchment exhibited earlier peak flows and higher peaks than a nearby undrained catchment. It was found that severe burning of the peat surface increased peak flows by reducing the storage capacity of the soil, although this effect was much smaller than the change due to drainage. On the other hand, Burke (1968) at Glenamoy, southern Ireland, showed that drainage increases the storage capacity above the water table, thus ensuring a less rapid response to rainfall in drained than undrained areas. It has been suggested (McDonald 1973) that soil type is the major factor in determining the effect of drainage on peak flows, but parameters such as type of drainage, topography and the amount and intensity of rainfall are also of relevance. In general, though, the majority of studies (see, for example, Burke 1968; Robinson 1980) suggest an increase in low flows following drainage.

At Llanbrynmair, a detailed investigation of the timing of peak flows from the Cwm catchment using a unit hydrograph approach has revealed that the drainage carried out by the Economic Forestry Group at the top end of the catchment (see Figure 1) has resulted in a significant increase in peak flows (see Plates 1 & 2). The increase for an individual rainfall event depends on its duration, ranging from 5% for a 10 hour duration rain storm to 20% for a 5 hour one. The average measured lag time between the centroid of storm rainfall and the resultant peak flow was cut from 2.7 hours to 1.8 hours after drainage.

The studies quoted above show the effects of initial drainage on the patterns of streamflow losses. These effects, however, may be only temporary because, after canopy closure, the infilling of drains by vegetation, the deep ground layer of leaves and needles and the higher interception losses may result in a smaller response than in the original upland pasture (Binns 1979). This was originally thought to be the case for

Plate 1. One of the steep stream flumes in the forested Severn catchment at Plynlimon during a flood event (Photograph G J L Leeks)

the established forest at Plynlimon, where a reduction in peak flows was found in the forested compared with the grassland catchment. Times to peak were slightly longer for the forested catchment although, when the analysis was restricted to identical rainstorm inputs, the reverse was true (Newson 1979). A more recent analysis of a larger data set suggests, however, that the response difference of the 2 catchments is small. G A Cole (pers. comm.) concludes 'it would appear that the mature closed forest canopy of the Severn, despite drainage, ameliorates floods sufficiently to give a comparable response, though a lower volume of runoff, compared with the neighbouring grassland Wye catchment'. Again, there is no indication at what stage in the forest development this will happen.

5 Temperature

Forestry will also affect stream temperatures because of the shading effect of the tree canopy. Roberts and James (1972) reported that at Plynlimon monthly mean streamwater temperatures in the forested catchment were generally 2°C cooler in the summer and up to 1°C warmer in the winter. Similar trends were obtained by Gray and Edington (1969), who found that the felling of a woodland bordering a small tributary of the River Coquet in Northumberland increased the summer maximum stream temperature by up to 6.5°C.

6 Chemistry

6.1 Afforestation

Substantial nutrient losses, particularly nitrogen, have been reported as a result of draining organic soils (Duxbury & Peverly 1978) and wet sloping land (Benoit 1973). Roberts *et al.* (1986), in their study of the effects of upland pasture improvement on nutrient losses, found enhanced nitrate concentrations (up to 16 mg l^{-1} of NO_3-N) following tile drainage at 10 m intervals, whilst the concentration of other forms of nitrogen and of phosphorus and potassium seemed unaffected. The draining of the Coalburn catchment prior to afforestation produced noticeable increases in the concentration of calcium and, to a lesser extent, magnesium, whilst the concentration of sodium and potassium showed little evidence of change (Robinson 1980). It was suggested that this represented a change in water chemistry from a predominantly peat catchment to a boulder clay type, as the influence of the inorganic soil was increased through its exposure by the drains. Stretton (1984) reported massive increases in total iron, manganese and aluminium following the draining of the Cray catchment. It has been suggested that road construction is also likely to have a considerable effect on water quality (Binns 1979), presumably as a result of the increased sediment losses referred to in Section 7.

In the Llanbrynmair experiment, as well as monitoring the outfalls of the 2 catchments using composite water samplers, spot samples are taken at 2-weekly intervals, beginning in February 1984, at 3 points in the Cwm catchment (see Figure 1).

The uppermost site represents an area of early ditching and planting by the Economic Forestry Group; the middle point is similar but separated from the upper point by a mire area, whereas the outfall represents contributions from the whole catchment including a later planting schedule for the lower basin. A rainfall sample is collected at the outfall of the Cwm catchment. All the samples are analysed for the various forms of nitrogen, phosphorus, potassium, silica, organic carbon, conductivity, and pH at the Severn-Trent Water Authority Laboratories at Shelton, Shrewsbury.

An initial analysis of the chemical data shows that, whilst nitrogen concentrations at the outfall of the 2 catchments were similar during the first 3 years of the study, those in the Cwm catchment were higher than those in the Delyn following the autumn of 1985. This trend is consistent up to the present time and is mainly due to differences in nitrate-N and, to a lesser extent, organic N concentrations, though the peak values are still less than 0.6 mg l^{-1} NO_3-N and 1 mg l^{-1} of total N. During the autumn of 1983, a massive flush of ammoniacal-N, with peaks in excess of 1.5 mg l^{-1} $NH4^+N$, were experienced at the outfalls of both catchments. Also observed were small, but significant, flushes of nitrate-N and organic N.

Nitrogen concentrations at the 3 sampling points within the Cwm catchment were very similar prior to autumn 1984. However, at this time and up to the present, ammoniacal-N concentrations in the upper basin (see Figure 1) have been much higher, with a peak value of 1.6 mg l^{-1} NH_4^+N, than those in the lower basin which, in turn, are higher than those at the outfall (see Figure 3). A similar, but much smaller, trend is also found for organic N. Nitrate-N concentrations, however, are consistently higher, but not to such an extent as ammoniacal-N, in the lower basin than at the outfall which, in turn, are higher than those in the upper basin.

In brief, therefore, what is being observed is a substantial release of ammoniacal-N in the upper basin following the autumn of 1984. This release is then manifest as nitrate-N lower down the basin, though it is obvious that total nitrogen concentrations are less in the lower basin, possibly due to denitrification effects or dilution. If the latter, it will be interesting to observe what effects, if any, will be identified following planting of the lower reaches.

Ortho-phosphate and organic phosphorus concentrations at the outfalls of the 2 catchments are usually below the limit of detection.

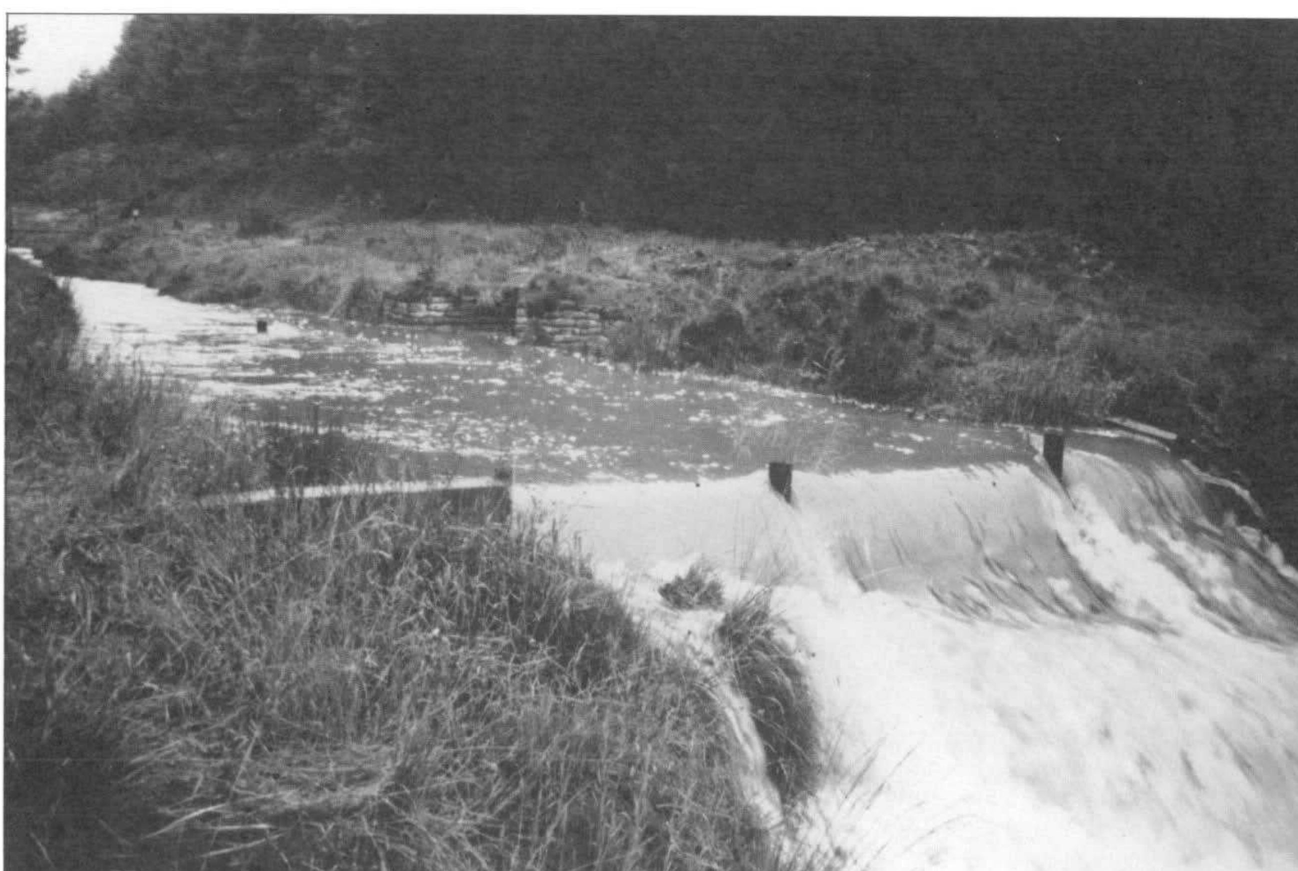

Plate 2. A bed-load trap in the forested Hore subcatchment at Plynlimon during a flood event (Photograph G J L Leeks)

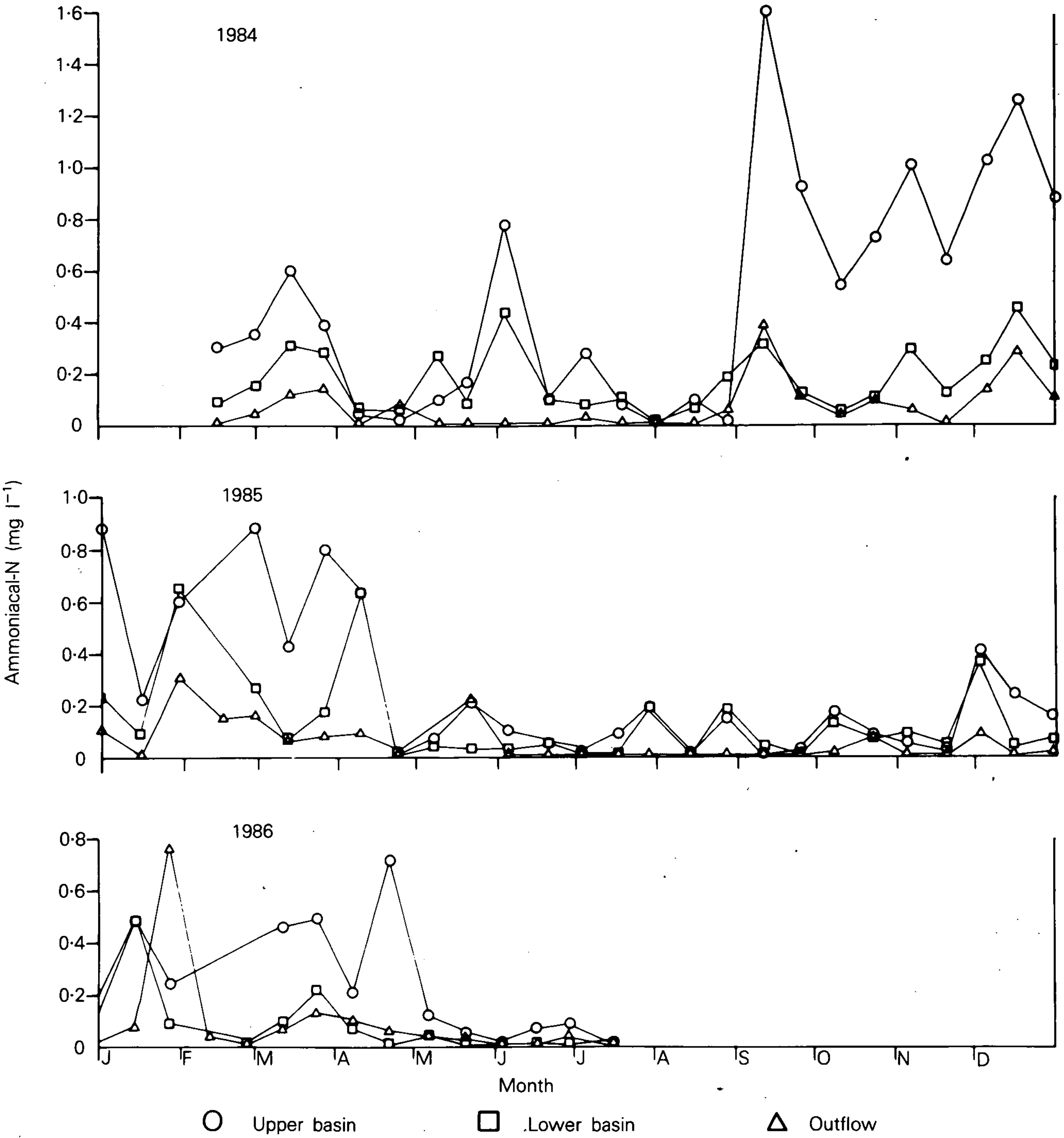

Figure 3. Ammoniacal-N concentrations at various points in the Afon Cwm catchment

Although some occasional high values have been observed, there is no consistent difference in the concentrations in the 2 streamflows. On the other hand, ortho-phosphate and, to a lesser extent, organic phosphorus concentrations have been consistently higher in the upper basin compared to the lower basin or the outfall of the Cwm catchment since the spot sampling began in February 1984. It remains to be seen whether these relatively high concentrations (peak of 0.44 mg l^{-1} ortho-P) will be manifest at the outfall of the catchment.

Potassium concentrations have generally been higher at the outfall of the Delyn catchment compared with the Cwm, although during 1986 the reverse is true. This pattern is confirmed by the results from the spot sampling within the Cwm catchment, which shows higher concentrations at all 3 sampling points in 1986 compared with 1984 and 1985.

Of the other determinands, higher concentrations of silica are found at the outfall of the Delyn compared with the Cwm, whilst the reverse is true for organic carbon. Conductivity and pH are higher in the Delyn.

For the spot sampling in the Cwm, organic carbon is much higher in the upper than in the lower basin, whilst the pH increases in a downstream direction.

In brief, an initial appraisal of the chemical data suggests that the afforestation is affecting concentrations within the upper basin of the Cwm catchment. With the possible exception of potassium, the increases have not yet been observed in the lower basin or at the outfall of the catchment. However, the currently observed increases in concentration within the upper basin do not constitute a problem for water supply purposes, though the ortho-phosphate concentrations may pose a threat as they are well above the value generally regarded as limiting for eutrophication.

No results are available from long-term studies of the effects of the planting and subsequent growth of young saplings on water chemistry.

6.2 Mature forest cover

Reliable chemical budgets for mature forest stands are few in number for British forests. Comparisons of nutrient concentrations in streamflows from land under rough pasture and established forestry at Plynlimon show very low concentrations and only minor differences between the 2 land uses (Roberts *et al.* 1983).

6.3 Felling phase

The part of the forestry rotation that has received the greatest attention, in terms of water quality, has been the clearfelling of established forestry. This emphasis follows the study at Hubbard Brook, in the White Mountains of New Hampshire (Likens *et al.* 1970), which showed a massive deterioration in water quality following the clearfelling of a 15.6 ha watershed. Nitrate-N losses of 104 kg ha^{-1} and 147 kg ha^{-1} were recorded, respectively, in the first and second year following felling. These figures compare with estimated losses of 1.3 kg ha^{-1} and 2.8 kg ha^{-1} from an undisturbed catchment. Post-felling nitrate-N concentrations in the streamflow exceeded for 2 years, almost continuously, the level of 11.3 mg l^{-1} recommended by the World Health Organisation for drinking water. Similar massive increases were found in the concentrations of other ions, notably potassium. Although this experiment was quite unlike a normal timber harvest (as all the cut timber was left on the catchment and vegetation regrowth suppressed by herbicides for 3 successive summers), nevertheless it did demonstrate potential losses and provoked a fear that conventional felling practices would result in similar rises in ionic concentration.

Since then, many studies, mostly in the USA, have been reported in the literature. These studies, as well as calculating nutrient losses from conventional felling techniques, have also looked at alternative harvesting and post-harvesting practices, which include logging road location and management, clear- and strip-felling, use of skyline cable systems, whole- or part-tree harvesting, slash burning and stream edge protection strips. Many study reviews have been given, including Sopper (1975), Stone *et al.* (1978) and Martin *et al.* (1984). The studies report a wide range of results reflecting the techniques adopted and showing the benefits of using various protection practices during felling operations. For example, O'Loughlin *et al.* (1980) found much smaller nitrate-N losses from a felled catchment where a riparian protection zone of intact forest nominally 20 m wide was left on each side of the stream. Similarly, Brown *et al.* (1973) demonstrated the benefits of patch-cutting as opposed to clearfelling. On the other hand, Neary *et al.* (1978) found higher concentrations of potassium in water draining a cut and burnt watershed in New Zealand than had previously been reported in the literature. The increase was attributed to the fact that most of the slash accumulated close to the stream. This material was burnt and converted to potassium-rich ash which was then leached into the stream by 2 subsequent storms.

In the Hore study, spot and composite samples have been taken at each site, with rainfall sampling at the head of the main Severn catchment. The only significant trend in the chemical data which has been observed to date has been in the nitrate-N and, to a much lesser extent, the potassium concentrations. Whereas samples collected during 1979-80 from the 3 sampling points gave very similar values (Roberts *et al.* 1983), nitrate-N concentrations from samples taken during this present study were significantly different. This difference was evident during the periods September 1983–February 1984 and September 1984–December 1984 when nitrate-N concentrations were consistently in the order Hafren>Hore>Upper Hore (see Figure 4), presumably as a result of prior thinning and felling practices. The differences were not large, however, with peak values less than 0.5 mg l^{-1} NO_3-N. Since then, a great deal of variation between the 3 sampling points is apparent, though no consistent trend can be observed. It seems, therefore, that to date there has been no increase in nutrient losses as a result of the clearfelling that has taken place since July 1985.

7 Sediment

7.1 Afforestation

In terms of water quality, the biggest effect of afforestation and its associated practices has been an increase in sediment losses and, again, drainage has been implicated as the main cause. Robinson and Blyth (1982) found that the pre-afforestation drainage of the Coalburn catchment referred to earlier increased sediment concentrations by over 2 orders of magnitude. It was calculated that the sediment yields over the following 5 years were equivalent to nearly half a century's load at pre-drainage rates. Subsequent sediment yields did not decline to pre-drainage levels, but remained about 4 times higher, as a result of the erosion of the drains. Most of the sediment, accounting for more than 99% of the total load, was in suspended form. There was no change in sediment concentration when the trees were planted. Burt *et al.*

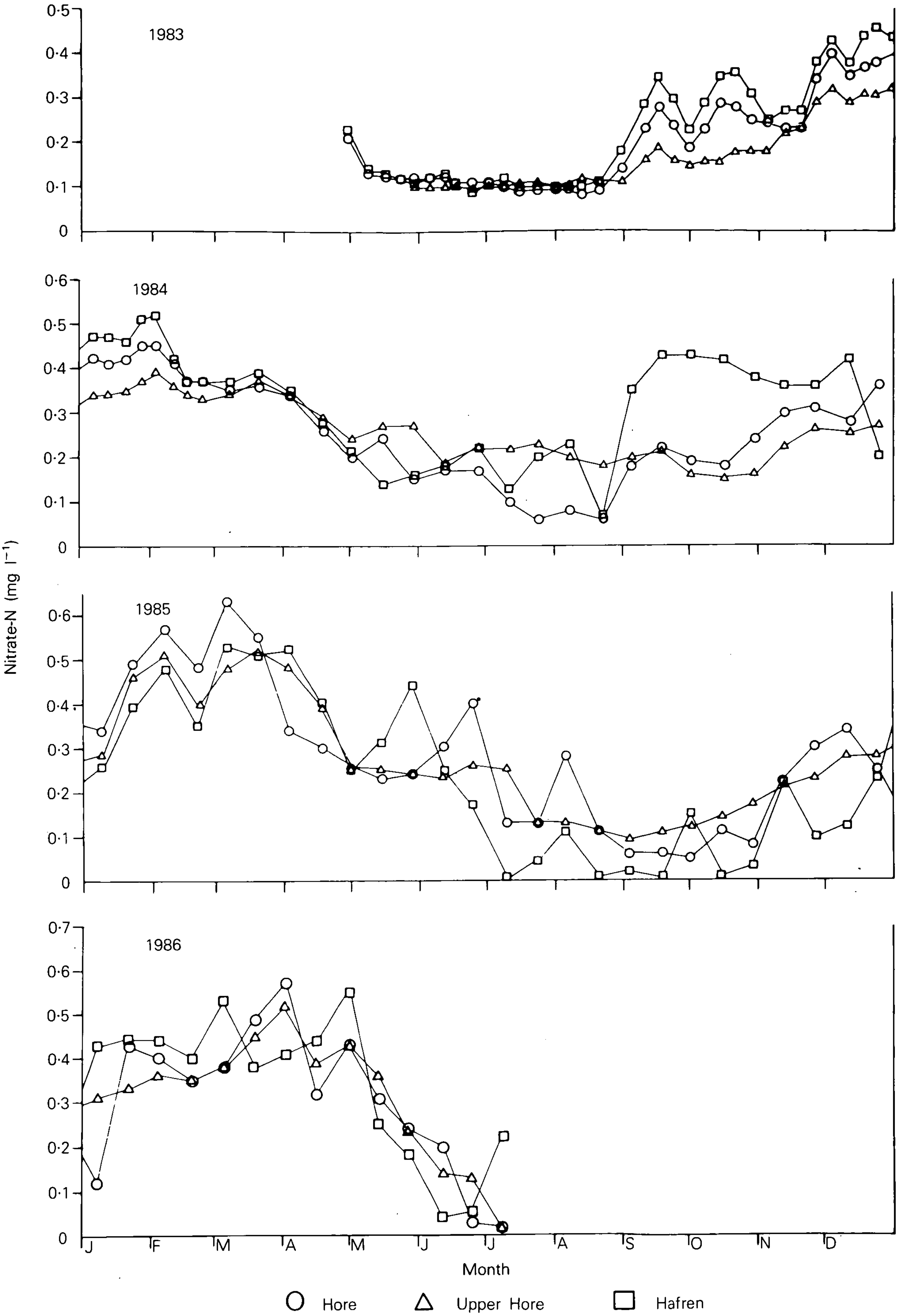

Figure 4. Nitrate-N concentrations in streamflows within the Hafren Forest

(1984) reported large suspended sediment yields following the open ditching of 2 small upland catchments for afforestation above Holmestyles Reservoir in the southern Pennines. These yields caused a major pollution problem at the reservoir, and a new treatment works had to be constructed to provide potable water (Austin & Brown 1982). Similar problems were caused for the water industry by the ploughing of 11.5% of the land in the Cray Reservoir catchment in south Wales for forestry in 1981 (Stretton 1984), and resulted in serious pollution incidents in 1982, involving discoloration and high turbidity of water treated for public supply.

In the IH Llanbrynmair catchments study, the land practices associated with the afforestation of the Afon Cwm have led to the mobilization of sediment from previously stable areas of the catchment. This increase in sediment availability has, in turn, led to increased sediment transport and yields.

In addition to natural erosion scars and stream banks, a number of new sediment sources have become active. The dense drain network in the upper basin has been subject to varying degrees of erosion. As might be anticipated, steep downslope drains and 2nd order drains appear to be most affected. The enhanced sediment load transported through the upper basin channel is demonstrated by in-channel shoals, blockages and over-bank deposits composed mainly of gravel-sized material.

Contour ploughing has reduced the initial outputs of fine sediment from the lower parts of the catchment to the stream channel (see Plate 3). However, road cutting has made a considerable amount of gravel material available to the stream from areas which were previously covered by thin, but relatively stable, soil and grasses. Loose gravels, exposed on steep road embankments, are readily transported by gravity and gully erosion into the stream channel (see Plate 4).

The annual bed-load yields and typical size analyses are shown in Figure 5. Bed-load yields will vary in accordance with a variety of factors, some of which do not relate directly to land use. For example, during the early parts of this study, an unusually high snowmelt flood led to high bed-load yields. This flood yielded sufficient sediment to overtop the weirs in both catchments (see Plate 5). Therefore, the bed-load trapped behind the weirs represented only the minimum values for yield.

The Delyn is relatively steep, with coarse sediment supply in the lower basin and finer gravel screes higher up. These screes contribute sediment directly to the stream channel. As a result, the Delyn bed-load yields are high relative to other mid-Wales grassland catch-

Plate 3. High outputs of fine sediment following drain excavation have been prevented by contour ploughing in the lower parts of the Afon Cwm catchment (Photograph G J L Leeks)

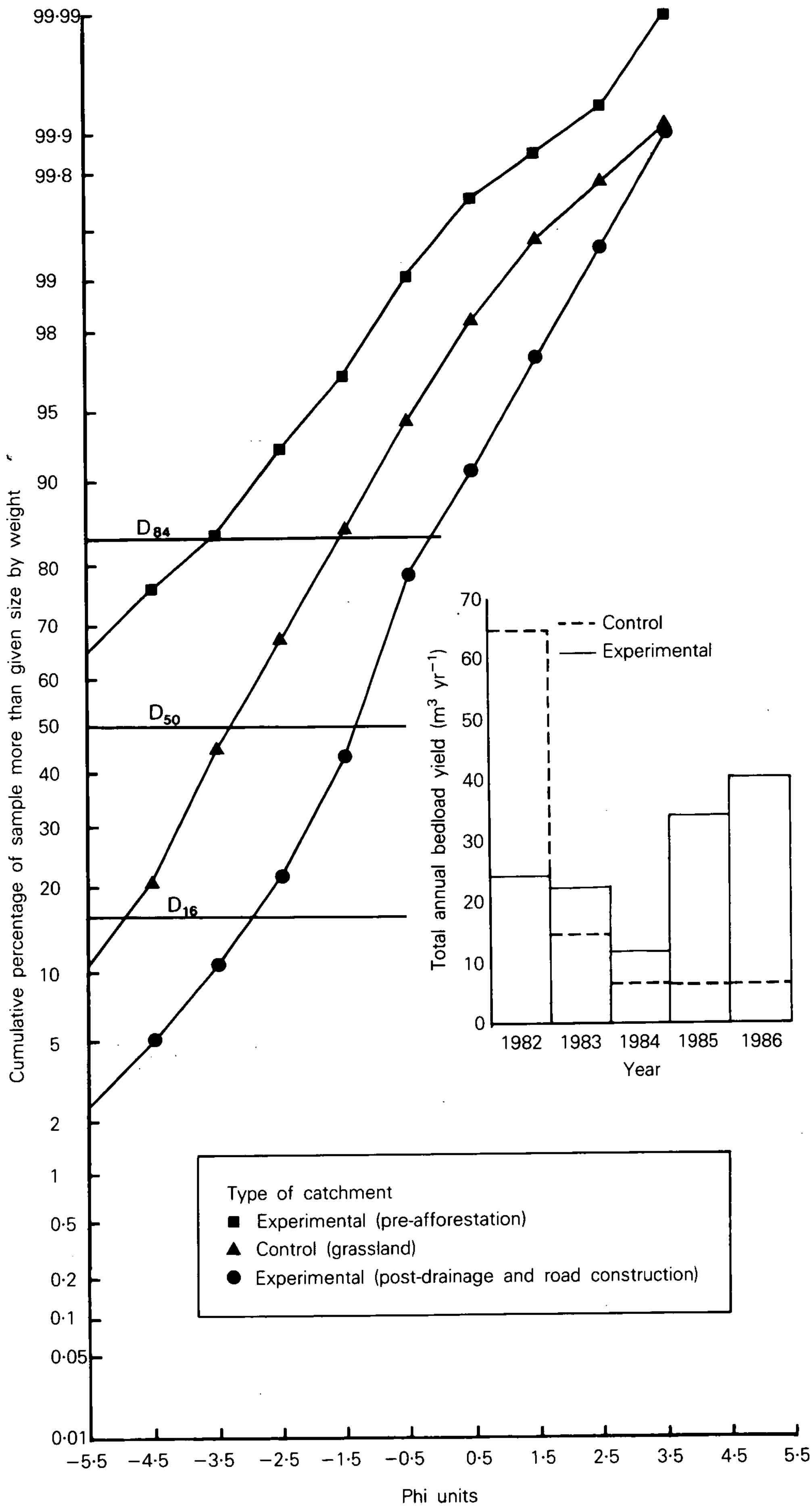

Figure 5. Bed-load size analysis and yields at Llanbrynmair experimental catchments

Plate 4. Loose gravels, exposed on steep road embankments, are readily transported by gravity and gully erosion into the stream channel. Afon Cwm catchment, Llanbrynmair (Photograph G J L Leeks)

ments, and throughout the pre-afforestation period yields are higher per unit catchment area than those from the Afon Cwm. Hence, in terms of the river sediment study, the Delyn yields cannot be regarded as representative of an ideal 'control' catchment.

The size analyses of the bed-load sediments also reveal a contrast between the 2 catchments before the afforestation. The size distributions of the Delyn bed-load tend to be finer than the Afon Cwm pre-afforestation samples (typical samples are shown in Figure 5). The most probable reason for this difference is again the supply of gravel from screes to the Delyn.

Despite the reservations expressed above with regard to the relative bed-load transport response of the 2 catchments, the data collected over the last 5 years do exhibit a number of interesting trends which can be related to land use change. In 1983 and 1984, yields were higher from the Afon Cwm. However, if the catchment areas are taken into account, the yield per square kilometre remains higher in the Delyn. Subsequent to road construction in the lower Afon Cwm catchment during 1984, there was a considerable rise in bed-load yield at the Cwm weir from the beginning of 1985. The supply of loose gravel from road cuttings and embankments is also indicated in the size distribution of bed-load from post-afforestation flood events, with an overall decrease in sediment size yield.

The results for 1986 show no sign of a decrease in yields from the Afon Cwm, and many sediment sources are still undergoing active erosion.

With regard to suspended sediment load, concentrations from 0.001 g l^{-1} up to 0.100 g l^{-1} have been measured at the Afon Cwm weir during natural flows.

These levels have been exceeded during short-lived pulses of sediment following machinery moving through the river (ie up to 0.380 g l^{-1}). However, the overall concentrations do not appear excessive relative to other mid-Wales rivers.

7.2 Mature forest cover

The long-term effects of open ditches have been demonstrated at Plynlimon. Yields of bed-load from sediment traps suggest that mature forested subcatchments are still yielding 3–5 times the volume of bed-load discharged from grassland subcatchments (Newson 1980b; Arkell *et al.* 1983). Similar ratios have been found between drained and undrained areas at Lake Vyrnwy, Nant-y-Moch and the Clywedog Reservoir. Forested streams may also experience increased stream bank erosion, as observed by Murgatroyd and Ternan (1983) in Narrator Brook at the south-western margin of Dartmoor. Bank erosion rates were observed to be higher along forested reaches relative to non-forested. This increased erosion was attributed to suppression by the forest cover of the development of thick grass turf and its associated dense root networks and, secondly, to the river attempting to

Plate 5. Flood events can result in considerable transport of bed-load sediments. Emptying trapped bed-load sediment from the Crump weir at the lower end of the Afon Cwm, Llanbrynmair (Photograph G J L Leeks)

by-pass log jams and debris dams in the stream channel.

The erosion of forestry roads has also been implicated in causing increased streamflow sediment loads (Mills 1980; Graesser 1979), though quantitative evidence is lacking, particularly in upland Britain. However, research carried out in the United States of America (see, for example, Swanson *et al.* 1982) has quantified losses from forestry roads and has identified factors such as means of construction, gradient, maintenance and traffic intensity as being important in determining the magnitude of the increased sediment losses.

The increased outputs of sediment from the uplands may also affect river stability in downstream reaches, as suggested in a regional study of mid-Wales rivers by Newson and Leeks (1987).

7.3 Felling phase

An extensive network of instrumentation has been installed in the Hore catchment. This network is designed to provide a range of data, from overall total sediment yields for whole subcatchments using bed-load traps, down to continuous records of suspended-load discharges, derived from the use of absorptiometric turbidity meters (Thorn & Burt 1975; HMSO 1981) and depth-integrated bulk samplers (Guy & Norman 1970; Leeks 1983). In addition to yield calculations, these data are being used to investigate thresholds in sediment movement and any change in such thresholds and sediment availability as a result of practices associated with tree harvesting.

Although the felling operation is still in progress and many data remain to be analysed, some preliminary results are worthy of mention. The suspended sediment concentrations, derived from vacuum filtration of bulk samples, have been regressed on water discharge to produce a rating curve for the Hore (see Figure 6). This curve can be combined with flow duration data to calculate average annual suspended sediment yields. The yields (shown in Table 1) are also divided by catchment area in square kilometres to permit comparison between the different sizes of catchment.

It is evident from Figure 6 that there is a considerable spread in the relationship between concentration and discharge. This spread is typical of many upland channels and contrasts with published rating curves for many lowland rivers. During the felling operations, there has been a significant increase in the suspended sediment yields of the Hore. Regression lines of concentration *vs* water discharge show higher concentrations for most discharges in comparison with pre-felling samples. The rating curves indicate an increase in concentration by up to an order of magnitude for moderate to high flows. This increase, in turn, is reflected in higher annual yields of suspended sediment (see Table 1), from 24.4 tonnes km^{-2} yr^{-1} up to 57.1 tonnes km^{-2} yr^{-1}.

Table 1. Average annual bed-load and suspended load yields in forested and unforested catchments in mid-Wales. The figures for the Hore catchment indicate the effect of felling operations on suspended load

Catchment	Area (km^2)	Bed-load yield ($t\ km^{-2}\ yr^{-1}$)	Suspended load ($t\ km^{-2}\ yr^{-1}$)	Land use
Hore	3.08	11.8	24.4 (57.1)	Mature forest (First year of felling operations)
Hafren	3.67	NA	35.3	Mature forest
Tanllwyth	0.89	38.4	12.1	Mature forest
Cyff	3.13	6.4	6.1	Pasture

NA-not available

In the case of bed-load, the catches have been accumulated, and then divided by the period of measurement in years and catchment size to facilitate similar comparisons between the yields of different catchments. Before the felling operation, the Hore catchment was discharging fairly low yields of bed-load relative to other nearby forested catchments (see Table 1). However, since the felling operations began, bed-load yield has increased 5-fold at the downstream end of the catchment. In addition, a network of traps on drains and small tributary streams is also being monitored. Following the felling and removal of trees using skidding techniques in one tributary, annual yield of bed-load increased from 1.2 m^3 km^{-2} yr^{-1} during 1983 up to 23.4 m^3 km^{-2} yr^{-1} during 1984. However, as felling continued, tree debris build-up in the channel has led to a decrease in annual yield to 5 m^3 km^{-2} yr^{-1}. It would therefore appear that, in the short term at least, leaving tree debris within the channel may have benefits in reducing bed-load discharge peaks.

It is to be expected that the bed-load response to the felling operations would be much slower than the suspended load, because bed-load tends to move gradually downstream through a number of within-channel stores. In the case of suspended sediment (mostly of clay, silt and fine sand grades), once entrainment has occurred much of the material is transported out of the uplands and into lowland alluvial sections of the river. The main 'wave' of bed-load transport may, therefore, still be upstream of the lower Hore flume.

7.4 Reduction of forested catchment sediment outputs

A number of guidelines to reduce the sediment yields from forests are listed below. These guidelines are based upon the Institute of Hydrology catchment studies, other authors and observed good forest practice.

i. The most appropriate time to plough is spring and early summer as some revegetation is possible,

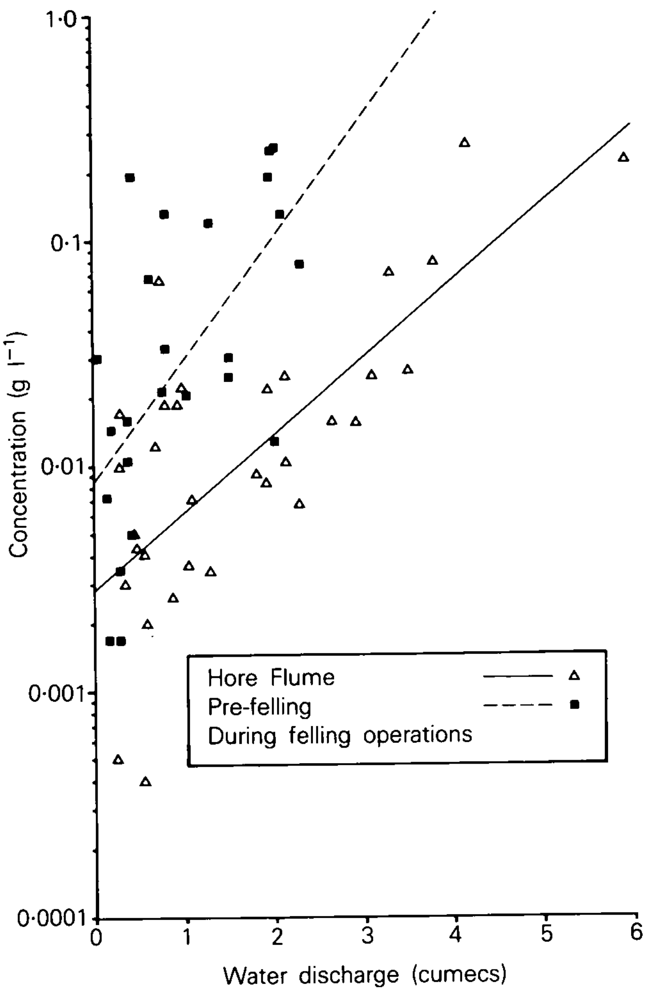

Figure 6. Suspended sediments rating curves for the Afon Hore subcatchment, Plynlimon

thereby reducing the likely suspended sediment outputs over the following year (Burt *et al.* 1984).

ii. When possible, contour ploughing may reduce initial sediment losses. The use of ripping techniques also shows promise.
iii. When excavating ditches through highly erodable materials, gradients of less than 2° are desirable to prevent scour (Newson 1980b).
iv. New forest ditches should be stopped short of the stream channel. Thompson (1979) makes a similar suggestion with regard to lakes and reservoirs. Drains which have suffered erosion during the first rotation could be modified for the second rotation by blocking off outlets to streams or dispersal of flow along new-cross drains. This practice might also be worthwhile during the first rotation, as significant erosion can persist in a drain for several decades unless remedial action is taken.
v. Following felling operations, it is usually considered desirable to clear drains of debris. However, while major blockages are not apparent, small debris dams can reduce peak sediment outputs and therefore reduce the downstream effects of felling operations. In such cases, some delay in drain clearance may be advantageous.
vi. The output of road drains directly into streams should be avoided.
vii. The erodability of road embankments in close proximity to streams can be reduced by protecting the toe with boulder-sized material or gabion baskets.
viii. The quick repair of road embankments in which incipient gullying is discovered near streams, with plastic netting or similar stabilizing material, is worthwhile.
ix. The movement of machinery through streams should be minimized, eg by detours to road bridges, whenever possible.

8 Conclusions from current work

It should be emphasized that the results of the afforestation and felling experiments reported in this paper are preliminary. The felling operations in the Hore have enhanced sediment yields, which were already higher than in comparable grassland catchments. However, to date no consistent trend has been apparent in data on nutrient losses.

In the Cwm, afforestation has led to a rise in chemical concentrations, mainly in the upper basin (notably in ammoniacal-N, ortho-phosphate and potassium). Road construction and drain erosion have led to continuing increases in bed-load yields. The adoption of contour ploughing techniques in the lower basin has effectively reduced the rise in suspended load often associated with open ditching.

9 Acknowledgements

The authors wish to thank their colleagues at the Institute of Hydrology for their help in the preparation of this paper, particularly Jim Blackie, Jim Hudson, Malcolm Newson and Simon Graham (EFG), in addition to the field assistance of Phil Hill and Alun Hughes. Analysis of a considerable number of samples by the Severn-Trent Water Authority is appreciated. The co-operation of the Forestry Commission, Economic Forestry Group and Fountain Forestry Ltd are also gratefully acknowledged.

The studies are part financed by the Department of the Environment and the Welsh Office.

10 References

Arkell, B., Leeks, G.J.L., Newson, M.D. & Oldfield, F. 1983. Trapping and tracing: some recent observations of supply and transport of coarse sediment from upland Wales. *Spec. Publ. int. Assoc. Sedimentol.*, **6,** 107-119.

Austin, A. & Brown, D. 1982. Solids contamination resulting from drainage works in an upland catchment, and its removal by flotation. *J. Inst. Water Eng. Sci.*, **36,** 281-288.

Benoit, G.R. 1973. Effect of agricultural management of wet sloping soil on nitrate and phosphorus in surface and subsurface water. *Water Resour. Res.*, **9,** 1296-1303.

Binns, W.O. 1979. The hydrological impact of afforestation in Great Britain. In: *Man's impact on the hydrological cycle in the United Kingdom*, edited by G.E. Hollis, 55-70. Norwich: Geobooks.

Blackie, J.R., Hudson, J.A. & Johnson, R.C. 1986. *Upland afforestation and water resources: preliminary analyses of* *phase 1 of the Balquhidder catchment studies.* (Progress report.) Wallingford: Institute of Hydrology.

Brown, G.W., Gahler, A.R. & Marston, R.B. 1973. Nutrient losses after clear-cut logging and slash burning in the Oregon Coast Range. *Wat. Resour. Res.*, **9,** 1450-1452.

Burke, W. 1968. Drainage of blanket peat in Glenamoy. *Trans. int. Peat Cong., 2nd, Leningrad*, 809-817.

Burke, W. 1975. Aspects of the hydrology of blanket peat in Ireland. In: *Hydrology of marsh-ridden areas.* (Publication no. 105.) IAHS/AISH UNESCO.

Burt, T.P., Donohoe, M.A. & Vann, A.R. 1984. A comparison of suspended sediment yields from two small upland catchments following open ditching for forestry drainage. *Z. Geomorph.*, n.s., 51-62.

Calder, I.R. 1976. The measurement of water losses from a forested area using a natural lysimeter. *J. Hydrol. (Amst.)*, **30,** 311-325.

Calder, I.R. & Newson, M.D. 1979. Land-use and upland water resources in Britain—a strategic look. *Water Resour. Bull. (U.S.)*, **15,** 1628-1639.

Conway, V.M. & Millar, A. 1960. The hydrology of some small peat covered catchments in the northern Pennines. *J. Inst. Water Eng.*, **14,** 415-424.

Duxbury, J.M. & Peverly, J.H. 1978. Nitrogen and phosphorus losses from organic soils. *J. environ. Quality*, **7,** 566-570.

Gash, J.H.C. & Stewart, J. 1977. The evaporation from Thetford Forest during 1975. *J. Hydrol. (Amst.)*, **35,** 385-396.

Gash, J.H.C., Wright, I.R. & Lloyd, C.R. 1980. Comparative estimates of interception loss from three coniferous forests in Great Britain. *J. Hydrol. (Amst.)*, **48,** 89-105.

Graesser, N. 1979. How land improvements can damage Scottish fisheries. *Salm. Trout Mag.*, **215,** 39-43.

Gray, J.R.A. & Edington, J.M. 1969. Effects of woodland clearance on stream temperature. *J. Fish. Res. Bd Can.*, **26,** 399-403.

Guy, H.P. & Norman, V. W. 1970. Field methods for measurement of fluvial sediment. In: *Techniques of water resource investigations of the USGS.* (Report no. C2 (3).) U.S. Geological Survey.

HMSO. 1981. *Colour and turbidity of waters. Methods for examination of waters and associated materials.* London: HMSO.

Institute of Hydrology. 1976. *Water balance of the headwater catchments of the Wye and Severn.* (Report no. 33.) Wallingford: IH.

Law, F. 1956. The effect of afforestation upon the yield of water catchment areas. *J. Br. WatWks Ass.*, **38,** 489-494.

Law, F. 1957. Measurement of rainfall, interception and evaporation losses in a plantation of Sitka spruce trees. *IUGG/IASH: Gen. Assembly, Toronto*, **2,** 397-411.

Leeks, G.J.L. 1983. Development of field techniques for assessment of river erosion and deposition in mid-Wales. In: *Catchment experiments in fluvial geomorphology*, edited by T.P. Burt & D.E. Walling, 299-309. Norwich; Geobooks.

Likens, G.E., Bormann, F.H., Johnson, N.M., Fisher, D.W. & Pierce, R.S. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed ecosystem. *Ecol. Monogr.*, **40,** 23-47.

Martin, C.W., Noel, D.S. & Federer, C.A. 1984. Effects of forest clear cutting in New England on stream chemistry. *J. environ. Qual.*, **13,** 204-210.

McDonald, A. 1973. Some views on the effect of peat drainage. *Scott. For.*, **27,** 315-327.

Mills, D.H. 1980. *The management of forest streams.* (Forestry Commission leaflet no. 78.) Edinburgh: HMSO.

Murgatroyd, A.L. & Ternan, J.L. 1983. The impact of afforestation on stream bank erosion and channel form. *Earth Surf. Process. Landf.*, **8,** 357-369.

Neary, D.G., Pearce, A.J., O'Loughlin, C.L. & Rowe, L.K. 1978. Management impacts of nutrient fluxes in beech-podocarp hardwood forest. *N.Z. J. Ecol.*, **1,** 19-26.

Newson, M.D. 1976. *The physiography, deposits and vegetation of the Plynlimon catchments.* (Report no. 30.) Wallingford: Institute of Hydrology.

Newson, M.D. 1979. The results of ten years experimental study on Plynlimon, mid-Wales and their importance for the water industry. *J. Inst. Water Eng. Sci.*, **33,** 321-333.

Newson, M.D. 1980a. The geomorphological effectiveness of floods—a contribution stimulated by two recent events in mid-Wales. *Earth Surf. Process.*, **5,** 1-16.

Newson, M.D. 1980b. The erosion of drainage ditches and its effects on bed-load yields in mid-Wales. *Earth Surf. Process.*, **5,** 275-290.

Newson, M.D. 1985. Forestry and water in the uplands of Britain—the background of hydrological research and options for harmonious land-use. *Q. Jl For.*, **79,** 113-120.

Newson, M.D. & Leeks, G.J.L. 1987. Transport processes at a catchment scale: a regional study of increasing sediment yield and its effects in mid-Wales, UK. In: *Sediment transport in gravel bed rivers*, edited by C. Thorne, J. Bathurst & R.D. Hey. Chichester: John Wiley.

O'Loughlin, C.L., Rowe L.K. & Pearce, A.J. 1980. Sediment yield and water quality responses to clear felling of evergreen mixed forest in western New Zealand. *Proc. Helsinki Symp.*, 285-292. (Publication no. 130.) International Association of Hydrological Sciences.

Roberts, G.R., Hudson, J.A. & Blackie, J.R. 1983. *Nutrient cycling in the Wye and Severn at Plynlimon.* (Report no. 86.) Wallingford: Institute of Hydrology.

Roberts, G.R., Hudson, J.A. & Blackie, J.R. 1986. Effect of upland pasture improvement on nutrient release in flows from a natural lysimeter and a field drain. *Agric. Water manage.*, **11,** 231-245.

Roberts, M.E. & James, D.B. 1972. Some effects of forest cover on nutrient cycling and river temperature. In: *Research papers in forest meteorology*, edited by J.A. Taylor, 100-108. Aberystwyth: Cambrian News.

Robinson, M. 1980. *The effect of pre-afforestation drainage on the streamflow and water quality of a small upland catchment.* (Report no. 73.) Wallingford: Institute of Hydrology.

Robinson, M. & Blyth, K. 1982. The effect of forestry drainage operations on upland sediment yields. *Earth Surf. Process. Landf.*, **7,** 85.

Sopper, W.E. 1975. The effects of timber harvesting and related practices on water quality in forested watersheds. *J. environ. Qual.*, **4,** 24-29.

Stone, E.L., Swank, W.T. & Hornbeck, J.W. 1978. The impact of timber harvest and regeneration systems on streamflow and soils in the eastern deciduous region. In: *Forest soils and land use*, edited by C.T. Youngberg, 516-535. Fort Collins: Colorado State University.

Stretton, C. 1984. Water supply and forestry—a conflict of interests: Cray Reservoir, a case study. *J. Inst. Water Eng. Sci.*, **38,** 323-330.

Swanson, F.J., Janda, R.J., Dunne, T. & Swanston, D. N. 1982. *Sediment budgets and routing in forested drainage basins.* (General technical report no. PNW-141.) U.S. Forest Service.

Taylor, G.G.M. 1970. *Ploughing practice in the Forestry Commission.* (Forest record no. 73.) London: HMSO.

Thompson, D.A. 1979. *Forest drainage schemes.* (Forestry Commission leaflet no. 72.) London: HMSO.

Thorn, M.F.C. & Burt, T.N. 1975. *Transport of suspended sediment in the tidal River Crouch.* (Report no. INT148.) Wallingford: Hydraulics Research Station.

The effects of forestry on soils, soil water and surface water chemistry

M HORNUNG, P A STEVENS and B REYNOLDS
Institute of Terrestrial Ecology, Bangor Research Station, Penrhos Road, Bangor, Gwynedd LL57 2LQ

Summary
The changes in soils, soil waters and drainage waters, resulting from afforestation with exotic conifers in the uplands, are discussed. The changes result partly from the replacement of the grassland, moorland or bog vegetation with forest vegetation, and partly from forest management practices. The impacts on soils are discussed for 2 groups: (i) brown podzolic soils and brown soils, and (ii) stagnopodzols, stagnohumic gleys and peats. The results of recent work on soil solution chemistry of brown podzolic soils and stagnopodzols under moorland and conifer plantations are outlined and linked to differences in chemistry of streams draining from moorland and forests. The impact of clearfelling on soil water and drainage water chemistry is reported; the impact of losses at felling on site fertility is considered. The long-term consequences of the changes in soils and soil waters, resulting from afforestation, are discussed.

1 Introduction
Vegetation is one of the major factors influencing soil properties and processes (Jenny 1941, 1980); studies in natural communities have clearly demonstrated changes in soil chemistry, biology and processes following invasion of heath or grassland by forests, or even by single trees (eg see review by Hornung 1985). The establishment of large conifer forests in upland Wales represents a drastic change in the plant cover of the planted areas. In most cases, the forests have replaced low-growing grassland, moorland or bog vegetation, but in some areas they have replaced hardwood stands. It would not be surprising if such a change in the vegetation, especially the conversion from non-tree vegetation to forest, resulted in changes to the underlying soils.

The establishment of forests in upland areas of Britain also involves site management which will influence the physical, biological and chemical properties of soils, eg ploughing, drainage, fertilization. The cycle of forest management, site preparation—planting—thinning—clearfelling—replanting, also introduces a series of perturbations into the ecosystem. These perturbations are likely to produce a cyclical pattern of variation in soil conditions which themselves may be reflected in changes in direction, or rate, of soil processes.

The physical, biological and chemical properties, and processes, of soils are also major factors influencing the chemistry of surface drainage waters. Physical properties influence water pathways, from surface to stream, and the residence time of water within the soil system. The chemical properties influence soil/water reactions, and hence the chemistry of drainage waters. Biological processes in soils often control the uptake and release of elements in soils, and to and from soil waters, and have a major impact on drainage water quality. If the creation and management of coniferous plantations cause modifications in soil properties and processes, there are likely to be consequent changes in water quality.

This paper identifies the changes in the site and soil environment consequent upon afforestation, reviews the results of relevant research, and assesses the long-term consequences of any changes. It draws upon data from recent and current research in Wales but, where relevant, also uses information from studies on similar soil types in the rest of Britain and in western Europe.

2 Changes in the site and soil environment following afforestation
Before reviewing the results of specific studies on the impact of conifers on soils, it is useful to identify those changes in the site and in vegetation/atmosphere, and vegetation/soil interactions consequent upon afforestation. We will consider 2 groups of interacting changes:
— those resulting from growth of the coniferous trees
— those resulting from forest management practices.

2.1 Changes resulting from tree growth
For the purpose of this discussion, we will concentrate on those situations where plantations have replaced grassland, moorland or bog vegetation. During the early years of a plantation, the trees probably exert little influence on the soils, and site management impacts will dominate at this stage. The main impacts of the trees probably become evident following canopy closure. In western Britain, interception losses of precipitation from the tree canopy are some 10–20% greater than those from grass or moorland vegetation (Calder & Newson 1979). Thus, 10–20% less moisture reaches the ground surface, and solute concentrations in precipitation will be increased in proportion. The tree canopy is also a much more efficient collector of particulate and aerosol material from the atmosphere than the low-growing grass, heath and bog species (Miller & Miller 1980). Conifers are more efficient collectors than broadleaves, such as oak (*Quercus* spp.) or beech (*Fagus* spp.) (Ulrich 1983). A particularly important effect in the uplands of western Britain seems to be the very efficient capture of aerosols in occult precipitation (mist, fog and cloud)

by conifer canopies (Unsworth 1984): this occult deposition has much higher concentrations of solutes, pollutant and non-pollutant, than rain or snow (Dollard *et al.* 1983; Lovett *et al.* 1982). As a result of this increased load of solutes 'captured' from the atmosphere, plus the concentration effect due to the enhanced transpiration and solutes washed from the tree canopy by canopy leaching, the waters reaching the ground below the forest canopies differ markedly in chemistry from those below grass or heath vegetation (eg Table 1). The higher concentrations of solutes in the throughfall under conifers than under grass or heath vegetation may be a more important factor influencing soil/solute interactions than the slightly increased acidity.

Table 1. Mean solute concentrations for one year in throughfall beneath Sitka spruce and mat-grass grassland at Plynlimon (concentrations in mg l^{-1}, except pH)

	Sitka spruce	Mat-grass
pH	4.4	4.6
Na	3.5	2.4
K	2.2	2.0
Ca	1.0	0.7
Mg	0.7	0.5
NH_4-N	0.28	0.15
NO_3-N	0.22	0.07
SO_4-S	2.31	0.96
Cl	5.9	5.0
DTOC*	5.3	11.8

* Dissolved total organic carbon

The amount, and chemistry, of the water reaching the ground also varies spatially. Stemflow is concentrated around the bases of the stems and can produce a large input in a small area. Stemflow also contains higher concentrations of solutes, and is usually more acid than the throughfall, or canopy drip (Table 2). In addition, the chemistry of throughfall varies markedly with tree species and age (Miller 1984a). Of the more commonly grown species, larch (*Larix* spp.) produces a more acid throughfall than spruce (*Picea* spp.) or pine (*Pinus* spp.) (eg Table 3). A study of an age sequence of Sitka spruce (*Picea sitchensis*) in Beddgelert Forest showed that up to 35 years of age throughfall was less acid than the incoming precipitation, but in older crops it was consistently more acid (Stevens 1987).

The rooting pattern of trees is very different from that of the grass, heath or moorland vegetation they replace; rooting patterns will vary considerably with species and soils. Tree roots create many large pores which, in drier soils, provide pathways for water movement. The increased transpiration of trees, added to the reduced water input to the soil, can result in a significant drying and cracking of soils. The rooting pores and drying cracks facilitate rapid water movement and can significantly alter the hydrological properties of the soils; they also provide avenues for air entry into the soil. The drying of the soil will result in

Table 2. Volume-weighted mean solute concentrations for one year in throughfall and stemflow beneath Sitka spruce (P.1936) in Beddgelert Forest (concentrations in mg 1^{-1}, except pH)

	Throughfall	Stemflow
pH	4.07	3.62
Na	12.3	32.0
K	1.4	3.7
Ca	1.0	3.2
Mg	1.5	4.3
NH_4-N	0.65	0.62
NO_3-N	0.92	1.17
SO_4-S	3.1	7.7
H_2PO_4-P	0.027	0.036
Cl	21.3	60.5
DTOC*	2.0	7.0

* Dissolved total organic carbon

changes in biological and chemical processes; the presence of roots in deeper horizons may also lead to changes in weathering and element release.

The organic matter on the forest floor may be very different in type, biology and chemistry to that from grass or heath vegetation. Most coniferous species will produce a moder, or mor humus, which may be significantly more acid than the organic horizons, if any, produced by the preceding vegetation. The breakdown products of the humus will also differ from those of other humus types. Nutrient cycling in the forest is markedly different to that in the preceding non-tree vegetation. In the early years of a plantation, there is a net accumulation of elements in the tree and the forest floor (the organic horizons which accumulate below the forest). At later stages, the release of nutrients from the forest floor, by decomposition, plus inputs from the canopy, may balance uptake (Miller 1984b). The pattern of element uptake may also differ in the forest as compared with the non-tree vegetation. While most elements will be taken up from near-surface horizons, there will be some uptake from deeper soil layers.

Table 3. Mean solute concentrations for one year in throughfall beneath Sitka spruce (P.1949) and Japanese larch (P.1949) at Plynlimon (concentrations in mg l^{-1}, except pH)

	Spruce	Larch
pH	4.37	3.9
Na	3.5	3.0
K	2.2	1.0
Ca	1.0	1.0
Mg	0.7	1.0
NH_4-N	0.28	0.15
NO_3-N	0.22	0.15
SO_4-S	2.3	3.4
Cl	5.9	6.4
DTOC*	5.3	8.2

* Dissolved total organic carbon

The dense canopy produced, particularly by spruce, will clearly result in reduced light penetration and a changed microclimate. At canopy closure, the ground flora will be shaded out, resulting in a large addition of dead plant material to the soil surface; breakdown of this material will release elements which may be taken up by the trees, held in soil or lost to drainage waters.

The temperature regime at ground level will change, with lower summer temperatures but higher winter ones than in the preceding non-forest vegetation. The changed humus and microclimate result in a modified soil fauna, with consequent influences on decomposition and mixing of surface organic materials.

2.2 Changes due to forest management practices

2.2.1 Site preparation

Most of the wetter and/or heather-dominated upland sites are ploughed prior to planting (Thompson 1984). Ploughing is designed to suppress competing vegetation, improve surface drainage and aeration, provide an improved planting position and increase rooting depth (see Plate 6). It produces inversion and mixing of surface soil. The disturbance and drying can produce an increased rate of decomposition, with an enhanced release of elements: these released elements may be taken up by the ground flora, retained within the soil or leached out into drainage waters, with a consequent impact on water quality. The ploughing also exposes subsurface soil, which may lead to increased rates of weathering and element release.

Drains are designed to remove surface and near-surface water from the site, and, therefore, to reduce waterlogging and improve rooting conditions (Thompson 1979). The drainage will cause drying of the soil and will expose subsoil horizons or drift in the ditch walls to erosion or weathering. Together, the plough furrows and drains can radically alter water pathways between soil surface and stream channel, reducing residence times of water and consequently water chemistry. A major effect may be an increase in the proportion of water reaching the streams from the surface horizons of soils.

2.2.2 Fertilization

The use of fertilizers will increase the soil store of the added elements. As the fertilizer breaks down, the released elements will be taken up by the trees or ground flora, retained in the soil or leached to drainage waters. The fertilizer may also change soil pH, leading to changes in soil processes. Phosphate, applied as rock phosphate, is the most widely used fertilizer in Welsh forests; it will add calcium to the soil, in addition to phosphorus.

2.2.3 Felling

Clearfelling, and to a lesser extent thinning, will cause a series of changes in site conditions, many of which are reversals of those associated with canopy closure (Hill *et al.* 1984). Capture of elements from the atmosphere, interception and transpiration loss will be reduced. The input of elements to the soil surface will

Plate 6. Land ploughed prior to planting—Dyfi forest (Photograph J H Williams)

Plate 7. Brash produced when felling the first rotation—Helmsley Forest, Yorkshire (Photograph J H Williams)

decline, but water inputs will increase. There is a sudden large addition of plant material to the soil surface as slash (see Plate 7). Uptake by plants of nutrients released by decomposition, and from mineral sources, will effectively cease. Light penetration and the microclimate at ground level will change. A significant quantity of nutrients will be removed from the site in the timber.

3 The impact on soils

3.1 Brown earths and brown podzolic soils

Most of the early, extensive, planting of exotic conifers in Wales was on brown earths and brown podzolic soils of the lower valley-sides. These soils would have carried mixed oak/birch (*Betula* spp.) woodland prior to forest clearance and would have largely evolved as forest soils. There has been little work in Wales on the impact of coniferous plantations on these soils, but a great deal of research on broadly similar soils (sol brun acide, sol brun ochreux, sol brun podzolique) has been carried out in western Europe.

Most of these studies compare the soils beneath adjacent stands of hardwoods and conifers, or below hardwood and conifer stands on soils which are assumed to have been similar prior to planting the conifers. Clearly, great care must be taken in this type of study to ensure that detected soil differences are a result of the differences in vegetation and not due to inherent variations in the soils. Because of this kind of consideration, many early studies which report acidification and podzolization of soils by conifers are now questioned (Stone 1975). There are, however, a number of reliable recent comparative studies, based on carefully evaluated sites, plus process studies comparing hardwood and conifer systems. Taken together, these studies identify a variety of soil changes resulting from growth of monocultures of exotic conifers, especially spruce. The most consistently reported change is the development of an acid mor humus, replacing mull or moder, with a lower nitrogen content and higher carbon/nitrogen ratio (eg Nihlgard 1971; Herbauts & de Buyl 1981; Nys & Ranger 1985). One result of the change in organic matter is an increased proportion of fulvic to humic acids in the breakdown products. The surface and near surface horizons are also generally acidified and the content of both total and exchangeable base cations reduced. The loss of base cations is generally assumed to indicate increased mineral breakdown and leaching, but Nys and Ranger (1985) concluded that the potassium and magnesium losses from the surface horizon which they measured under spruce were a result of increased clay illuviation; this clay was retained in the B horizon and did not represent a loss from the site. An increased translocation of iron and aluminium from near-surface horizons has been reported from a number of studies (eg Nys & Ranger 1985; Herbauts & de Buyl 1981); in a few instances, the development of a clear eluvial horizon has been reported (Nihlgard 1971; Bonneau 1973). Herbauts and de Buyl (1981) suggest that the increased ratio of iron to aluminium in NaOH/Na-tetraborate extracts from the B horizon below spruce shows evidence of marked podzolization, compared to below beech. The same authors report an increased penetration of fulvic acids into the B horizon. Increased breakdown of clay minerals under spruce is also reported by Nys (1981) and Herbauts and de Buyl (1981); this evidence is taken as an indication of an increased trend towards podzolization. Structural changes were found by Nys and Ranger (1985), Schlenker *et al.* (1969) and Bonneau *et al.* (1977). Nys and Ranger report a 30–40% decrease in porosity beneath spruce and a reduction in structural stability. These latter authors also summarize the detected changes beneath coniferous species and assess whether or not they are reversible (Table 4).

Table 4. Summary of detected changes in soils beneath coniferous species replacing broadleaves (source: Nys & Ranger 1985)

PHYSICAL	
Bulk density change	Reversible?
Structural degradation	Reversible?
Reduction in porosity	Reversible?
Particle migration	Irreversible
CHEMICAL AND PHYSICO-CHEMICAL	
Structural degradation	Irreversible
Organic matter: loss of N	Reversible?
Reduction of mineral cation exchange capacity associated with leaching	Irreversible
Change in the exchange complex	Irreversible
Total loss of elements	Irreversible
— by drainage out of the ecosystem	Irreversible
— beyond the rooting zone	Irreversible

The impact of conifer plantations will, however, vary with soil type and with crop species. Bonneau *et al.* (1979) stress the importance of variations in soil parent material, and suggest that the impact on fine-textured parent materials, and those with high levels of exchangeable bases, is negligible. Soils with parent materials derived from crystalline rocks or acid sediments poor in iron and bases are considered the most sensitive. In this respect, it is worth noting that the development of a thick eluvial horizon under spruce, reported by Bonneau (1973), occurred on freely drained, sandy, base-poor material. Care must be taken, therefore, when extrapolating results from one site to another.

Three British studies have examined the impacts of conifers on brown earths or brown podzolic soils. Results from a study by Grieve (1978) broadly parallel those reported from France and Belgium. He compared the soils beneath stands of 50-year-old spruce with those below mixed oak/beech, last replanted in 1815, in the Forest of Dean. The soils were classified as brown earths of the Neath series. There was significant leaching of iron under the spruce, with the formation of eluvial and illuvial horizons. A discrete humus horizon had also formed under the spruce, horizon boundaries were sharper and the structure was coarser and weakened. Grieve (1978) concluded that there had been a change in the balance of the soil-forming processes with a move towards podzolization under the spruce.

Hornung and Ball (1972) compared the surface horizons in 30-year-old Sitka spruce plantations, and adjacent fescue/bent (*Festuca/Agrostis*) grasslands at 3 sites in north Wales. The soils at all 3 sites were brown podzolic of the Manod series (Rudeforth *et al.* 1984). The 0–5 and 5–10 cm depths were compared, having first removed the forest floor. Both sampled zones were significantly more acid below the spruce at all 3 sites. Two sites showed increases in loss-on-ignition and total nitrogen, whilst the third showed a reverse trend. Data on exchangeable cations showed no consistent trends. Page (1968) examined soils under size sequences of Sitka spruce, Douglas fir (*Pseudotsuga menziesii*) and Japanese larch (*Larix leptolepis*) in Gwydyr Forest, north Wales: all 3 species were growing on brown podzolic soils. Generally similar trends were found under all 3 species: litter thickness and moisture content increased up to a top height of 18 m (60′) to 27 m (80′) and then declined again to the level found in unplanted soils. Bulk density and pH decreased until a top height of 18–27 m and then increased back to the starting value below 36 m (120′) tall trees. The A_2 (Ea) horizon below Sitka spruce showed a gradual and continuous increase with top height. This study by Page (1968) highlights the difficulties in drawing conclusions from studies based on one point in the crop rotation.

Several of the changes in soils discussed above could be taken as indicating an increasing tendency towards podzolization, which may actually be an intensification of already existing processes in the soil. Thus, Herbauts and de Buyl (1981) conclude that the soil under beech shows indications of podzolization which become clearer under spruce.

3.2 Peats, stagnopodzols and stagnogleys

The majority of the extensive forest plantings in upland Wales have occurred on humic gley soils, stagnohumic gleys, stagnopodzols and peats. In some areas, particularly at the lower end of their altitudinal range, these soils have evolved from former forest soils, under the influence of heath or moorland vegetation. The replacement of the forest vegetation led eventually to the development of soils with organic, or peaty surface horizons, and zones of intensive weathering and eluviation in the near surface mineral horizons. Podzols were developed on rather better drained sites, with stagnohumic gleys or peats on benches or gentle slopes. They are all naturally very acid, base-poor soils; in the mineral horizons, the exchange complex is dominated by aluminium. There have been very few studies of the impact of afforestation on the properties of such soils. There are few areas of similar soils in mainland Europe, particularly those areas where exotic conifers have been planted. The emphasis in Britain has been on developing improved silvicultural methods for use on these rather difficult soils, or on the performance of the trees, rather than on impacts of the trees on the soils.

There have, however, been a number of studies on the drying of peat, following afforestation, and the linked changes in exchangeable cations, nitrogen availability and acidity (eg Binns 1979; Pyatt 1976; Williams *et al.* 1978; Boggie & Miller 1976). Pyatt (1976) found that the extent of drying and the development of shrinkage cracks in peat were related to the original depth of peat, degree of humification, tree species and, probably, climate. In common with other workers, he found that lodgepole pine (*Pinus contorta*) produced by far the greatest drying effect of the commonly planted species. The drying tended to be more intense and cracking more rapid in relatively shallow, and well-humified peat: at a site near Dumfries, shrinkage cracks had already developed under 9-year-old lodgepole pine. Pyatt (1976) also reports that the drying is irreversible. The increased drying below lodgepole pine, compared with the adjacent unplanted bog, increased the percentage air volume down to 40 cm, doubling it in the top 20 cm, at the site studied by Boggie and Miller (1976). Binns (1979) and Williams *et al.* (1978) report increased acidity of the dried peat, increased bulk density, increased exchangeable sodium but decreased calcium. The calcium decrease seems to be linked to uptake by the crop. The increased sodium is thought to be due to enhanced aerosol capture on the canopy. The increased acidity is said to be a result of increased exchangeable hydrogen on newly created exchange sites, formed as a consequence of greater organic matter breakdown in the more aerobic environment.

Similar changes might be expected in the surface peaty horizons of stagnohumic gley soils (peaty gleys) and stagnopodzols (peaty podzols). Pyatt (1973) has reported pronounced drying of the peaty horizon of a stagnohumic gley in Kielder Forest, Northumberland. More surprisingly, he found significant drying of the underlying mineral horizons down to 90 cm, although rooting was limited to 20–30 cm. Further studies in Kielder Forest (King *et al.* 1986) have shown considerable lowering of the water table, especially in the summer months, by Sitka spruce and lodgepole pine on stagnohumic gley soils, and a corresponding improvement in the oxygen regime. In a study of water and oxygen regimes in a range of soils in Newcastleton Forest, south Scotland, Pyatt and Smith (1983) found healthy roots present in brown earths to a depth of 85 cm and in an ironpan stagnopodzol to 75 cm. In the latter soil, the roots had penetrated the iron pan and the resultant macropores must have had an important effect on water pathways and movement in that soil. Recent work by the authors on stagnopodzols in Hafren and Towy Forests revealed an increase in cation exchange capacity and exchangeable hydrogen in the surface peaty horizon, as compared with similar soils below moorland.

Most sites with peat, stagnogley, gley or stagnopodzol soils have been ploughed and drained prior to planting. The drying effects reported from these soils will reflect the combined influence of increased interception and transpiration and of ploughing and drainage.

Ross and Malcolm (1982) examined the physical effects of ploughing on a peaty ferric stagnopodzol in south-east Scotland. The cultivated soil had lower bulk density, was better aerated, showed faster infiltration and had higher mean annual temperatures than untilled soil. The ploughing produced an intimate mixing of the organic and mineral horizons to a depth of 60 cm.

It is very surprising that there are no published data on the impacts on soil biology and chemistry of such ploughing and drainage operations.

3.3 Harvesting effects on soils

At harvesting, heavy machinery is used for felling and timber extraction. The ground traversed by this machinery becomes compacted, especially those areas used as skid trails or for repeated access by forwarders. A recent study of a site in Scotland indicated that some 10% of the ground was affected by passage of machinery (H G Miller, pers. comm.). There are, as yet, no British data available on the impact of this traffic on bulk density or structure, or on the consequential effects on infiltration and soil erosion, or on the growth of the next crop. Studies in north America and New Zealand, however, have reported significant increases in bulk density, which persisted well into the next rotation.

4 The impact on soil water and drainage water chemistry

4.1 Site preparation

As noted above, ploughing and drainage of sites involve disturbance and mixing of surface soil, and exposure of soil to the atmosphere, resulting in drying of the soil and consequent modification to soil chemical and biological processes. To date, there are no published studies on the impact of ploughing and drainage on soil water chemistry, although work is in progress by the authors as part of the Llyn Brianne study and at other sites in Wales. The soil changes produced by ploughing and drainage may be expected to influence the chemistry of surface waters draining from the site. There have, however, been few attempts at characterizing, or quantifying, any changes in water quality. Robinson (1980) monitored water quality for a short period during ploughing and drainage of a site on stagnohumic gleys and peats in Cumbria, also drained by the Coal Burn, a tributary of the Irthing. Concentrations of calcium, magnesium, nitrogen and potassium increased following ground treatment. There was also a change in the relative abundance of the 4 main cations, from Na Ca Mg K before drainage to Ca Na Mg K after drainage. The additional calcium and magnesium were probably derived from the glacial till exposed in the drains and some of the plough furrows. The increased levels of nitrogen and potassium probably reflect enhanced release from organic sources. Studies in Finland (eg Hynninen & Sepponen 1983) have found increased levels of ammonium and nitrate in drainage waters following ploughing and drainage of peats; these increases have been linked to higher rates of decomposition following drying of the peat.

Unpublished results from a study at Nant-y-Moch in west Wales show large increases in sulphate, ammonium and aluminium following ploughing and drainage (A S Gee, pers. comm.). The sulphate and ammonium were probably produced by enhanced decomposition and oxidation as a result of drying, while the aluminium was probably mobilized from the exposed mineral horizons. At Llanbrynmair in mid-Wales, ploughing close to the contour has been used in an attempt to limit the impact of site preparation on water quality. Data obtained from a study carried out at this site by the Institute of Hydrology (Leeks & Roberts, this volume) have shown no changes in drainage water chemistry following site preparation. The impacts on the soils will remain the same, but the products of the changed decomposition and the drying are being kept on-site.

4.2 Established crop

4.2.1 Soil waters

The emphasis of most studies on stagnogley soils, stagnopodzols and peats, discussed above, has been on physical changes, with only a limited amount of work on changes in peat chemistry and none on the chemistry of the deeper horizons. The authors have recently established a number of studies on soil solution chemistry at a series of sites in Wales and northern England (Hornung *et al.* 1986a, b; Reynolds *et al.* 1987). The results to date show clear differences in solution chemistry between waters extracted from initially similar soils below coniferous plantations and nearby grassland or moorland. There are also differences between the waters from different soils within the forest, and from below different crop species on the same soil.

The forest soil waters contain higher concentrations of most measured solutes than those from the moorland soils (Table 5). The largest increases are shown by sodium, chloride, sulphate and aluminium: aluminium and sulphate concentrations in the mineral horizons of the forest soil waters are almost 3 times those in the moorland soil, while sodium and chloride concentrations are some 50% higher. The aluminium appears to be mobilized from cation exchange sites, by ion exchange. Hydrogen ions, either input in throughfall or stemflow, or mobilized by ion exchange in the very acid, surface organic horizons, exchange for and displace the aluminium into solution. The process is driven, however, by the increased input of inorganic anions, mainly sulphate, to the forest soils (Reynolds *et al.* 1987), which are derived, ultimately, from atmospheric sources. The greater sulphate input to the forest soils reflects enhanced deposition of aerosols on to the forest canopy, with deposition of occult precipitation likely to be particularly important. There will, however, also be a contribution from the increased chloride input and from organic anions derived from the forest floor and from decomposition of the pre-existing peat horizon. The contribution from organic anions, however, seems to be small.

Table 5. Mean soil water solute concentrations for one year in the E, B and C horizons of a stagnopodzol under Sitka spruce and mat-grass/fescue grassland at Plynlimon (concentrations in mg l^{-1}, except pH)

	Forest			Grassland		
	E	B	C	E	B	C
pH	4.1	4.3	4.5	4.3	4.4	4.7
Na	4.9	6.2	5.8	4.3	4.0	4.5
K	0.1	0.2	0.3	0.2	0.2	0.3
Ca	1.1	0.9	0.7	0.4	0.3	0.3
Mg	0.7	0.7	0.6	0.5	0.5	0.6
NH_4-N	0.01	0.02	0.02	0.02	0.02	0.02
NO_3-N	0.15	0.02	0.22	0.54	0.39	0.61
SO_4-S	2.6	3.3	3.0	1.4	1.1	1.2
Cl	8.3	11.6	10.0	7.4	6.5	7.2
DTOC*	11.8	6.1	4.1	6.0	3.7	2.3
Fe	0.30	0.05	0.01	0.07	0.04	0.02
Al	1.2	1.5	1.5	0.5	0.4	0.6
Si	1.5	1.5	2.0	1.2	1.0	0.9

* Dissolved total organic carbon

Aluminium concentrations in the waters from the forest soils under Sitka spruce at sites in Towy, Hafren and Beddgelert Forest range from 0.7 mg l^{-1} in brown podzolic soils to 1.0 mg l^{-1} in intergrades between brown podzolic soils and stagnopodzols, and to over 2 mg l^{-1} in an ironpan stagnopodzol at high altitude. Preliminary data also suggest a species effect, with higher aluminium concentrations in similar intergrade soils under larch (1.5 mg l^{-1}) than Sitka spruce (1.0 mg l^{-1}). This finding may reflect a greater production of nitrate in the larch forest floor (cf Carlisle & Malcolm 1986); some of the nitrate is apparently leached down the soil profile, increasing the anion load and leading to additional aluminium mobilization.

4.2.2 Surface waters

Recent studies in Wales (Stoner *et al.* 1984; Stoner & Gee 1985), north-west England (Bull & Hall 1986) and Scotland (Harriman & Morrison 1982) have reported differences in water chemistry between streams draining from established upland plantations and from adjacent unplanted moorland on otherwise similar sites. A number of solutes are present at higher concentrations in the forest streams than in those draining moorland. Concern about the differences in water chemistry has focused, however, on the increased acidity and higher aluminium concentrations in the forest streams. For example, mean annual aluminium concentrations in forest streams at our site at Beddgelert (Table 6) are greater than 0.5 mg l^{-1}, but normally less than 0.2 mg l^{-1} in a nearby moorland stream; the pH of the forest stream is 0.4 units lower than the moorland stream. These particular changes in chemistry have been linked to reductions in the diversity of invertebrate populations and reductions in fish numbers (Ormerod *et al.*, this volume).

Table 6. Discharge-weighted mean solute concentrations in streams draining Sitka spruce forest and moorland at Beddgelert (concentrations in mg l^{-1}, except pH)

	Forest	Moorland
pH	4.38	4.80
Na	6.2	4.1
K	0.25	0.12
Ca	1.5	0.9
Mg	0.9	0.6
NO_3-N	0.63	0.08
SO_4-S	2.4	1.4
Cl	11.5	7.2
Al	0.56	0.2

The link between increased aluminium concentrations and acidity, and afforestation is not found at all sites, and it seems to be restricted to those areas where acid soils overlie massive, base-poor bedrock. These conditions obtain over a large proportion of the Welsh uplands. Given these conditions, aluminium concentrations and acidity may be greater in the forest streams at all flow levels. The differences between aluminium concentrations in forest and moorland streams are, however, greatest during periods of high flow. Thus, at Beddgelert, aluminium concentrations have reached more than 2.5 mg l^{-1} during flood events, while remaining below 0.2 mg l^{-1} in adjacent moorland streams. The magnitude of the difference in solute chemistry between forest and moorland streams seems to vary somewhat with soil type, being less in catchments dominated by brown podzolic soils than in those dominated by stagnopodzols and stagnohumic gleys. The levels reached by aluminium concentrations during a specific storm vary with the intensity of the storm and with antecedent conditions. Even when streams show similar acidity, the aluminium levels may differ. Thus, Reynolds *et al.* (1986) found that forest and moorland streams on similar bedrock, in the Plynlimon area, had similar pH and calcium levels (Table 7), but that the aluminium concentrations were significantly greater in the forest stream.

The causes of the increased acidity and aluminium concentrations are still being investigated, and it seems that a number of processes may be involved (Miller 1985). The increased interception and transpiration of the forest, compared to moorland or grassland, produce a concentration effect. The deposition, or capture, of aerosols, especially those in occult deposition, is greater on to forest canopies than on to

Table 7. Discharge-weighted mean solute concentrations in streams draining Sitka spruce forest and moorland at Plynlimon (concentrations in mg l^{-1}, except pH)

	Forest	Moorland
pH	4.7	4.8
Na	4.5	3.7
K	0.16	0.14
Ca	0.9	0.8
Mg	0.8	0.7
NO_3-N	0.42	0.21
SO_4-S	1.5	1.2
Cl	7.7	6.3
Al	0.28	0.1

grassland or moorland vegetation. Together, these mechanisms produce an increased input of salts to the forest soils. The acid organic layers which develop below the forest also produce organic acids during decomposition. Uptake of nitrogen in ammonium form, by the conifers, will result in the balancing release of hydrogen ions from the roots. Accumulation of base cations in the tree may also have a long-term acidifying effect on the soils (Nilsson *et al.* 1982).

Analysis of our data on soil water chemistry suggests that ion exchange, driven mainly by the increased input of anions resulting from enhanced 'capture' on the canopy, explains the raised levels of aluminium in the forest soil waters (Reynolds *et al.* 1987). The soils provide, therefore, a source of water with high concentrations of aluminium. The ploughing and draining, and resulting drying cracks, plus the macropores created by tree roots, alter the soil and site hydrology. A major result of the changed hydrology is an increase in the proportion of water reaching streams from the acid, upper soil horizons. The water is also transferred to the stream quicker, with less time, therefore, for buffering. Whitehead *et al.* (1986) have used hydrochemical models to demonstrate the importance of changing the proportions of streamwater derived from different sources, in particular the balance between groundwater and acid surface soil water. These 2 processes of increased solute loadings in the soils, but especially of sulphate, and changed site hydrology probably interact to give the detected changes in streamwater chemistry. At our Beddgelert Forest site, however, the forest streams are more acid and contained higher concentrations of aluminium than the moorland stream (Table 5), even though the site was not ploughed or drained. At this site, the dominant influence appears to be increased mobilization of aluminium as a result of the greater anion loading.

4.3 Clearfelling

Many studies on the impact of clearfelling on water quality have been carried out in north America (eg Likens *et al.* 1970; Aubertin & Patric 1974; Cole *et al.* 1975; Vitousek & Melillo 1979), Scandinavia (eg Tamm *et al.* 1974; Haveraaen 1981) and New Zealand (eg Neary 1977; Dyck *et al.* 1981). Several of these studies have reported increased concentrations of nitrate and base cations following felling. The increased nitrate concentrations, in particular, have given rise to considerable concern about the possible effects on drinking waters. A series of studies to examine the impact of felling, in UK conditions, on soils, soil waters and water quality is now being carried out by the Institute of Terrestrial Ecology, the Institute of Hydrology, and the Forestry Commission at Beddgelert Forest, in north Wales, Kershope Forest, in Cumbria, and Hafren Forest, in mid-Wales.

Initial results from Beddgelert Forest show large increases in concentration and flux of inorganic N, potassium and phosphate-P in waters in stagnopodzol soils following felling. The nitrogen flux was greater in the second year after felling than in the first: 96 kg ha^{-1} of inorganic N was transferred below the rooting zone in the second year. This large flux of nitrate through the subsoil also resulted in an acidification of the soil waters. The major post-felling flux of potassium was in the upper horizons in the first year, and the lower horizons in the second year. In the second year, potassium concentrations in waters from the upper horizon had reverted to pre-felling levels. It appears that a front of potassium gradually moved down through the soil, taking some 2–3 years from felling to pass from the O to the C horizons. Phosphate fluxes declined in the second year after felling, but were still much greater than before felling, but little phosphate reached the subsoil, most being immobilized in the upper horizons.

Process studies at Kershope and Beddgelert Forests have confirmed that the increased K and PO_4-P fluxes after felling are derived from the felling debris. The inorganic N, however, is derived from the pre-existing forest floor and soil organic horizons. Mineralization of organic N continued after felling but, in the absence of root uptake, the nitrate produced was lost in drainage waters.

Drainage water from the Kershope site showed marked increases in concentrations of nitrate, ammonium and potassium following felling, reflecting the increased concentration in the soil solution. A parallel reduction in the levels of Na, Ca, Mg, SO_4-S and Cl in drainage water is explained by reduced 'capture' from the atmosphere and dilution, and by the increased water throughput. In the year following felling at Kershope, output of inorganic N and of K from a completed cleared plot was 5 times greater than that of an unfelled control plot. Streamwater concentrations of K and NO_3 have increased to a lesser extent at Beddgelert, where only a proportion of the catchments were felled, than at Kershope. The Beddgelert situation of partial felling of a stream catchment seems more realistic in practice than that at Kershope.

5 Long-term consequences and management options

It seems clear that monocultures of conifers, particularly spruce, cause modifications to the biological, chemical and physical properties of some brown earths, brown podzolic and similar soils. These changes are most marked on coarse-textured, base-poor parent material; Bonneau (1975) reports the development of a podzol with a distinct Ea horizon in such material. The changes include the development of a mor humus, surface acidification and leaching, an increased trend towards podzolization and structural degradation. While coming to similar conclusions, Bonneau (1978) and Manil (1966) suggest that, in most cases, the modifications to the soils are slight, most of which could be corrected by additions of fertilizer and lime, and do not represent a significant decrease in long-term site fertility. Bonneau (1978) does, however, suggest that there may be significant short-term effects on availability of some base cations, and Nys and Ranger (1985) have identified several soil changes which they regard as irreversible. The views of Manil (1966) and Bonneau (1978) are largely addressed to the continued use of the site for forestry. The mor humus, and the general surface acidification, may affect the vegetation which would develop on the site after felling; certain acid-sensitive species may not return. The magnitude of this effect will vary with the initial soil type and the tree species planted. The major control on post-felling vegetation would probably be the nature of the available soil seed bank and of nearby seed sources (cf Hill, this volume).

Structural degradation may have important consequences. At clearfelling, the exposed soil would be much more sensitive to further structural damage due to the passage of heavy equipment and raindrop impact, and, as a result, to soil erosion. On sloping sites, it may be necessary to protect the soils or to limit the size of the felling coupe. Nys and Ranger (1985) have identified most of the soil changes consequent upon planting of exotic conifers as reversible. We are unable, however, to forecast timescales for the recovery, or, more properly, the adjustment of the soils to a subsequent changed vegetation. It may take a considerable period to restore soil structure, during which time the site will be at increased risk to soil erosion.

The main effects on the peats, stagnopodzols, stagnogleys and gleys are probably physical. The combined effects of ploughing, drainage and tree growth produce a marked drying in many soils, the extent of the drying depending on initial soil conditions, ground treatment and tree species. The drying also produces oxidation of organic nitrogen and sulphur compounds and more rapid decomposition. There do not appear to be large changes in chemistry of the mineral horizons, but there are important changes in soil water chemistry with large increases in aluminium levels. Some of the drying effects, particularly in peats, are irreversible. The penetration and disruption of the ironpan in ironpan stagnopodzols and the general cracking of the E horizons in stagnopodzols may also have long-lasting effects. Some sites, especially stagnogley and gley sites, seem to 'wet-up' again remarkably quickly after felling (eg Pyatt *et al.* 1985), even though drains remain open and active. Some of the initially wetter peat sites would not, however, return quickly to the wet bog or moorland vegetation which existed before planting. The dried, humified and cracked peat may also be liable to erode following removal of the protection of the forest canopy. Base cation availability in the organic horizons has declined on some sites, but this may be a short-term effect until the forest nutrient cycle is established. It is unlikely that planting will have reduced the site fertility on these soil types, although losses of phosphorus at harvesting may be significant in the short term. There may also be problems of synchronizing nutrient availability with nutrient demand in successive rotations. The effects on any subsequent, non-forest, vegetation will most probably be linked to the drying, and physical changes, rather than to alterations in soil chemistry.

It is difficult to conceive of management options which will ameliorate the physical impacts. The establishment of a crop on the wetter soils requires some form of drainage, and the ironpan in ironpan stagnopodzols needs to be disrupted to improve rooting conditions. The drying effect due to tree growth is inevitable. The effects of ploughing and drainage on drainage water chemistry can be ameliorated by modifying the design of the ground treatment. The fact that no significant changes in solute concentrations have been detected during the second phase of ground preparation at Llanbrynmair suggests that the approaches now being used are successful. The increased ion input, especially sulphate, to forest soils, due to canopy scavenging, will not be affected by forest management. Enhanced levels of aluminium in soil waters of forests on sensitive soils, therefore, seem inevitable, without a reduction in anion inputs from the atmosphere. Even given a reduction in sulphur and nitrogen levels, the additional capture of sea-derived solutes by forest canopies, compared with moorland or grassland, will lead to higher aluminium levels in the forest soil waters, although the difference would be much less than at present. The impacts of established plantations on the acidity and aluminium concentrations in streams may be reduced by changes in design of drainage schemes. If waters can be kept on site longer, and ditches not fed directly into streams, then some additional buffering may take place. These principles are now being incorporated into new planting schemes. Liming of forest soils would also reduce acidity and aluminium levels, but it may prove to be easier to treat the problem in drainage waters than in the soils. The liming of both waters and soils is, however, now being explored. It has also been suggested that increased buffering of drainage waters would be achieved if the water moved to depth and came into contact with more base-rich subsoil, drift or rock. This approach may be feasible on some sites and could be achieved by the use of very deep drains or specially excavated sumps. The technique does not, however, seem to have much potential on the very acid slates and mudstones of central Wales.

The longer-term impacts of soil compaction produced during harvesting are as yet unknown. In the United States, reduced growth in the succeeding rotation has been reported of trees planted in the compacted soils. The affected trees tended to catch up in the later years of the rotation, and, in the relatively long rotations used in Britain, compared with the southern USA, this timescale may be acceptable. The impact should, however, be quantified. In the immediate post-felling period, the most important effects will be a reduction in infiltration, increased surface wetness and soil erosion. Some impact on water quality at clearfelling also seems inevitable. Our work at Beddgelert suggests, however, that felling of the normal-sized coupe is unlikely to produce changes in stream chemistry which will require additional water treatment or have significant impacts on freshwater biota.

The enhanced output of nutrients in drainage waters after felling is significant, but initial analysis suggests that it will not have a major impact on long-term site fertility. The released, and subsequently fixed, phosphate, however, represents a large part of the readily available P in the system, and the availability of the fixed phosphate needs further study.

6 References

Aubertin, G.M. & Patric, J.H. 1974. Water quality after clearcutting a small watershed in West Virginia. *J. environ. Qual.*, **3,** 243-249.

Binns, W.O. 1979. Some effects of tree growth on deep peat. In: *Proc. int. Peat Congress, 3rd, Quebec, 1978,* 358-365. Ottawa: Department of Energy, Mines and Resources; National Research Council of Canada.

Boggie, R. & Miller, H.G. 1976. Growth of *Pinus contorta* at different water-table levels in deep blanket peat. *Forestry,* **49,** 123-131.

Bonneau, M. 1973. Les enrésinements risquent-ils de diminuer la fertilité des sols? *Rev. for. fr.,* **25,** 259-268.

Bonneau M. 1978. Conséquences pédologiques des enrésinements en forets. *C. r. hebd. Séanc. Acad. Agric. Fr., 14 Juin 1978,* 931-942.

Bonneau, M., Brethes, A., Lacaze, J.F., Lelong, F., Levy, G., Nys, C. & Souchier, B. 1977. *Modification de fertilité des sols sous boisements artificiels de resineaux purs.* (Compte rendue fin d'études.) Delegation Générale à la Recherche Scientifique et Technique.

Bonneau, M., Brethes, A., Lelong, F., Levy, G., Nys, C. & Souchier B. 1979. Effets de boisements resineux purs sur l'évolution de la fertilité du sol. *Rev. for. fr.,* **31,** 198-207.

Bull, K.R. & Hall, J.R. 1986. Aluminium in the Rivers Esk and Duddon, Cumbria, and their tributaries. *Environ. Pollut. B,* **12,** 165-194.

Calder, I.R. and Newson, M.D. 1979. Land-use and upland water resources in Britain—a strategic look. *Water Resour. Bull.* (U.S.), **15,** 1628-1639.

Carlisle, J.C. & Malcolm, D.C. 1986. Larch litter and nitrogen availability in mixed larch–spruce stands. II. A comparison of larch and spruce litters as a nitrogen source for Sitka spruce seedlings. *Can. J. For. Res.,* **16,** 327-329.

Cole, D.W., Crane, W.J.B. and Grier, G.C. 1975. The effect of forest management practices on water chemistry in a second-growth Douglas-fir ecosystem. In: *Forest soils and forest land management*, edited by B. Bernier & C.H. Wright, 195-208. (Proc. N. American Soils Conf., 4th.) Quebec: Université Laval.

Dollard, G.J., Unsworth, M.H. & Harvey, M.J. 1983. Pollution transfer in upland regions by occult precipitation. *Nature, Lond.*, **302,** 241-243.

Dyck, W.J., Webber, B.D. & Barton P.G. 1981. Soil-water nutrient concentrations after clearfelling and burning of *Pinus radiata*. *N. Z. J. For. Sci.*, **11,** 128-144.

Grieve, I.C. 1978. Some effects of the plantation of conifers on a freely drained lowland soil, Forest of Dean, UK. *Forestry*, **51,** 21-28.

Harriman, R. & Morrison, B.R.S. 1982. Ecology of streams draining forested and non-forested catchments in an area of Scotland subject to acid precipitation. *Hydrobiologia*, **88,** 251-263.

Haveraaen, O. 1981. *Virkning av hogst pa vannmengde og vannkvalitet fra en ostnorsk barskog.* (Meddelelser no. 36.) Norsk Institutt for Skogforskning.

Herbauts, J. & de Buyl, E. 1981. The relation between spruce monoculture and incipient podzolisation in ochreous brown earths of the Belgian Ardennes. *Pl. Soil*, **59,** 33-49.

Hill, M.O., Hornung, M., Evans, D.F., Stevens, P.A., Adamson, J.K. & Bell, S.A. 1984. The effects of clear-felling plantation forests. *Annu. Rep. Inst. terr. Ecol. 1983*, 9-11.

Hornung, M. 1985. Acidification of soils by trees and forests. *Soil Use Manage.*, **1,** 24-28.

Hornung, M. & Ball, D.F. 1972. Current studies involving soil chemical variability. *Welsh Soils Discuss. Grp Rep.*, no. 13, 71-90.

Hornung, M., Adamson, J.K., Reynolds, B. & Stevens, P.A. 1986a. Influence of mineral weathering and catchment hydrology on drainage water chemistry at three upland sites in England and Wales. *J. geol. Soc. Lond.*, **143,** 627-634.

Hornung, M., Stevens, P.A. & Reynolds, B. 1986b. The impact of pasture improvement on the soil solution chemistry of some stagnopodzols in mid-Wales. *Soil Use Manage.*, **2,** 18-26.

Hynninen, P. & Sepponen, P. 1983. Eraan soualeen ojituksen vaikutus purovesioan laatuum Kuminkjoen vesistolucclla Pohjois-Suomessa. *Silva fenn.*, **17,** 23-43.

Jenny, H. 1941. *Factors of soil formation: a system of quantitative pedology.* London: McGraw-Hill.

Jenny, H. 1980. *The soil resource.* New York: Springer.

King, J.A., Smith, K.A. & Pyatt, D.G. 1986. Water and oxygen regimes under conifer plantations and native vegetation on upland peaty gley soil and deep peat soils. *J. Soil Sci.*, **37,** 485-497.

Likens, G.E., Bormann, F.H., Johnson, N.M., Fisher, D.W. & Pierce, R.S. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. *Ecol. Monogr.*, **40,** 23-47.

Lovett, G.M., Reiners, W.A. & Olson, R.K. 1982. Cloud droplet deposition in subalpine balsam fir forests: hydrological and chemical inputs. *Science, N.Y.*, **218,** 1303-1304.

Manil, G. 1966. Le problème de la conservation de la fertilité des sols sous monoculture de résineaux. *Compte rendu de congres forestière mondial, 6th, Madrid*, Vol. 2, 2239-2250.

Miller, H.G. & Miller, J.D. 1980. Collection and retention of atmospheric pollutants by vegetation. In: *Ecological impact of acid precipitation*, edited by D. Drablos & A. Tollan, 33-40. (SNSF project.) Norwegian Council for Scientific and Industrial Research.

Miller, H.G. 1984a. Deposition—plant—soil interactions. *Phil. Trans. R. Soc. Lond., B*, **305,** 339-352.

Miller, H.G. 1984b. Dynamics of nutrient cycling in plantation ecosystems. In: *Nutrition of plantation forests*, edited by G.D. Bowen & E.K.S. Nambiar, Chapter 3. London: Academic Press.

Miller, H.G. 1985. The possible role of forests in streamwater acidification. *Soil Use Manage.*, **1,** 28-30.

Neary, D.G. 1977. Impact of timber harvesting on nutrient losses in streamflow. *N.Z. Jl For.*, **22,** 53-63.

Nihlgard, B. 1971. Pedological influence of spruce planted on former beech forest soils in Scania, south Sweden. *Oikos*, **22,** 302-314.

Nilsson, S.I., Miller, H.G. & Miller, J.D. 1982. Forest growth as a possible cause of soil and water acidification: an examination of the concepts. *Oikos*, **39,** 40-49.

Nys, C. 1981. Modifications des caracteristiques physico-chemiques d'un sol brun acide des Ardennes primaires par la monoculture d'Epicéa commun. *Ann. Sci. for.*, **38,** 237-258.

Nys, C. & Ranger, J. 1985. Influence de l'espece sur le fonctionnement de l'écosystème forestier. Le cas de la substitution d'une essence resineuse à une essence feuillue. *Sci. Sol*, **21,** 203-216.

Page, G. 1968. Some effects of conifer crops on soil properties. *Commonw. Forest. Rev.*, **47,** 52-62.

Pyatt, D.G. 1973. The effects of drainage treatments and tree crops on soil physical properties. *Rep. Forest Res., Lond., 1973*, 62-66.

Pyatt, D.G. 1976. Classification and improvement of upland soils—deep peats. *Rep. Forest Res., Lond., 1976*, 24-25.

Pyatt, D.G. & Smith, K.A. 1983. Water and oxygen regimes of four soil types at Newcastleton Forest, south Scotland. *J. Soil Sci.*, **34,** 465-482.

Pyatt, D.G., Anderson, A.R., Stannard, J.P. & White, I.M.S. 1985. A drainage experiment on a peaty gley soil at Kershope Forest, Cumbria. *Soil Use Manage.*, **1,** 89-94.

Reynolds, B., Neal, C., Hornung, M. & Stevens, P.A. 1986. Baseflow buffering of streamwater acidity in five mid-Wales catchments. *J. Hydrol. (Amst.)*, **87,** 167-185.

Reynolds, B., Neal, C., Hornung, M. & Stevens, P.A. 1987. Controls on aluminium and hydrogen chemistry in some stagnopodzols beneath grassland and forest vegetation in mid-Wales. *Water Air Soil Pollut.* In press.

Robinson, M. 1980. *The effect of pre-afforestation drainage on the streamflow and water quality of a small upland catchment.* (Report no. 73.) Wallingford: Institute of Hydrology.

Ross, S.M. & Malcolm, D.C. 1982. Effects of intensive forestry ploughing practices on an upland heath soil in south-east Scotland. *Forestry*, **55,** 155-171.

Rudeforth, C.C., Hartnup, R., Lea, J.W., Thompson, T.R.E. & Wright, P.A. 1984. *Soils and their use in Wales.* (Bulletin no. 11.) Harpenden: Soil Survey of England and Wales.

Schlenker, G., Babel, V., Benecke, E., Blume, H.P., Everss, F.H., Muller, S., Munnoch, O. & Zimmerman, U. 1969. Untersuchungen über Answirkungen des Fichtenreinanbans auf Parabraunerden und Pseudogleye des Neckarlandes. *Mitt. Ver. Forstl. Standortskunde ForstpflZcht.*, no. 19.

Stevens, P.A. 1987. Throughfall chemistry beneath Sitka spruce of four ages in Beddgelert Forest, north Wales, UK. *Pl. Soil.* In press.

Stone, E.L. 1975. Effects of species on nutrient cycles and soil change. *Phil. Trans. R. Soc. Lond., B*, **271,** 149-162.

Stoner, J., Gee, A.S. & Wade, K.R. 1984. The effects of acidification on the ecology of streams in the Upper Tywi catchment in west Wales. *Environ. Pollut., Ser. A*, **35,** 125-157.

Stoner, J.H. & Gee, A.S. 1985. Effects of forestry on water quality and fish in Welsh rivers and lakes. *J. Inst. Water Eng. Sci.*, **39,** 27-45.

Tamm, C.O., Holmen, H., Popovic, B. & Wikland, G. 1974. Leaching of plant nutrients from soils as a consequence of forestry operations. *Ambio,* **3,** 211-221.

Thompson, D.A. 1979. *Forest drainage schemes.* (Forestry Commission leaflet no. 72.) London: HMSO.

Thompson, D.A. 1984. *Ploughing of forest soils.* (Forestry Commission leaflet no. 71.) London: HMSO.

Ulrich, B. 1983. Interaction of forest canopies with atmospheric constituents: SO_2, alkali and earth alkali cations and chloride. In: *Effects of accumulation of air pollutants in forest ecosystems,* edited by B. Ulrich & J. Pankrath, 33-45. Dordrecht: D. Reidel Publishing Co.

Unsworth, M.H. 1984. Evaporation from forests in cloud enhances the effect of acid deposition. *Nature, Lond.,* **312,** 262-264.

Vitousek, P.M. & Melillo, J.M. 1979. Nitrate losses from disturbed forests: patterns and mechanisms. *For. Sci.,* **25,** 605-619.

Whitehead, P.G., Neal, C. and Neale, R. 1986. Modelling the effects of hydrological changes on streamwater acidity. *J. Hydrol. (Amst.),* **84,** 353-364.

Williams, B.L., Cooper, J.M. & Pyatt, D.G. 1978. Effects of afforestation with *Pinus contorta* on nutrient content, acidity and exchangeable cations in peat. *Forestry,* **51,** 29-35.

The influence of forest on aquatic fauna

S J ORMEROD*, G W MAWLE+ and R W EDWARDS*
*Dept of Applied Biology, University of Wales Institute of Science and Technology, PO Box 13, Cardiff CF1 3XF
+Welsh Water Authority, Pentwyn Rise, Nelson, Treharris, Mid Glamorgan CF46 6LY

Summary
Because a large proportion of upland Wales is now covered by coniferous plantations, many river systems rise in forests or receive drainage from substantial planted areas. The possible consequences for aquatic ecology are many, and we review evidence for influences by:

i. chemical applications (nutrients and herbicides);
ii. physical changes (runoff timing and quantity, erosion and sedimentation, and habitat effects);
iii. energy inputs (light, heat and tree products);
iv. acidification and the mobilization of metals.

There are no indications from Wales of detrimental impacts by chemical applications. Problems associated with physical changes and, in vulnerable areas, acidification remain a pressing need for further research into management options. In particular, we suggest that concepts concerning 'buffer strips' require some re-assessment, particularly when introduced retrospectively into streams whose banksides were previously planted. There is also a need to demonstrate the efficacy of buffer strips or the use of deciduous trees in newly planted riparian situations.

1 Introduction
Afforestation represents one of the major land use changes in Britain today and forestry now covers 10% of the total land area (Forestry Commission 1985; Nature Conservancy Council 1986). In Wales, approximately 11.5% (235 kha) is covered by productive forest, of which non-native conifers such as Sitka spruce (*Picea sitchensis*) account for over 75%. Because most afforestation in Wales has occurred in upland areas (Parry & Sinclair 1985), many major river systems now either rise in forest, or receive drainage from substantial planted areas.

The possible consequences for aquatic ecology are profound. In Scotland, Egglishaw *et al.* (1986) recently demonstrated that regional decreases in salmon catches could be related to the amount of forest around nursery streams. In Wales, the diversity of invertebrates is often markedly reduced in streams draining plantations (Figure 1), an effect which is enhanced in acidic streams but occurs also independently of pH (Table 1). Only in some instances have the pathways leading to these effects been adequately described. In this paper, we review the possible effects of forest on the fauna of streams and lakes, basing our approach on the pathways illustrated in Figure 2. Where possible, we use data from Welsh studies, but in some instances can only speculate using information from other areas.

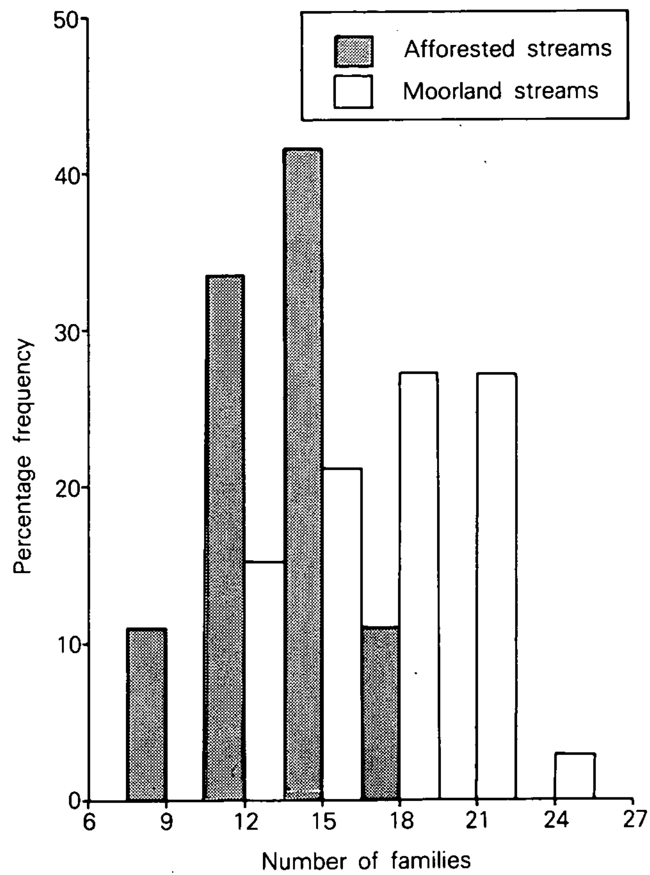

Figure 1. The percentage frequency distributions of kick-samples with given taxon richnesses from moorland and afforested streams. Based on 72 samples from 25 sites in the Wye and Tywi catchments

Table 1. Groups of sites revealed by 2-way Indicator Species Analysis (TWINSPAN) of macroinvertebrate data

i. Sites in the Cothi catchment, west Wales

Site group	Mean taxon richness (range)	Mean pH	Mean % afforestation
A	53 (44–63)	6.9	2
B	50 (41–60)	6.5	20
C	44 (31–57)	6.7	49
D	35 (22–42)	6.6	37

ii. Sites throughout mid- and north Wales

Site group	Mean taxon richness (range)	Mean pH	Mean % afforestation
P	44 (>40)	6.6	12
Q	32 (25–40)	6.1	11
R	22 (15–30)	5.8	25
S	17 (10–25)	5.2	42

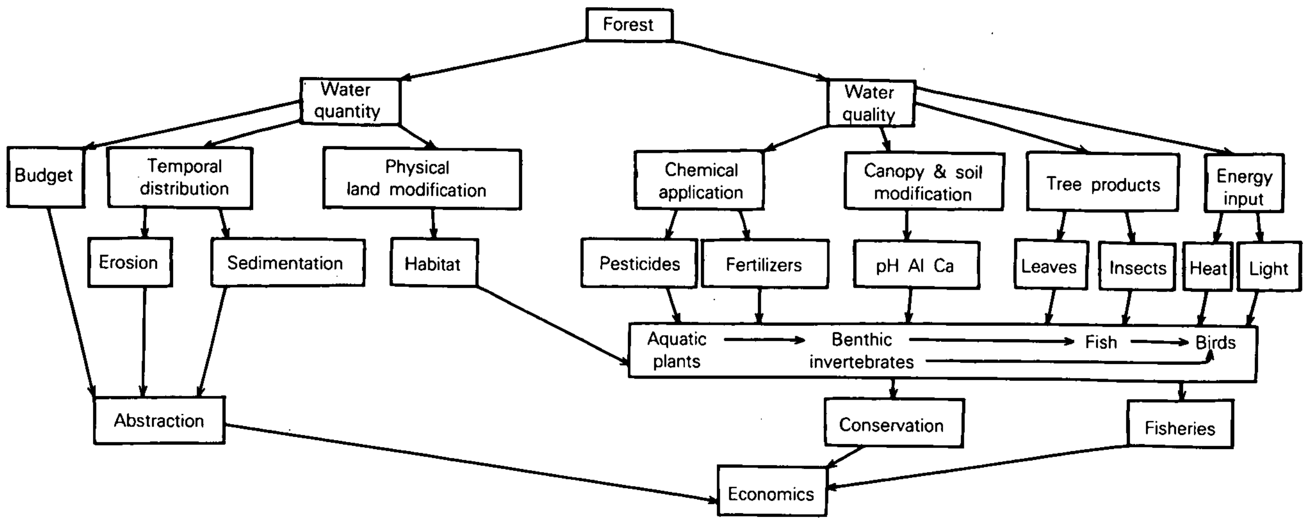

Figure 2. Selected pathways of forest influence on aquatic fauna and water utilization

2 Chemical applications

2.1 Nutrients

The establishment of coniferous forest at high elevations and on nutrient-poor soils is often accompanied by the application of fertilizers containing nitrate-N, orthophosphate-P and potassium. Additionally, the disturbance of the upper soil layers during pre-afforestation ploughing can result in the oxidation and mineralization of organic material, leading to the mobilization of ammonium, nitrate, phosphorus and sulphate (Hornung & Newson 1986). Forest clearance, particularly where brash is not removed, may also lead to pronounced changes in runoff chemistry, including increased concentrations of N, P and K (Hornung & Stevens 1985).

Harriman (1978) compared N and P leaching from afforested catchments with and without fertilizer additions, and also in the same stream 'before' and 'after' catchment applications (47 kg ha^{-1} mineral phosphate, 77 kg ha^{-1} ammonium nitrate and 104 kg ha^{-1} potassium chloride). P concentrations in streams draining the fertilized area reached 0.137 mg l^{-1}, compared with 0.007–0.011 mg l^{-1} in reference streams; catchment losses of 2 kg ha^{-1} yr^{-1} amounted to 15% of the initial quantity applied, and these values remained elevated for at least 3 years after fertilization. K losses were also high (20% of the quantity applied), whilst N losses did not exceed 5%, and concentrations of both K and N returned to background levels in 2 and 3 years respectively. At Coal Burn in Northumberland, P concentrations rose from 0.01–0.06 mg l^{-1} to 0.25–0.35 mg l^{-1} immediately following the application of 375 kg ha^{-1} of rock phosphate to a recently ploughed site prior to afforestation; catchment loss increased correspondingly from 0.072 kg P ha^{-1} to 2.9 kg P ha^{-1} immediately after addition, falling to 0.13–0.33 kg ha^{-1} in subsequent years (Robinson 1980).

The biological consequences of such enriched runoff are likely to be more pronounced in standing than in running waters. For example, Gibson (1976) sampled 26 reservoirs in Ireland and found the highest phosphorus concentrations (0.09–0.247 mg l^{-1}) in afforested upland areas. Separate instances were described of blooms by N-fixing blue-green algae and diatoms. Richards (1984) also gives instances of *Melosira* and *Oscillatoria* blooms which followed fertilizer use in the catchment of a Scottish reservoir. No data were available on the consequences of these changes to aquatic fauna. In addition to trophic effects within standing waters, enhanced primary production might be expected to cause increased densities amongst filter-feeding invertebrates (eg Simuliidae, Hydropsychidae) in rivers downstream (Brooker 1981).

The direct effects on upland rivers of nutrient-rich runoff are more difficult to assess. P is adsorbed on to bryophytes (eg *Scapania*) and sediments, and it is taken up both by decomposing organic matter and the epilithon—an assemblage of bacteria, algae and micro-organisms on stone surfaces which is grazed by invertebrates (Meyer 1980; Lock *et al.* 1984). Nitrate-N may also be immobilized and utilized by periphytic algae (Kaushik *et al.* 1981). In one of the few instances in which P and N concentrations were experimentally increased in upland streams, bacterial numbers and some algal populations were enhanced relative to controls (Kownacki *et al.* 1985). Additionally, the decomposition of coarse particulate organic matter, such as leaves, is faster at increased concentrations of N, P and other minerals (Elwood *et al.* 1981; Meyer & Johnson 1983). Such influences could be beneficial to invertebrates which graze epilithically or which feed on decomposing organic matter and its by-products. By contrast, organisms which feed by shredding coarse organic matter may be at a disadvantage where the turnover of coarse particulate organic matter is high (Hildrew *et al.* 1984). The consequences to fisheries are unknown.

2.2 Pesticides

Herbicides are used widely in coniferous forest to suppress competition from other plants at the establishment and restocking phase of the forest cycle. Drainage into runoff may be minimized due to knapsack or low-volume spraying, but there are few field data on the concentrations in surface waters which follow application. The principal herbicides used, glyphosate, asulam and 2–4,D, are cleared for riparian use because of their relatively low toxicity to aquatic fauna. However, detailed field studies have not yet established the absence of possible adverse ecological effects, eg through toxic influences on primary producers.

Several instances of ecological impact have been described following the use of insecticides to control forest pests. The earliest investigations in northern America revealed the toxic effects on fish and invertebrates of DDT used to control spruce budworm (*Choristoneura fumiferana*) (Kerswill & Edwards 1967). More recently, organophosphates such as Fenitrothion have been used in Scotland against pine looper moths (*Panolis flammea*) on lodgepole pine (*Pinus contorta*). Concentrations in rivers reached 18–48 $\mu g\ l^{-1}$ following aerial spraying, but fell to 0.5 $\mu g\ l^{-1}$ only 24 hours later. No acute effects were noted on fish, but the drift of some invertebrates increased markedly and their benthic densities declined significantly (Wells *et al.* 1978; Morrison & Wells 1981). Similar results had previously been noted in north America and, whilst fish had high LC_{50}s (>2600 $\mu g\ l^{-1}$ in 48 hours for salmonids), sublethal effects at 100 $\mu g\ l^{-1}$ included impaired swimming efficiency, reduced feeding and growth, increased risk of predation and impaired learning ability (see references in Morrison & Wells 1981; Morrin *et al.* 1986).

In Wales, the only frequent and relatively widespread insecticidal treatment is carried out against pine weevils (*Hylobius abietus*) and great spruce bark beetles (*Dendroctonus micans*). Control involves dipping or spraying logs with HCH (= lindane), a persistent organochlorine, and, although this technique is unlikely to produce high concentrations in runoff, few data are available. Infestations in Wales by pine beauty or pine looper moths have so far been minor, possibly because pine trees do not form extensive forest covering. However, the sawflies *Gilpinia hercyniae* and *Cephalcia laricipha* have locally reached numbers in spruce at which aerial spraying has been considered. Clearly, any such pest control measures likely to affect watercourses should be notified to the statutory water undertakings and the effects on non-target organisms should be monitored closely.

3 Physical changes

Many physical changes occur in aquatic habitats as a result of forestry practice, with different changes occurring to different degrees during the forest rotation. Amongst those expected, in approximate chronological order, are changes in the timing and quantity of runoff, alterations in turbidity and patterns of sedimentation, modifications to the physical habitat, alteration in system energetics through inputs of light and heat, and the addition to the aquatic system of tree products.

3.1 The timing and quantity of runoff

At Coal Burn, Northumberland, Robinson (1980) assessed influences on the flood hydrograph during the early phases of forest establishment. The development of an artificial drainage network, in the form of plough furrows and ditches, increased peak discharges from 0.122–0.138 $m^3\ s^{-1}$ to 0.161–0.254 $m^3\ s^{-1}$ immediately following ground treatment. Moreover, the increased flows were condensed into relatively shorter hydrographs of base length 13–24 hours (cf 34–39 hours pre-ploughing) and times-to-peak of 1–4 hours (cf 4–6 hours pre-ploughing). Similarly, in the upper Tywi, the runoff from small catchments correlated strongly with the density of drainage channels, a feature strongly influenced by forest. Increased drainage density also lowered the water table (reducing evapotranspiration) and, overall, was the single most important factor affecting runoff (Jones 1975).

In catchments covered by closed canopy forest, the effects of enhanced drainage became subordinate to the processes of soil drying and water loss by evapotranspiration (Hornung & Newson 1986). Comparison between the adjacent upper Severn (afforested) and upper Wye (moorland) on Plynlimon, for example, shows a reduction in runoff of 20–30% in the former; normal flood events reach lower peaks in the Severn and droughts may be prolonged due to the increased storage capacity beneath the forest canopy and in the forest soil (Hornung & Newson 1986).

In addition to their influences on turbidity and on habitats in the stream substratum or at the river margins (see below), flow changes themselves have consequences for aquatic fauna. Most invertebrates show ranges of tolerance to current velocity outside which activities such as movement or feeding may be restricted (Hynes 1970). For example, the construction of filtering nets, used in feeding by larval hydropsychids, occurs only within a narrow range of current speed (Philipson & Moorehouse 1974). *Gammarus, Simulium* and several mayfly nymphs either move towards the river bank or migrate vertically into the substratum at high flows (Milner *et al.* 1981). However, in extreme spates or where sudden increases in flow occur, bed-load movements and increased velocity may cause an increase in drift, and a reduction in benthic density (Hynes 1968; Petran & Kothé 1978). Such enhanced drift has recently been recorded in upland streams in mid-Wales (Ormerod *et al.*, unpubl.), although there are no data from streams draining afforested catchments. The washout of salmonid eggs and displacement of fry are also likely in enhanced flows, but impacts by forestry on these losses have yet to be assessed.

Regarding drought, any increase in the likelihood of a stream drying could have pronounced effects on fish and invertebrate fauna. In a tributary of the upper Severn, Cowx *et al.* (1984) showed that drought in 1976 eliminated the year's production of young salmon, probably because of increased water temperature—an effect which may be ameliorated under forest (see below). Influences on invertebrates included an initial reduction in abundance during the dry period and a change in both abundance and community structure in the subsequent year; decreased provision of oviposition sites and impaired survival of young nymphs were responsible (Hynes 1958; Cowx *et al.* 1984).

3.2 Erosion and sedimentation

As a consequence of alterations to the drainage network and storm hydrograph, erosion and sediment yields during the early stages of the forest cycle may be particularly enhanced. Robinson and Blyth (1982) noted that weekly sediment yields of 5–275 kg increased to 70–15 240 kg following ploughing in the catchment of Coal Burn, a stream discharging at only 43–57 l s^{-1}. Concentrations of suspended solids initially reached a maximum of 7720 mg l^{-1} (mean 563 mg l^{-1}) and concentrations still peaked at 574 mg l^{-1} during 2 subsequent years (Robinson 1980). At Plynlimon, the erosion of drainage ditches prolonged the effect into the closed canopy phase (Hornung & Newson 1986) and other operations, such as the building of forest roads, can also increase sediment yields (Stretton 1984).

Although fish may tolerate very high concentrations (>80 000 mg l^{-1}) of suspended solids for short periods, sublethal effects, such as gill inflammation and disease, may occur at only 100–270 mg SS l^{-1} (Alabaster & Lloyd 1980). Impaired visibility in turbid waters may also reduce foraging efficiency (Wilzbach *et al.* 1986). In downstream reaches where sedimentation occurs, the increased proportion of fine material may affect spawning sites. Reduced void space, and reduced intra-gravel flow generally limit the supply of oxygen to developing eggs, with consequent effect on their survival (Turnpenny & Williams 1980; Milner *et al.* 1981). Therefore, Alabaster and Lloyd (1980) proposed an upper safe limit of 25–80 mg SS l^{-1} for salmonid fisheries, values probably exceeded intermittently in all streams but perhaps for longer periods and at higher concentrations in many afforestation schemes.

The abundance and diversity of benthic macroinvertebrates have also been related to the size and heterogeneity of substrate particles, and occlusion of the river bed by fine material could limit some species (Milner *et al.* 1981). However, in north America, Murphy *et al.* (1981) concluded that increased primary productivity resulting from shade removal could mask or over-ride the detrimental effects on invertebrates of sedimentation.

3.3 Physical structure of the aquatic habitat

Besides the erosive impact of flash floods on the banksides and bed, the habitat structure of forest streams reflects the effect of dense shading which prevents the development of emergent vegetation and riparian shrubs (eg birch (*Betula* spp.), willow (*Salix* spp.), alder (*Alnus* spp.)). The latter stabilize undercut banks and provide cover for fish in their roots and overhanging boughs. For example, Smith (1980) compared trout densities between contiguous sections of a stream as it flowed through meadow (0.35–2.69 trout m^{-2}; 1.61–13.95 g m^{-2}), deciduous spinney (0.86 trout m^{-2}, 9.40 g m^{-2}) and coniferous forest (0.01–0.12 trout m^{-2}, 0.06–2.28 g m^{-2}), and she was able to relate the differences to the habitat structure which was least suitable in the afforested reach. However, Milner *et al.* (1985) examined relationships between trout density and habitat characteristics in Welsh streams, and found that predictive models were satisfactory only for relatively hard waters (>25 mg $CaCO_3$ l^{-1}). Similarly, Wilzbach (1985) noted that the emigration of trout from experimental channels was greater under conditions of low than high food biomass, irrespective of the amount of available cover. Clearly, in soft waters, such as those draining upland forests, the direct or indirect effects of stream chemistry will have influences on salmonid biology which over-ride habitat suitability (see below).

Fewer authors have considered the influence of coniferous forest on the habitat requirements of invertebrates. In addition to the dependence of some taxa on either pools or riffles (Logan & Brooker 1983), many invertebrates in Welsh rivers are strongly associated with marginal habitats such as tree roots or emergent vegetation (Jenkins *et al.* 1984; Ormerod 1985, Table 2). In the catchment of the River Teifi, for example, the taxon richness of invertebrates correlated with habitat diversity, and species of conservation importance (eg *Baetis digitatus*) were sometimes exclusive to specific physical niches. Habitat selection by macroinvertebrates occurs even in small upland streams (Figure 3), and it is unknown whether the absence of some species from forest streams is a consequence of their physical structure.

Table 2. Macroinvertebrate taxa showing significant association with marginal habitats in the catchment of the River Wye (n=45 sites and 2 sampling occasions) (source: Ormerod 1985)

Mollusc	*Pisdidium subtruncatum*
Mayfly	*Baetis niger*
,,	*Paraleptophlebia submarginata*
,,	*Ephemera danica*
,,	*Centroptilum luteolum*
Stone-fly	*Leuctra nigra*
,,	*Nemoura cambrica*
,,	*N. avicularis*
Caddis-fly	*Halesus* spp.
Beetle	*Oreodytes sanmarki*
Alder-fly	*Sialis fuliginosa*

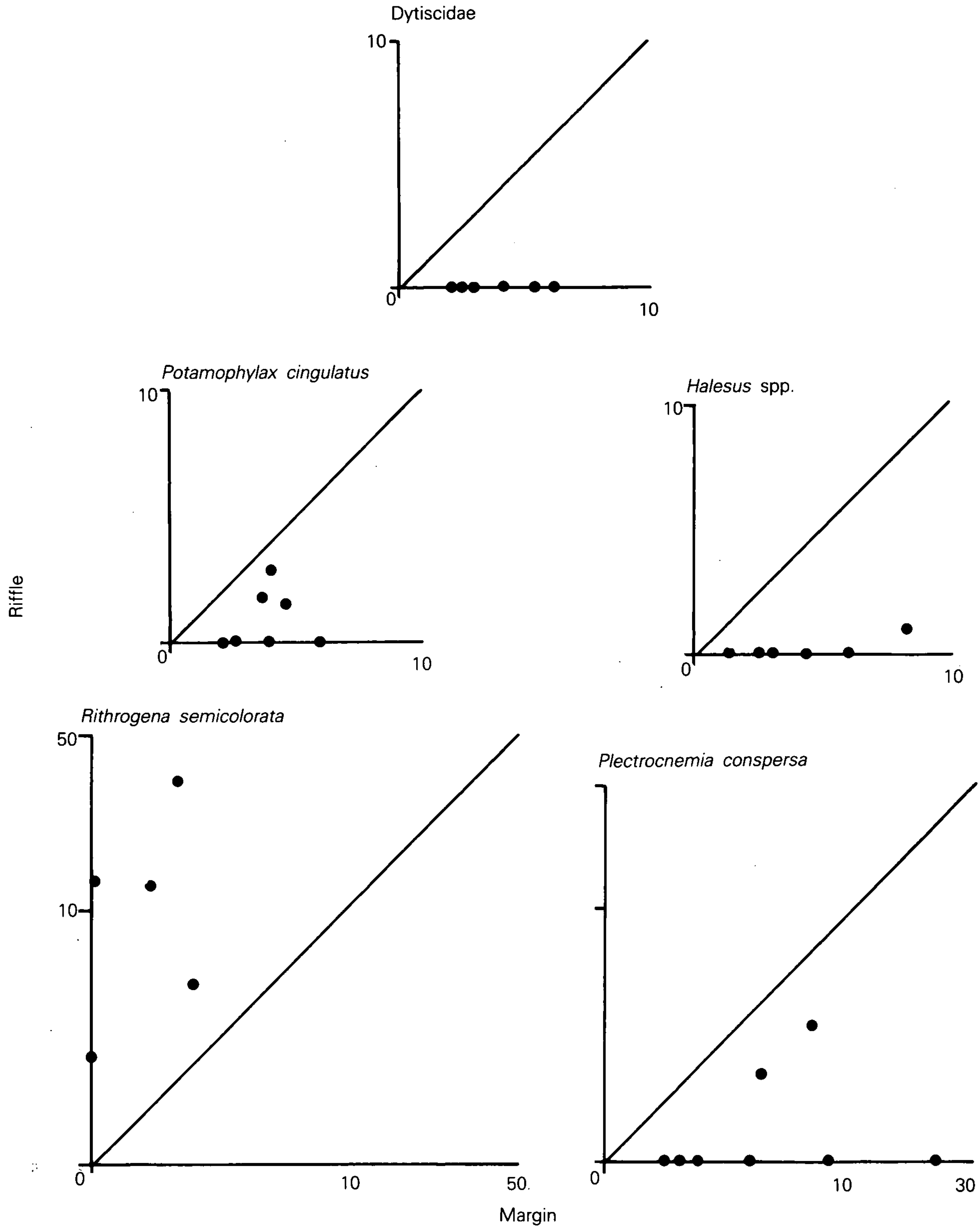

Figure 3. The percentage contribution by 5 taxa to the individuals collected from riffles and margin habitats of streams in the upper Tywi

4 Energy inputs

4.1 Light

The amount of light reaching the bed of a stream or river determines whether the ecosystem functions autotrophically (ie with primary production ≥ utilization) or heterotrophically, with most inputs of energy from terrestrial sources (Minshall 1978). Whichever pathway is dominant will determine whether the invertebrate assemblage consists mostly of epilithic/epiphytic grazers, or of shredders and collectors which process coarse organic material (Cummins 1974). Light intensity also influences the foraging efficiency of salmonid fish (Wilzbach *et al.* 1986). Shading by a closed canopy, which can reduce illumination at the stream bed to 10% of that outside the forest (Smith 1980), clearly has considerable influence on these aspects of stream ecology.

Most evidence on relationships between forest cover, primary production and invertebrate ecology has come from north America, when stream catchments have been clearfelled or logged. Almost invariably, newly logged sections give rise to streams with a higher biomass and production of periphyton (both Chlorophyceae and diatoms), greater invertebrate densities (notably of grazers such as *Baetis* spp.), and higher densities of vertebrate predators (Cottidae, Salmonidae and salamanders) than shaded sections (Behmer & Hawkins 1986; Wallace & Gurtz 1986; Wilzbach & Cummins 1986). The effect tends to be reversed in years following logging as shading once again increases (Wallace & Gurtz 1986). However, attempts to reconstruct this situation, by clearing 'buffer strips' around Welsh streams, have not always enhanced the densities of fish or invertebrates. Indeed, an experimentally cleared stream in the upper Tywi has a particularly low invertebrate abundance despite an enhanced primary production (Figure 4; Proctor 1986).

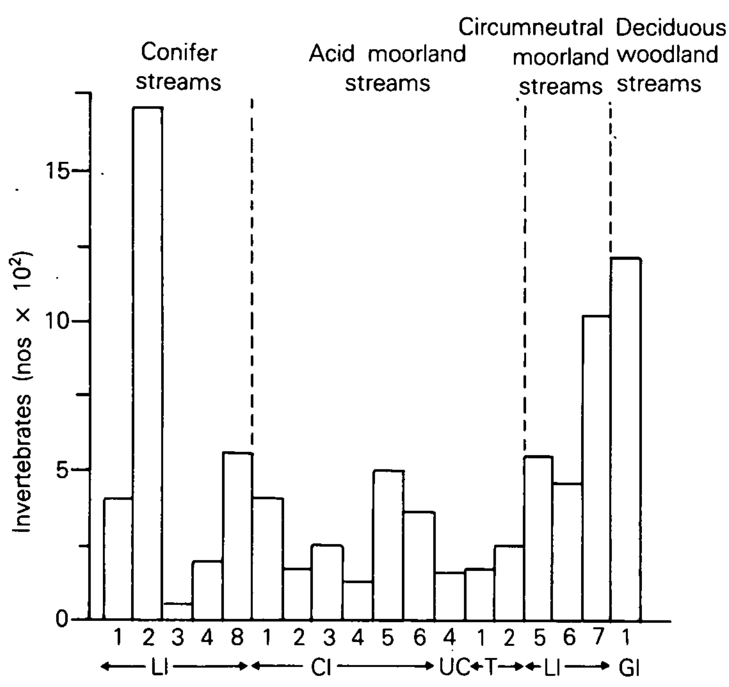

Figure 4. The numbers of invertebrates collected in April 1983 by timed kick-samples in streams in the upper Tywi in relation to land use. Stream L13 had undergone bankside clearance to a width of 10 m either side

In this instance, the dominant growth is of filamentous green algae in which a high cellulose content prevents assimilation by grazing invertebrates. Additionally, diatoms (a heavily used food source by grazing invertebrates) are scarce in streams draining coniferous forest in the Tywi, irrespective of shading, possibly because they are restricted by low pH (Ziemann 1975; Proctor 1986). Alternatively, epilithic grazers such as *Baetis* mayflies may be excluded because of chemical influences in acidic streams, irrespective of their trophic status (see below).

4.2 Heat

River temperature is an important biological variable which affects the embryonic development, growth, life cycle, physiology and distribution of fish and aquatic invertebrates. It is influenced by several factors which include air and ground temperature, distance from source, and insolation, the latter depending in part on shading by riparian vegetation. In the upper Tywi, continuous records from catchments of comparable size and aspect have shown that the presence of coniferous forest has a strong moderating influence on stream temperature (Figure 5). Streams which are heavily shaded (eg LI1) have lower summer maxima, but higher winter minima, than either adjacent moorland streams (LI6) or those whose banks have been cleared to a width of 10 m (LI3). As a consequence, trout growth (predicted using equations given by Elliott 1975) in forest streams could be maintained during periods when the temperature in adjacent moorland streams becomes too high or too low (Figure 6; cf Edwards *et al.* 1979). However, simulations throughout a whole year, based on monthly mean temperatures, indicate that a 10 g fish (on adequate food rations) would attain a weight 15% lower in an afforested stream than in a moorland stream (41.95 g) due to the overall difference in mean temperatures (see Figure 6). Growth in a stream whose banks had been cleared would be intermediate. Further simulations of the influence of forest on biological processes in fish and invertebrates are currently in progress.

4.3 Tree products

As an alternative to internal (autochthonous) energy production, many small wooded streams receive most of their energy externally (allochthonously), in the form of leaves and litter from the surrounding habitats (Bird & Kaushik 1981). Processing by the stream involves chemical leaching, microbial conditioning and subsequent conversion into animal products. However, the quantity and quality of allochthonous inputs vary with season and with the species mix of the surrounding vegetation. For example, leaves differ between tree species in their chemical composition, their refractiveness to fungal conditioning, and hence in their rate of decay (Bird & Kaushik 1981); given a choice, invertebrates usually show feeding preferences for leaves which correspond with the decay rate (eg elm (*Ulmus*) > maple (*Acer*) > alder = oak (*Quercus*) > beech (*Fagus*), the slowest decomposer and least preferred of these species; Kaushik & Hynes 1971).

There are few data available on the processing of leaves from the spruces and pines found typically in Welsh forests. However, Bärlocher *et al.* (1978) have demonstrated that leaves from red pine (*Pinus resinosa*) are colonized and conditioned only slowly by

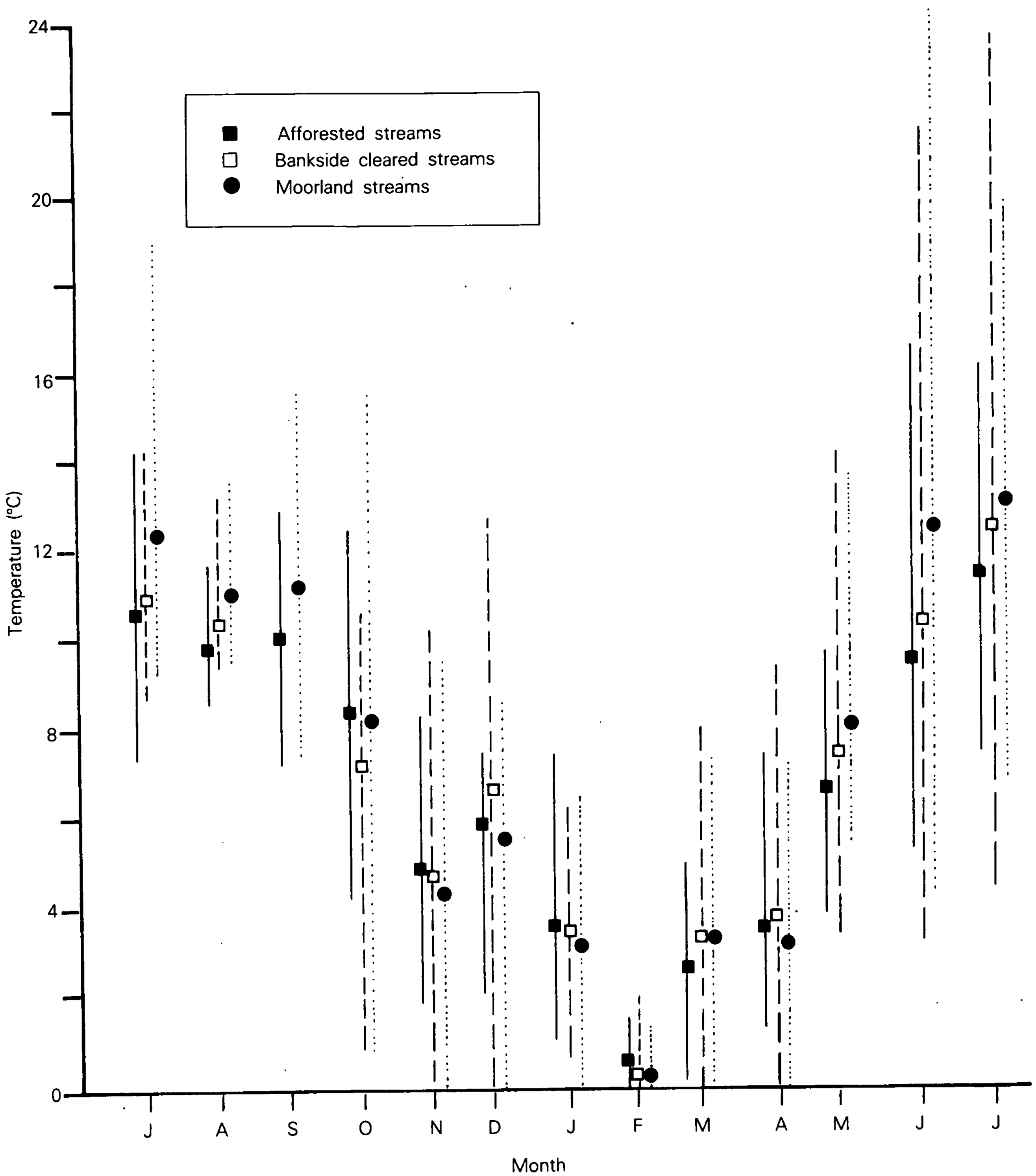

Figure 5. Monthly mean temperatures (with range) in afforested, bankside cleared, and moorland streams in the upper Tywi. Based on continuous monitoring (resolution = 15 minutes)

hyphomycete fungi, a group generally important in the decay of leaves in streams. The thick cuticle and epidermal layers of pine needles act as a physical barrier to colonization but, more importantly, the needles of pine and other conifers contain fungal inhibitors (Bärlocher & Oertli 1978a, b). Sedell *et al.* (1975) showed that leaves from Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) lost weight slowly in the stream and they held fewer invertebrates than did rapidly decomposing vine maples (*Acer circinatum*). Nevertheless, once conditioned, the conifer leaves were consumed readily by shredding invertebrates. Similarly, Summerbell and Cannings (1981) found that 4 conifer species were readily grazed by the chironomid *Brillia retifinis*, once conditioned by Oomycetes and Hyphomycetes. In these instances, conifer litter provided a usable energy input throughout the year (Sedell *et al.* 1975).

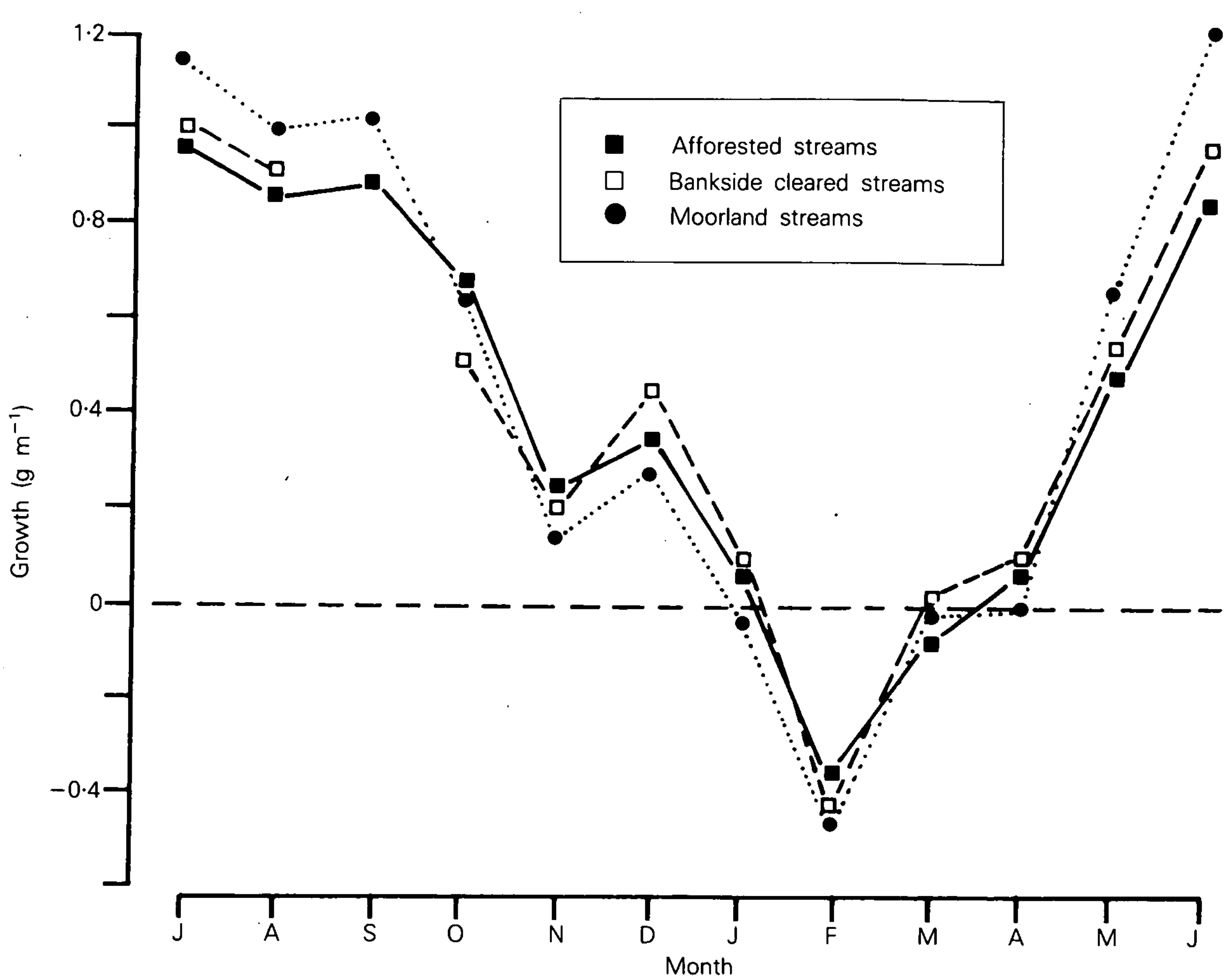

Figure 6. Simulated monthly growth of 10 g brown trout (source: Elliott 1975) in afforested, bankside cleared, and moorland streams, based on monthly mean temperatures. Negative values involved slight extrapolation outside the range at which the growth equation was developed

In Scottish streams, Harriman and Morrison (1982) noted that invertebrate biomass was not reduced in afforested streams by comparison with adjacent moorland streams, even though the diversity was lower. The pattern in the upper Tywi is similar, except where bankside clearance has occurred (Figures 4 & 7). It is, therefore, possible that conifer litter makes a significant input to the energy budget of some upland streams in Wales, and further work is required on this aspect.

The vegetation surrounding streams also contributes material in the form of terrestrial insects which are used as a food source by Salmonidae. In the upper Tywi and Wye during June and July 1986, fewer invertebrates (504 m^{-2} d^{-1}±218 SD, n=10) fell into water traps alongside streams through forest than into traps by streams surrounded by bracken and heather (2408 m^{-2} d^{-1}±1734 SD, n=9) or deciduous woodland (1942 m^{-2} d^{-1}±1734 SD, n=9) (Ormerod *et al.*, unpubl.).

5 Acidification and the mobilization of metals

One of the most prominent assertions concerning forest impact in recent years has been that conifers enhance the acidification of surface waters and influence the concentrations of ecologically important ions such as calcium and aluminium (Harriman & Morrison 1982; Stoner *et al.* 1984; Reynolds *et al.* 1986). The effect has been noted particularly in upland areas where acid soils overlie base-poor bedrock; consequently, much research has been undertaken in Wales.

In the upper Tywi, for example, streams with similar hardnesses differed in mean pH (by 0.5–1.0 units) and aluminium concentration (by 0.1–0.4 mg l^{-1}) depending on whether they drained moorland or forest (Table 3; Stoner *et al.* 1984); the differences were particularly pronounced at high flows when pH in the afforested streams fell to 4.0 and aluminium concentrations reached > 1.0 mg l^{-1}. Subsequent data have confirmed these patterns (Welsh Water Authority, unpubl.). In the neighbouring River Irfon and in some tributaries of the River Wye, historical records of winter pH showed a decline of up to 1.7 units between 1963 and 1984 following catchment afforestation (Ormerod & Edwards 1985). On Plynlimon, Reynolds *et al.* (1986) reported no difference in pH between soft water streams draining moorland and forest, but aluminium

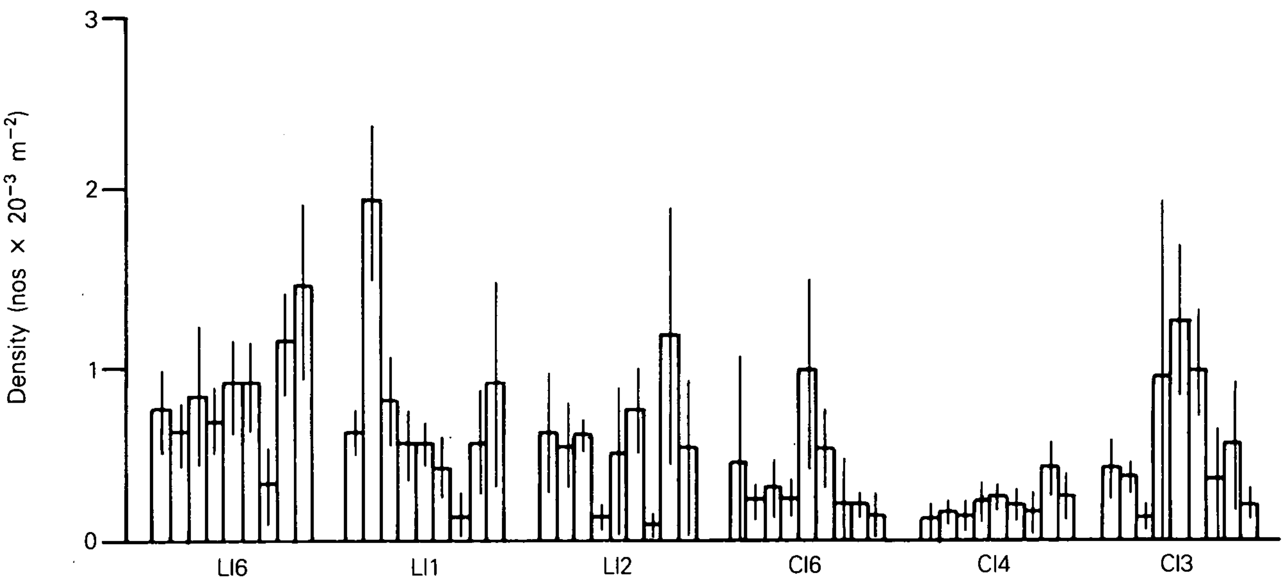

Figure 7. Seasonal changes in invertebrate density (mean±1 SD excluding oligochaetes; n=5 per month) in streams in the upper Tywi. LI6 is a circumneutral stream draining moorland, LI1 and LI2 are acidic streams draining forest and CI6, CI4 and CI3 are acidic streams draining moorland. (Sampling sequence: April, May, June, July, September, November, April, May, June)

concentrations were higher in the latter. Indeed, throughout Wales, soft water streams generally show increasing aluminium concentrations with increased catchment afforestation (Figure 8), and similar conditions prevail in upland lakes (Stoner & Gee 1985). Whilst the actual pathways producing these effects are still being studied (Hornung, this volume), it seems likely that the influence of forest *per se* is to acidify runoff and/or mobilize aluminium, and several biological effects have been described.

5.1 Invertebrates

Elsewhere in Britain, field data show a close relationship between the chemistry of streams and their invertebrate faunas (Sutcliffe & Carrick 1973; Townsend *et al.* 1983). Acidic streams draining coniferous forest are no exception and, whilst their invertebrate density may be higher than in adjacent moorland streams (see Figure 7), their diversity is usually reduced (eg Stoner *et al.* 1984; Gee & Smith, unpubl.). Groups such as crustaceans, mayflies and some caddis-flies are particularly restricted at pH 5.7 and >0.1 mg Al l^{-1} and these taxa are often scarce in forest streams (Figure 8).

There is still considerable debate over whether sensitive taxa, such as mayflies, are influenced by direct physiological action, or whether they are limited by a reduced food supply. For example, limits to the production of diatoms or the food-rich epilithon could restrict grazing invertebrates at low pH (Ziemann 1975; Winterbourn *et al.* 1985). Nevertheless, *Baetis rhodani*, a species scarce in acidic forest streams, shows rapid responses to short episodes (24 h) of acidity and elevated aluminium (Ormerod *et al.* 1987); these effects (mortality and enhanced drift) were independent of changes in food supply.

Further discussion of relationships between afforestation, chemistry and the invertebrates of Welsh rivers is given by Ormerod *et al.* (1987), Ormerod and Edwards (1987) and Wade and Ormerod (1986a, b).

5.2 Fish

In the upper Tywi (Stoner *et al.* 1984; Table 3) and on Plynlimon (Crisp *et al.* 1980), salmonids were scarce or absent in afforested streams. Similarly, Stoner and Gee (1985) related declining angling catches in several Welsh lakes to their chemistry and land use. These patterns are probably a consequence of low pH and elevated aluminium. Field data from more than 100 sites in upland Wales indicated that salmonid densities were closely correlated with these variables (Welsh Water Authority, unpubl.), whilst the toxic response of caged fish in forest streams was highly correlated with the concentration of aluminium during acid episodes. Moreover, Ormerod *et al.* (1987) recently showed by experimental manipulation of water quality in a stream that salmon and trout mortality was dramatically enhanced in the presence of aluminium (0.35 mg l^{-1}) at pH 5.0, but was very low at pH 4.3 with no aluminium.

Work elsewhere has shown that both acute and chronic pathways are involved in influencing salmonids at low pH and high aluminium concentrations, and include loss of body salts, occlusion of the gills resulting in hypoxia, and the development of lesions (Muniz & Leivestad 1980; Dalziel *et al.* 1985).

5.3 Other vertebrates

Other vertebrates associated with fresh waters include amphibians, birds and mammals, such as otters. Cummins (1986) has recently demonstrated lethal and sublethal effects by low pH and high aluminium on

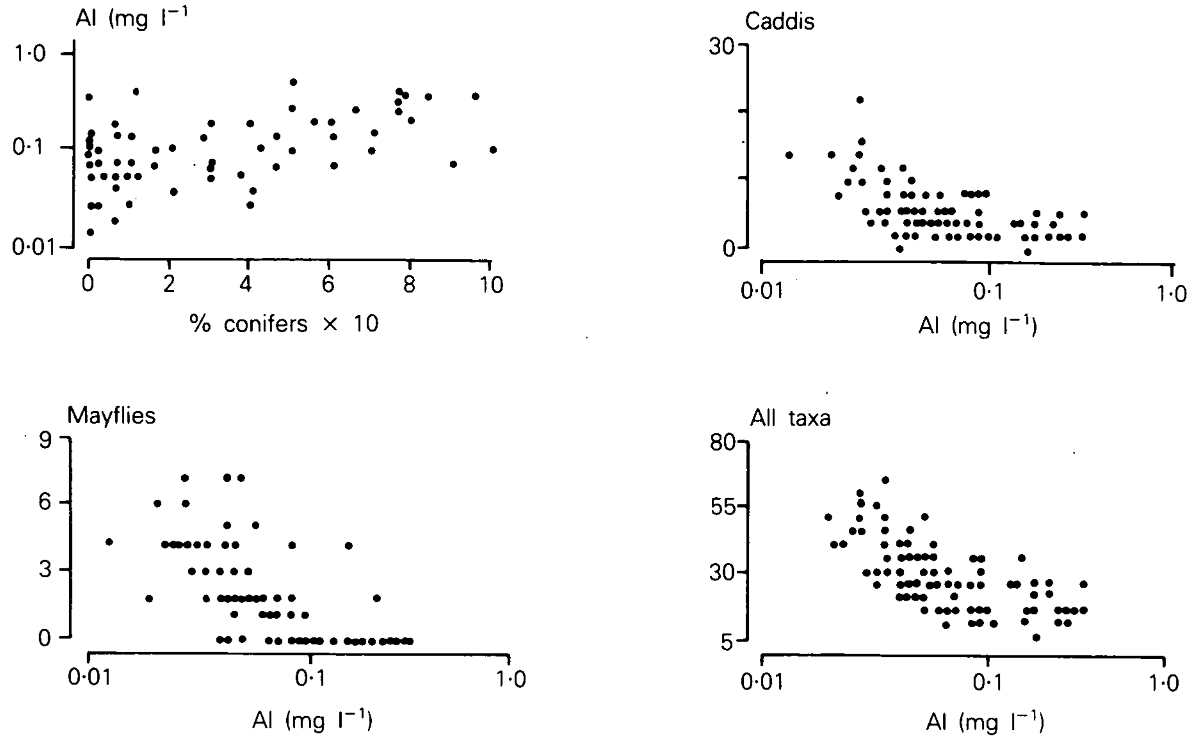

Figure 8. Concentrations of filterable aluminium in relation to catchment afforestation, and numbers of species from selected groups in relation to filterable aluminium (source: Welsh Water Authority regional survey of acid waters; Wade & Ormerod 1986a)

frogs (*Rana temporaria*). Regarding birds, Ormerod *et al.* (1985) described a decline in the abundance of breeding dippers (*Cinclus cinclus*) which accompanied the afforestation and acidification of the River Irfon. Dippers were also scarce along other streams with low pH (<5.7), high aluminium (>0.1 mg l^{-1}) and heavily afforested catchments, probably because they provided inadequate food supplies (Ormerod *et al.* 1986).

6 Research needs and management options

Several of the possible influences of forest on aquatic fauna are not yet evident in Wales, eg effects by runoff containing fertilizers and pesticides. Any future detrimental impacts in these instances will be prevented by sensible management (eg low volume applications), adequate consultation and careful monitoring programmes, both short- and long-term.

Three particular areas of forest impact are of greater concern and represent pressing needs for further research:

i. problems associated with runoff, erosion and sedimentation;
ii. forest design and its influence on the physical structure and energy cycling through forest streams;
iii. acidification and the mobilization of metals.

Mills (1980, 1986) has already suggested some options for offsetting the impacts of (i) and (ii). These include the implementation of contour ploughing, preventing drainage ditches emptying directly into streams, and leaving or promoting buffer strips of deciduous trees or unplanted ground along banksides. Clearly, research programmes are required at the catchment level to examine the influence of different

Table 3. The pH, aluminium concentration and fishery status of streams in the upper Tywi in relation to total hardness and land use: groups I, II A and III A were moorland streams, whilst II B and III B drained forest (source: Stoner *et al.* 1984)

Class	Total hardness (mg Ca CO_3 l^{-1})	pH	Filterable aluminium (mg l^{-1})	Salmonid density (no. m^{-2})
I	10.0	6.0	0.135	0.6–1.8
II A	8–10	5.5–6.0	0.135	0.5–1.7
II B	8–10	5.0–5.5	0.225–0.342	0
III A	6–8	5.0–5.5	0.135–0.180	0.1
III B	6–8	4.5–5.0	0.252–0.450	0

drainage methods, and some work is already under way in Wales.

Further work is also required on the 'buffer strip' concept: clear banksides may not provide optimal temperature conditions for fish growth and may reduce the input of some allochthonous material. By contrast, the streamside planting of deciduous trees may be beneficial in enhancing habitat diversity, providing thermal insulation, increasing allochthonous input of leaf and invertebrate material and in protecting the stream from silvicultural operations of spraying or harvesting. Much work is now required on the relative merits of different deciduous species by comparison with conifers.

Perhaps the most pressing problem in soft water areas, where effects will over-ride management strategies which might otherwise be beneficial, is through acidification and the mobilization of metals. Even in the absence of acidification, the enrichment of aluminium in drainage from forest streams will be biologically damaging at pH 5.0–5.5. In the upper Tywi, several land management options are now being examined with respect to their influence on pH and aluminium concentrations. These options include the liming of buffer strips, direct liming of forest and permutations of planting with or without ploughing.

Work is also under way to assess the route through which aluminium is generated in forest drainage. It is not yet possible to forecast the results of these investigations.

7 Acknowledgements

Our thanks are due to the Welsh Water Authority for allowing access to unpublished data and to Linda Moy for help with computing. Contributions by GWM reflect his own views and not necessarily those of the Welsh Water Authority.

8 References

Alabaster, J.S. & Lloyd, R. 1980. *Water quality criteria for freshwater fish.* London: FAO/Butterworths.

Bärlocher, F. & Oertli, J.J. 1978a. Inhibitors of aquatic hyphomycetes in dead conifer needles. *Mycologia,* **70,** 964-974.

Bärlocher, F. & Oertli, J.J. 1978b. Colonization of conifer needles by aquatic hyphomycetes. *Can. J. Bot.,* **56,** 57-62.

Bärlocher, F., Kendrick, B. & Michaelides, J. 1978. Colonization and conditioning of *Pinus resinosa* needles by aquatic hyphomycetes. *Arch. Hydrobiol.,* **81,** 462-474.

Behmer, D.J. & Hawkins, C.P. 1986. Effects of overhead canopy on macroinvertebrate production of a Utah stream. *Freshwater Biol.,* **16,** 287-300.

Bird, G.A. & Kaushik, N.K. 1981. Coarse particulate organic matter in streams. In: *Perspectives in running water ecology,* edited by M.A. Lock & D.D. Williams, 41-68. New York: Plenum.

Brooker, M.P. 1981. The impact of impoundments on the downstream fisheries and general ecology of rivers. *Adv. appl. Biol.,* **6,** 91-151.

Cowx, I.G., Young, W.O. & Hellawell, J.M. 1984. The influence of drought on the fish and invertebrate populations of an upland stream in Wales. *Freshwater Biol.,* **14,** 165-177.

Crisp, D.T., Cubby, P.R. & Robson, S. 1980. *A survey of fish populations in the streams of the Plynlimon experimental catchments.* Unpublished report to the Institute of Hydrology.

Cummins, C.P. 1986. Effects of aluminium and low pH on growth and development in *Rana temporaria* tadpoles. *Oecologia,* **69,** 248-252.

Cummins, K.W. 1974. Structure and function of stream ecosystems. *BioScience,* **24,** 631-641.

Dalziel, T.R.K., Morris, R. & Brown, D.J.A. 1985. *Further investigations into sodium uptake and inhibition in brown trout* (Salmo trutta *L.*) *exposed to elevated aluminium concentrations at low pH.* (TPRD/L/2908/N85.) Leatherhead: Central Electricity Generating Board.

Edwards, R.W., Densem, J.W. & Russell, P.A. 1979. An assessment of the importance of temperature as a factor controlling the growth rate of brown trout in streams. *J. Anim. Ecol.,* **48,** 501-507.

Egglishaw, H., Gardiner, R. & Foster, J. 1986. Salmon catch decline and forestry in Scotland. *Scott. geogr. Mag.,* **102,** 57-61.

Elliott, J.M. 1975. The growth rate of brown trout *Salmo trutta* L. fed on maximum rations. *J. Anim. Ecol.,* **44,** 805-824.

Elwood, J.N., Newbold, J.D., Trimble, A.F. & Stark, R.W. 1981. The limiting role of phosphorus in a woodland stream ecosystem: effects of P enrichment on leaf decomposition and primary producers. *Ecology,* **62,** 146-158.

Forestry Commission. 1985. *Facts and figures, 1985.* Edinburgh: FC.

Gibson, G.E. 1976. An investigation into the effects of forestry plantations on the water quality of upland reservoirs in Northern Ireland. *Wat. Res.,* **10,** 995-995.

Harriman, R. 1978. Nutrient leaching from fertilized forest watersheds in Scotland. *J. appl. Ecol.,* **15,** 933-942.

Harriman, R. & Morrison, B.R.S. 1982. Ecology of streams draining forested and non-forested catchments in an area of central Scotland subject to acid precipitation. *Hydrobiologia,* **88,** 251-263.

Hildrew, A.G., Townsend, C.R., Francis, J. & Finch, K. 1984. Cellulotic decomposition in streams of contrasting pH and its relationship with invertebrate community structure. *Freshwater Biol.,* **14,** 323-328.

Hornung, M. & Newson, M.D. 1986. Upland afforestation: influences on stream hydrology and chemistry. *Soil Use Manage.,* **2,** 61.65.

Hornung, M. & Stevens, P.A. 1985. *Effects of harvesting of soil and water chemistry.* Prince of Wales Committee Environmental Research Group

Hynes, H.B.N. 1958. The effect of drought on the fauna of a small mountain stream in Wales. *Verh. int. Verein. Limnol.,* **13,** 826-853.

Hynes, H.B.N. 1968. Further studies of the invertebrate fauna of a Welsh mountain stream. *Arch. Hydrobiol.,* **65,** 360-379.

Hynes, H.B.N. 1970. *The ecology of running waters.* Liverpool : Liverpool University Press.

Jenkins, R.A., Wade, D.R. & Pugh, E. 1984. Macroinvertebrate–habitat relationships in the River Teifi catchment and the significance to conservation. *Freshwater Biol.,* **14,** 23-42.

Jones, A. 1975. *Rainfall, run-off and erosion in the upper Tywi catchment.* PhD thesis, University of Wales.

Kaushik, N.K. & Hynes, H.B.N. 1971. The fate of the dead leaves that fall into streams. *Archiv Hydrobiol.,* **68,** 465-515.

Kaushik, N.K., Robinson, J.B., Stammers, W.N. & Whiteley, H.R. 1981. Aspects of nitrogen transport and transformation in headwater streams. In: *Perspectives in running water ecology,* edited by M.A. Lock & D.D. Williams, 113-139. New York: Plenum.

Kerswill, C.J. & Edwards, H.E. 1967. Fish losses after forest spraying with insecticides in New Brunswick, 1952-67, as shown by caged specimens and other observations. *J. Fish. Res. Bd Can.*, **24,** 709-729.

Kownacki, A., Dumnicka, E., Grabacka, E., Kawecka, B. & Starzecka, A. 1985. Stream ecosystems in mountain grassland (West Carpathians) 14. The use of the experimental stream method in evaluating the effect of agricultural pollution. *Acta hydrobiol., Krakow,* **27,** 381-400.

Lock, M.A., Wallace, R.R., Costerton, J.W., Ventullo, R. M. & Charlton, S.E. 1984. River epilithon: toward a structural functional model. *Oikos,* **42,** 10-22.

Logan, P. & Brooker, M.P. 1983. The macroinvertebrate fauna of riffles and pools. *Wat. Res.*, **17,** 263-270.

Meyer, J.L. 1980. Dynamics of phosphorus and organic matter during leaf decomposition in a forest stream. *Oikos,* **34,** 44-53.

Meyer, J.L. & Johnson, C. 1983. The influence of elevated nitrate concentrations on the rate of leaf decomposition in a stream. *Freshwater Biol.*, **13,** 177-184.

Mills, D.H. 1980. *The management of forest streams.* (Forestry Commission leaflet no. 78.) London: HMSO.

Mills, D.H. 1986. The effects of afforestation on salmon and trout rivers and suggestions for their control. In: *Effects of land use on freshwaters,* edited by J.F. de Solbé, 422-431. Chichester: Ellis Horwood.

Milner, N.J., Hemsworth, R. J. & Jones, B.E. 1985. Habitat evaluation as a fisheries management tool. *J. Fish. Biol.*, **27,** (Suppl. A), 85-108.

Milner, N.J., Scullion, J., Carling, P.A. & Crisp, D.T. 1981. The effects of discharge on sediment dynamics and consequent effects on invertebrates and salmonids in upland rivers. *Adv. appl. Biol.*, **6,** 153-220.

Minshall, G.W. 1978. Autotrophy in stream ecosystems. *BioScience,* **28,** 767-777.

Morrin, R., Gaboury, G. & Mamarbachi, G. 1986. Fenitrothion and Aminocarb residues in water and balsam fir foliage following spruce budworm spraying programs in Quebec, 1979–1982. *Bull. environ. Contam. Toxicol.*, **36,** 622-628.

Morrison, B.R.S. & Wells, D.E. 1981. The fate of fenitrothion in a stream environment and its effect on the fauna, following aerial spraying of a Scottish forest. *Sci. Total Environ.*, **19,** 223-252.

Muniz, I.P. & Leivestad, H. 1980. Toxic effect of aluminium on the brown trout (*Salmo trutta* L.). In: *Ecological impact of acid precipitation,* edited by D. Drablos & A. Tollan, 84-92. (SNSF project.) Norwegian Council for Scientific and Industrial Research.

Murphy, M.L., Hawkins, C.P. & Anderson, N.H. 1981. Effects of canopy modification and accumulated sediment on stream communities. *Trans. Am. Fish. Soc.*, **110,** 469-478.

Nature Conservancy Council. 1986. *Afforestation and nature conservation in Britain.* Peterborough: Nature Conservancy Council.

Ormerod, S.J. 1985. *The distribution of aquatic macroinvertebrates in the catchment of the River Wye in relation to ionic composition.* PhD thesis, University of Wales.

Ormerod, S.J. & Edwards, R.W. 1985. Stream acidity in some areas of Wales in relation to historical trends in afforestation and the usage of agricultural limestone. *J. environ. Manage.*, **20,** 189-197.

Ormerod, S.J. & Edwards, R.W. 1987. The ordination and classification of macroinvertebrates in the catchment of the River Wye in relation to environmental factors. *Freshwater Biol.* In press.

Ormerod, S.J., Tyler, S.J. & Lewis, J.M.S. 1985. Is the breeding distribution of dippers influenced by stream acidity? *Bird Study,* **32,** 33-39.

Ormerod, S.J., Allinson, N., Hudson, D. & Tyler, S.J. 1986. The distribution of breeding dippers (*Cinclus cinclus* L., Aves) in relation to stream acidity in upland Wales. *Freshwater Biol.*, **16,** 501-507.

Ormerod, S.J., Boole, P., McCahon, P., Weatherley, N.S., Pascoe, D. & Edwards, R.W. 1987. Short-term experimental acidification of a Welsh stream: comparing the biological effects of hydrogen ions and aluminium. *Freshwater Biol.* In press.

Parry, M. & Sinclair, G. 1985. *Mid Wales uplands study.* Cheltenham: Countryside Commission.

Petran, M. & Kothé, P. 1978. Influence of bedload transport on the macrobenthos of running waters. *Verh. int. Verein. Limnol.*, **20,** 1867-1872.

Philipson, G.N. & Moorehouse, B.H.S. 1974. Observations on the ventilatory and net-spinning activities of the larvae of the genus Hydropsyche Pict. (Trichoptera, Hydropsychidae) under experimental conditions. *Freshwater Biol.*, **4,** 525-535.

Proctor, J. 1986. *Effects of acidification on algal epilithon.* MSc thesis, University of Wales.

Reynolds, B., Neal, C., Hornung, M. & Stevens, P.A. 1986. Baseflow buffering of streamwater acidity in five mid-water catchments. *J. Hydrol. (Amst.).* In press.

Richards, W.N. 1984. Problems of water management and water quality arising from forestry activities. In: *Woodlands, weather and water,* edited by D.J.L. Harding & J.F. Fawell, 67-85. (Proc. Symp. Inst. Biol.) London: Institute of Biology.

Robinson, M. 1980. *The effect of pre-afforestation drainage on the streamflow and water quality of a small upland catchment.* (Report no. 73.) Wallingford: Institute of Hydrology.

Robinson, M. & Blyth, K. 1982. The effect of forestry drainage operations on upland sediment yields: a case study. *Earth Surf. Process. Landf.*, **7,** 85-90.

Sedell, J.R., Triska, F.J. & Triska, N.S. 1975. The processing of conifer and hardwood leaves in two coniferous forest streams: 1. Weight loss and associated invertebrates. *Proc. int. Ass. theor. appl. Limnol.*, **19,** 1617-1627.

Smith, B.D. 1980. The effect of afforestation on the trout of a small stream in southern Scotland. *Fish. Manage.*, **11,** 39-57.

Stoner, J.H. & Gee, A.S. 1985. Effects of forestry on water quality and fish in Welsh rivers and lakes. *J. Inst. Water Eng. Sci.*, **39,** 27-45.

Stoner, J.H., Gee, A.J. & Wade, K.R. 1984. The effects of acidification on the ecology of streams in the upper Tywi catchment in west Wales. *Environ. Pollut. A,* **36,** 125-157.

Stretton, C. 1984. Water quality and forestry—a conflict of interests: Cray reservoir, a case study. *J. Inst. Water Eng. Sci.*, **38,** 323-330.

Summerbell, R.C. & Cannings, R.A. 1981. Fungi and *Brillia retifinis* (Diptera: Chironomidae) in the decomposition of conifer leaves in a British Columbia stream. *Syesis,* **14,** 125-130.

Sutcliffe, D.W. & Carrick, T.R. 1973. Studies on mountain streams in the English Lake District. 1. pH, calcium and the distribution of invertebrates in the River Duddon. *Freshwater Biol.*, **3,** 437-462.

Townsend, C.R., Hildrew, A.G. & Francis, J. 1983. Community structure in some southern English streams: the influence of physicochemical factors. *Freshwater Biol.*, **13,** 521-544.

Turnpenny, A.W.H. & Williams, R. 1980. Effects of sedimentation on the gravels of an industrial river system. *J. Fish Biol.*, **17,** 681-693.

Wade, K. & Ormerod, S.J. 1986a. *Assemblages of macroinvertebrates in upland Welsh rivers in relation to stream acidity.* Unpublished report, Welsh Water Authority.

Wade, K.R. & Ormerod, S.J. 1986b. *Macro-floral assemblages in upland Welsh rivers in relation to stream acidity and invertebrate fauna.* Unpublished report, Welsh Water Authority.

Wallace, J.B. & Gurtz, M.E. 1986. Response of *Baetis* mayflies (Ephemeroptera) to catchment logging. *Am. Midl. Nat.*, **115,** 25-41.

Wells, D.E., Morrison, B.R.S. & Cowan, A.A. 1978. Chemical and biological observations in streams following aerial spraying of forests with fenitrothion. In: *Control of pine beauty moth by fenitrothion in Scotland, 1978,* edited by A.V. Holden & D. Bevan, 103-132. Edinburgh: Forestry Commission.

Wilzbach, M.A. 1985. Relative roles of food abundance and cover in determining the habitat distribution of stream-dwelling cutthroat trout (*Salmo clarki*). *Can. J. Fish. aquat. Sci.*, **42,** 1668-1672.

Wilzbach, M.A., Cummins, K.W. & Hall, J.D. 1986. Influence of habitat manipulations on interactions between cutthroat trout and invertebrate drift. *Ecology,* **67,** 898-911.

Winterbourn, M.J., Hildrew, A.G. & Box, A. 1985. Structure and grazing of stone surface organic layers in some acid streams of southern England. *Freshwater Biol.*, **15,** 363-374.

Ziemann, H. 1975. On the influence of hydrogen ion concentration and the bicarbonate concentration on the structure of biocoenoses of mountain brooks. *Int. Revue ges. Hydrobiol.*, **60,** 523-555.

Recreation potential of Welsh forests

D O BAYLIS
Forestry Commission, Victoria House, Victoria Terrace, Aberystwyth, Dyfed SY23 2DQ

Summary
The Forestry Commission's forests in Wales have been partially developed for recreation, generally where demand was already evident but latterly as a process of co-ordinated utilization of the resource. This programme was truncated by constraints to public expenditure. The Commission's earlier pre-eminence in countryside recreation has been overtaken by private and other public bodies.

An assessment of current potential and the future demand for forest recreation in Wales suggests that new developments should respond to an enhanced public interest in specialist outdoor activities and environmental issues, whilst at the same time recognizing that for many people on limited incomes the greatest value of forests lies in their proximity to their homes and eminent suitability for informal leisure pastimes.

Plantation forests can be made more attractive and diverse for people. Improved access can provide for specific interests and can also open the forests to all people, including those with disabilities. Facilities for interpretation must be upgraded. There are limited prospects for new overnight accommodation.

1 Review of development

The Forestry Act of 1967 and Countryside Act 1968 gave the Forestry Commission powers to respond to the upsurge in countryside recreation which had grown throughout a decade of rising affluence, increased leisure time and mobility. New policies marked the end of an era of limited encouragement of public access, which had prevailed since the Commission was formed in 1919. Many Forest Officers welcomed the opportunity to share with a wider public their knowledge of richly varied landscapes beyond austere plantation forestry. They established car parks and picnic places, usually at sites where the public had already demonstrated that they wanted to be. Waymarked trails were set out and informative guide-leaflets produced. The disposition of recreation facilities generally reflected the enthusiasm of individuals rather than a co-ordinated deployment of the resource.

By 1972, the Commissioners felt that professional guidance was needed for the main thrust of forest recreation development. Clear guidelines were set out and territorial Conservators were required to identify priorities and to produce recreation plans containing rolling development plans for the succeeding years. A small planning and design group was set up at the Commission's Headquarters to co-ordinate the programme; specially trained staff were appointed at the Conservancies.

The task was tackled using conventional planners' methods, appraisal of resources and assessment of demand. The resources were huge—1.25 Mha in Britain, 160 kha in Wales (1972). A survey—public recreation in national forests—carried out by the University of Edinburgh in 1963 and 1964 (Mutch 1968), had established basic facts. Most people were remarkably tolerant of conifers (many expressed a preference for them), 76% of all visitors were in family groups, and most expressed a desire for improved facilities (particularly better sanitation and more picnic tables), but 65% of all visitors were opposed to commercialization of recreation in forests.

In Wales, the available results of surveys of tourism and leisure gave an incomplete picture of demand for facilities and the incidence of countryside recreation (Research and Strategic Planning Unit 1976; Wales Tourist Board 1974, 1985, 1986). The distinction between day-trippers from home and visitors from holiday accommodation was a significant feature of tourism in the Principality. In north-west and mid-Wales, there were about 3 holiday residents to every day-tripper from home, but this diminished to a ratio of about 1:3 in north-east Wales and the Borders, whilst in south Wales (except the west) the visitors were almost all home-based (147 000 people in the valleys live within half a mile of a forest).

The policy was to give the main emphasis to the provision of facilities for day visitors, particularly where they were readily accessible to visitors from towns and nearby holiday centres. Surveys of visitors to attractions and to tourist information centres provided an indication of demand, whilst an appraisal of the attractiveness of forests, based on landscape quality, ease of access and distribution of age classes, enabled priorities for development to be identified. A small number of mature, extensive and very attractive forests in the mountains of Snowdonia were undoubted candidates for further development, ie Gwydyr, Beddgelert, and Coed y Brenin, whilst priorities to a lesser extent were established at Clocaenog, Rheidol, Ystwyth, Tywi, Tintern and Wentwood. In the south Wales valleys and in north-east Wales, the proximity of forests to urban areas indicated special consideration of the need for day visitor facilities, particularly at Ebbw, Rhondda, St Gwynno, Margam, Crynant and Clwyd. Priorities were also evident at forests on tourist routes in the National Parks, such as Dyfi, Coed-y-Rhaiadr, Coed Taf and Mynydd Du.

The new thrust of planned recreational development put the Commission in the forefront of environmental interpretation in Britain, partly in response to a strong demand for reception of educational visits, but primarily to encourage a wider use and better understanding of the forests by the general public. In Wales, the first forest visitor centre was created by local staff in Gwydyr in 1969, and was followed during the 1970s by professionally designed centres at Coed-y-Brenin (Maesgwm), Coed Taf (Garwnant), Rheidol (Bwlch Nant-yr-Arian), Clocaenog (Bod Petrual) and, jointly with West Glamorgan County Council, at the Afan Argoed Countryside Centre. Most recently, the Commission has provided interpretive exhibitions jointly with the Snowdonia National Park at Betws-y-Coed (Y Stablau) and with Islwyn Borough Council at Cwmcarn (Cwmcarn Forest Drive).

The provision of overnight accommodation in the forests has been an essential element of the Commission's recreation provision since the mid-1930s, primarily to enable people to visit forests in the more remote areas, often associated with the finest scenery. In Wales, a camp site was established at Beddgelert Forest in 1938 as an integral part of the newly designated Snowdonia National Forest Park. This remains the only 'Class A' camp site (providing full facilities) in Wales managed by the Forestry Commission.

The appointment in 1973 of Coopers and Lybrand Associates Limited to investigate and report on the possible development of low-cost tourist accommodation on Forestry Commission land was a milestone in British tourist development. The Consultants' report (Coopers & Lybrand 1973) predicted a huge growth in the demand for holiday accommodation by the end of the decade and, on the basis of an elaborately contrived but hastily executed assessment of potential, made proposals for 7000 cabins, almost 2000 of which were to be in Wales. The criteria for site selection were extremely searching, and subsequent, more detailed study rejected all but a few sites. Two were developed in England, 2 in Scotland. They have been a financial success and have received considerable public acclaim. In Wales, one site reached the development stage but was eventually abandoned after strong local objections led to a planning refusal.

By the end of the 1970s, the period of planned recreation development had been brought to a halt by the recession. In common with other Government departments, the Commission had to make substantial reductions in manpower and expenditure. A declared policy of 'recreation on limited resources' gave priority to the maintenance of existing facilities to a high standard, particularly visitor centres, popular day visitor facilities close to towns, profitable commercial recreation and certain specialist facilities. This policy continues with only slight relaxation. Notable exceptions have been joint developments with local authorities, partly funded by them or facilitated by the availability of specially recruited Manpower Services teams. A rational development of forest recreation resources was halted almost before it began, and a headlong rush into fresh developments is unlikely in the foreseeable future. We have time to take stock. We need to reassess an immense resource.

2 Assessment

The achievement of little more than a decade of development was considerable. The Commission's Annual Report of 1985–86 recorded over 100 picnic places and almost 160 forest walks and nature trails in Wales, together with the 4 visitor centres, camp site, and forest drive (established with the encouragement of the Countryside Commission in 1974) and a total annual recreation and amenity subsidy of £161,000. The last full national survey of visitors to forest in 1976 (unpublished) gave an estimate of 1.75 million visitors annually to the Commission's forests in the Principality.

Perhaps the greatest achievement of the period was the establishment of high standards and an unmistakable style for forest recreation in Britain. The now familiar signs and the simple functional furniture and buildings are an assurance to the public of a safe, pleasurable place for leisure, where the trappings of town have been excluded and the distinctive qualities of the rural environment preserved.

In reality, the accomplishment in Wales is less than the schedules of sites and facilities would have us believe. Many locations provide no more than a minimal parking space and an arrowed 'forest walk' sign directing the visitor along an undistinguished forest road. Small open spaces which were sunlit glades when they were created are now dank and shady, often quite out of scale with the trees around. In some places, persistent vandalism and uncontrollable fly-tipping have eroded the enthusiasm of forest staff.

Standards of reception and presentation of recreation facilities in the countryside have greatly improved during the 1980s. Stately homes, historic places, country parks and nature reserves commonly exhibit to the visitor a generous welcome and a professionalism in presentation which extend beyond tidy car parks and explicit signing, to the demeanour of guides and rangers. By comparison, the reticent, unobtrusive style of the Forestry Commission often seems less effective. Perhaps it is the most difficult style to accomplish with real flair and imagination and should sometimes be set aside in favour of a more positive, more commercial approach to leisure facilities in the forests. An elitist policy has tended to serve the needs of individuals ready and capable of seeking out their own recreative experience in forests, rather than those who use forests merely as a convenient and pleasant setting for outdoor pursuits.

The effort has been essentially amateur, with a minimum of professional guidance, the quality of the facility dependent on the ability, commitment and priorities of changing staff. No training in recreation has been available since 1979.

3 Trends and new emphases

Despite the recession, the standard of living for those in employment has continued to rise. The average household has a higher disposable income than 10 years ago and, although less money is spent on food and drink, a huge rise in expenditure on transport and vehicles has occurred (particularly between 1973 and 1981), indicating the importance of mobility upon which countryside recreation is dependent (Department of Employment 1981). A dramatic increase in the holiday entitlement of manual workers also occurred during the same period, the percentage of workers entitled to 4 weeks' paid holiday rising from 5% to 85% (Department of Employment 1982, 1986). The trends in countryside recreation have been towards increased participation in specific activities while casual activities such as 'driving for pleasure' have decreased. There has been an enormous growth of interest in the natural history and beauty of our islands, manifest in the abundant choice of popular literature in these subjects and the popularity of television programmes such as 'Kingdom of the ice bear' which can command an audience of 4.25 million.

Recreation in the Welsh forests during the succeeding decade must respond to a situation of increasing polarity. On the one hand, people with more leisure, money and knowledge are seeking the reality behind the media images. They will be looking for new life-styles and healthier living. On the other hand, we must assume that unemployment will not diminish significantly. In 1986, the number unemployed in Mid Glamorgan is 18.4% of the working population; in Clwyd and Gwent the figure is 17.0%. This sector of the community has surplus leisure but is constrained by lack of mobility and disposable income, requiring recreation opportunities on the doorstep.

In Wales, tourism continues to be a major industry and source of employment in the rural areas. In the depressed industrial areas, local authorities not traditionally associated with tourism are turning their attention to it with some vigour and are viewing the forests as valuable local assets.

The industry struggles to retain its share of a falling domestic tourism market. A modest recovery in 1983 and 1984 was followed by a fall of 20% in holiday bed-nights and 13% in day-trips to Wales, probably influenced by aggressive marketing of overseas package holidays and one excessively wet season. On the other hand, an increase in overseas visitors to Wales has been sustained for several years (Wales Tourist Board 1985, 1986). There are indications of a growth of flexible, all-year-round breaks, in part compensating for the decline in the custom of taking a traditional 2–3 week holiday. The industry's confidence in the medium- to long-term outlook is indicated by substantial investment in new and improved facilities.

Camper nights at Beddgelert camp site reached a peak of 96 600 in 1977, fell to 71 600 in 1981 and are currently recorded at about 74 000 annually. The numbers of visitors to the Cwmcarn Forest Drive fell from 66 000 in 1978 to 41 000 in 1985. Attendances at the forest visitor centres have fluctuated only slightly over a period of 10 years.

4 Analysis/proposals

The analysis of potential for future forest recreation and proposals for future directions are considered under 4 subject heads: leisure space, access, interpretation, overnight facilities.

4.1 Leisure space

The main objective in plantation forestry is the production of timber. The degree to which the process of efficient timber production is modified in order to achieve a resource of high aesthetic quality and which is environmentally sound is crucial to the quality of the forest as a space for leisure. The public take for granted the availability of forests for leisure activities, but the diversity of these activities requires fundamental decisions to be made about their management. For many people, the gregarious situation is the most satisfying one. Others will seek peace and solitude for refreshment of the spirit.

In Britain, we still enjoy huge landscapes created in the 18th century for a wealthy few. Landscapes with the power to excite or calm the human spirit have scarcely found a place in modern forestry. The opportunities now afforded by second-rotation forests and the increasing sophistication of our handling of trees in the mass for aesthetic purposes have brought such designs within our capabilities.

4.1.1 Proposals

Fundamental changes will be required in the structure of forests to achieve landscapes which are harmonious and vistas which are exciting. In appropriate locations, particularly close to large urban areas, open sunlit spaces will be created for gregarious activities such as barbecues (see Plate 8), adventure playgrounds, fitness tracks. These locations may justifiably include features such as sculptures and water gardens.

The interior of more remote forests will reflect the visitor's desire for solitude and the discovery of interesting plant and animal habitats. Opportunities will be created for the enhancement of such habitats.

4.2 Access

The most common form of access is by the non-specialist on foot. Provision has seldom been better

Plate 8. A large group of people from a local 'Round Table' organize their own barbecue at car park no. 1 on the Cwmcarn Forest Drive, Ebbw Forest (south Wales), July 1982 (Photograph Forestry Commission)

than adequate but the public is relatively uncomplaining. Where waymarked footpath networks and guide-maps have been created, the dedicated walker has been able to select routes and to find his way safely into the forest interior and back. The system has been well proven at Coed-y-Brenin, Beddgelert, and Gwydyr, and has obvious application at other extensive, popular forests. Access paths to beautiful tree-scapes, waterfalls and viewpoints are often underused because they lack a simple map board, prominently displayed at the start.

In providing access on foot, there has been a tendency to favour the experienced walker who is appropriately clothed and a competent map reader. This tendency is inappropriate in the near-urban forests where many thousands of people living close to the forests are denied access to beautiful places because they are physically unequipped to traverse paths which are characteristically rough and steep. These forests will become increasingly attractive and varied with age, and the abandonment of substandard roads from the earlier harvesting network will provide a major opportunity for enhanced access for all.

The provision of special facilities for the public to drive in the forest requires heavy investment in tarmac surfaces and long-term crop management commitments; there is also a strong disincentive to extend the intrusive effects of cars on the forest environment. The recent success of small-scale 'safari tours' by concessionaires suggests a more effective way of facilitating public access in depth.

New forms of access have provided a new cycle sport, and a new cycling holiday experience using mountain bikes on specially designated routes at Irfon Forest. A successful cycle route at Margam Forest and proposals for cycle routes at Beddgelert and Gwydyr have been initiated by other agencies. We take the view that the cycling fraternity should take the initiative in the designation of cycle routes. Orienteering is an athletic activity uniquely dependent on forest terrain. The sport continues to grow under the auspices of the British Orienteering Federation and, provided there is a sensible rationalization of the resource by the designation of specific areas for orienteering, there is considerable further potential.

Wayfaring, which is a family activity, has been very successful where there is an established demand by holiday-makers and residents of outdoor pursuit centres, but seems never to have had the success it deserves in the near-urban forests.

Cross-country motor cycles are an intrusive and dangerous element everywhere in the forests. Preventing trespass has proved an expensive task but, where we have made provision for motor cycle trials, the record of compliance and orderliness has been encouraging. With a huge land resource close to urban centres, there is considerably more that can be done to satisfy an unquantified demand, provided youngsters can be persuaded to join specially formed clubs.

4.2.1 Proposals

The construction or adaption of safe, easily traversed paths for people of all ages and physical abilities is the primary proposal, giving access on foot to beautiful places, particularly in forests close to towns and popular tourist locations. For the long-distance walkers, better and more concise information will be needed at the starting point of conventional waymarked paths. The waymarked network and guide-map system will be introduced at popular forests like Margam and Tintern.

The further development of 'safari tours' by concessionaires is proposed as an alternative to forest drives.

Wayfaring will be further developed in association with places which are attractive to all the family, and adequately promoted. Provision must also be made for jogging, particularly near to towns.

Further development of mountain biking and cycling routes is desirable but we may need to stimulate the interest of local voluntary organizations to set them up.

The support of local voluntary organizations and the Auto Cycle Union should be sought to create, in special locations, motor cycle trial tracks for young people.

Other potential subjects for new access provisions will include long distance horse-riding (see Plate 9), cross-country ski-ing and gliding.

4.3 Interpretation

For some people, visitor centres are their only contact with the forest. Such centres have many functions: they are a focus of interpretation and also disseminate information. Each centre represents a substantial commitment of capital and future running costs which can only rarely be justified (Dartington Amenity Research Trust 1978).

A survey of 20 forest centres (3 in Wales) by the University of Surrey's Department of Psychology in 1979 enabled the effectiveness of displays and media to be evaluated for the first time. At least one of the centres in Wales gave indications that the visitor's desire to learn about specific forest environment factors had been considerably underestimated. Future interpretive programmes will need to meet this need and to give honest answers to questions about plantation forestry and environmental quality.

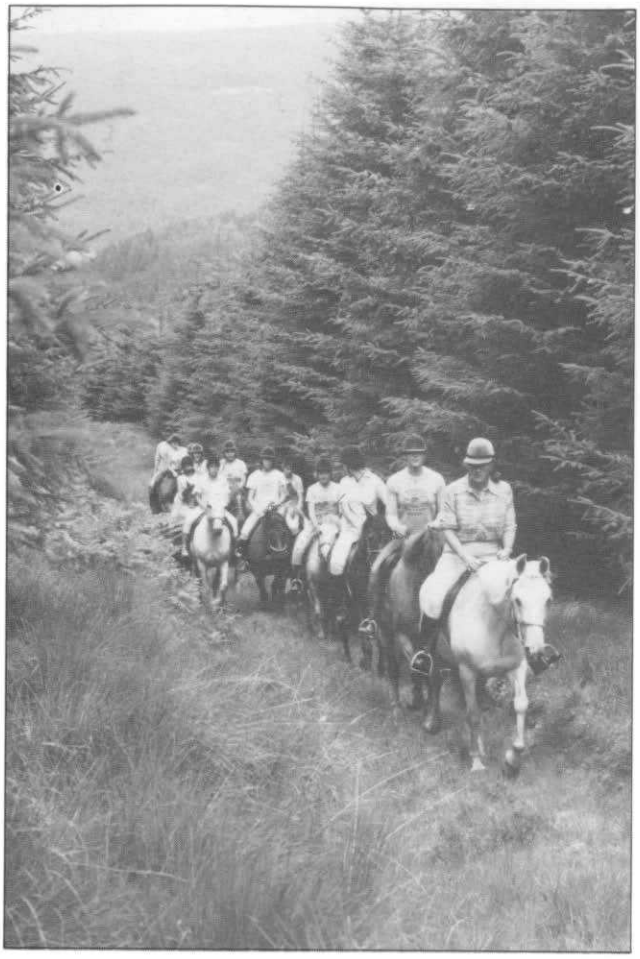

Plate 9. A group of pony trekkers at Brongrehelm in Tywi Forest coming through Sitka spruce (Photograph Forestry Commission)

On the other hand, the most popular displays were those which had a direct appeal (wildlife tableaux for instance, see Plate 10) and made least demand on the cognitive ability of the visitor. Forestry is a technical subject but can be presented in an attractive and stimulating way for the majority of visitors who are seeking entertainment rather than enlightenment.

The surveys also indicated that some visitors failed to obtain the information they needed because they had made no contact with the Ranger. This lack of contact was sometimes due to bad circulation within the building, sometimes to the personality of staff.

Forest centres must be evaluated in the context of a wide field of public reception facilities in the countryside. However serious the subject matter may be, the presentation is designed essentially for the visitor's pleasure and almost always satisfies a need for simple refreshment. We need to set aside the 'ivory tower' approach to visitor centres and consider them in this light.

Ten years have elapsed since Dartington Amenity Research Trust (1976) prepared an appraisal of self-guided trails in Britain. The report suggested that

Plate 10. A wildlife display in the interpretive centre, Gwydyr Forest (Photograph Forestry Commission)

Forestry Commission managers should question the necessity for interpretive trails in addition to waymarked walks. It thought a series of boards *en route* might better achieve the interpretive objectives, particularly for the casual visitor. On the other hand, it suggested a comprehensive 'souvenir' guide might appeal to both casual and regular visitors, rather than the traditional 'numbered stop' leaflet. This is the type of publication generally adopted by the Commission in Wales. It tends to be less repetitive, is easier to update and allows the route to be varied.

The report also suggested that it should be possible to design self-guided trails for those with a specific interest: to trace changes in vegetation and ecology or the history of a landscape, for instance. There are a few examples of this type of on-site interpretation also. Where they are linked with a visitor centre, they have stimulated a repeat visit to the centre and provoked discussion with staff. There are clear indications that new patterns of enjoyment and learning in the countryside are emerging.

It is rare these days to find an unoccupied hide on a nature trail. The sheer pleasure of watching birds and animals in the wild is, for most people, unmatched by the best that interpretive media can provide. Questions about forest wildlife are the commonest subjects directed to rangers at visitor centres.

4.3.1 Proposals

Visitor centres need to be periodically refurbished to meet changing needs. Professional, technically adroit interpretation will be used to enable the environment of the forests to be better understood and to provide for the needs of those who wish to study specific aspects, as well as for those seeking an enjoyable experience in the countryside. Catering concessions will be a normal element of all visitor centres.

Opportunities will be taken for the development of new centres in partnership with other authorities having responsibility for countryside management.

The level of on-site interpretation must also be re-examined to satisfy the growth in specialist interests. Guide literature needs to be better researched and presented, text and graphics should be made available on-site, and more demonstrations, guided tours and open days provided.

New opportunities for the observation of wildlife should be created. These may include, for example, the regular feeding of wildfowl or deer and the provision of hides.

4.4 Overnight accommodation

The aspect of wildness combined with shelter from the elements makes forest camping particularly attractive in a country where so much of the land is urbanized, intensively farmed or open moorland. The pleasure of camping in Wales is often marred by discomfort due to wet clothing, boggy ground and the presence of insects. At Snowdonia Forest Park camp site, Beddgelert (open throughout the year), we have invested in measures to offset these problems and to encourage more campers to use the site in the shoulder months of the season. Specially prepared tent and caravan pitches and purpose-designed ablution buildings have been constructed. Any new 'class A' camp sites in Wales would be of this standard. The optimum size for financial viability is about 300 units. Few inland locations can be assured a sufficient demand to justify such a development.

Simple 'Class B' camping sites, providing minimum facilities, attract mainly touring caravanners and a small number of campers who prefer a less gregarious camping experience. The demand for additional sites is not known, but exceptionally attractive locations within or close to the National Parks would succeed.

The simplest form of overnight accommodation is required by the long-distance walker or back-packer who is mainly catered for in Wales by farmers. Bothy accommodation, usually a disused barn or cottage with basic sleeping provision, is appropriate in very remote locations (we have 2 bothies leased to the Mountains Bothies Association).

In the Scandinavian countries, low-cost, simple cabins are provided as a means of overcoming the disadvantages of camping in a wet, cool climate. These 'timber tents' usually form part of a camping complex and are served by a communal ablutions block. The system is unknown in Britain but suggests an avenue for the development of new low-cost accommodation at a time when many people are seeking frugal, healthy, outdoor living.

4.4.1 Proposals

The development of at least one cabin site remains a possibility. Shortage of capital will inhibit further development of 'Class A' camp sites but a small number of basic facility 'Class B' camp sites may be developed in very favourable locations. A new 'Class B' camp site could incorporate a small 'timber tents' development experimentally.

The further provision of basic overnight facilities for youth group camping, back-packers and other long-distance walkers is also suggested.

5 References

Coopers and Lybrand Associates Ltd. 1973. Development of forest cabins. In: *Possible development of permanent low cost tourist accommodation.* Private report to Forestry Commission.

Countryside Recreation Research Advisory Group. 1982. Trends in countryside recreation. In: *General household survey, 1977, 1980.* Cheltenham: Countryside Commission.

Dartington Amenity Research Trust. 1976. Evaluation of self guided trails. In: *Self guided trails,* 70–71. Cheltenham: Countryside Commission.

Dartington Amenity Research Trust. 1978. Evaluation of visitor centres. In: *Visitor centres,* 65. Cheltenham: Countryside Commission.

Department of Employment. 1982, 1986. Changes in holiday entitlement, current levels of employment. *Employ. Gaz.* (various).

Department of Employment. 1981. Changes in holiday expenditure. In: *Family expenditure survey* (various). London: HMSO.

Forestry Commission. 1985-86. Summary of recreation facilities, areas of forest land. In: *Rep. For. Commn* (various).

Mutch, W.E.S. 1968. Public response to forest recreation. In: *Public recreation in national forests,* 81, 83, 87. London: Forestry Commission.

Research and Strategic Planning Unit. 1976. Tourism trends in Wales. In: *Tourism in Wales—a plan for the future,* 3.1–3.6. Cardiff: Wales Tourist Board.

Wales Tourist Board. 1974. *Surveys of visitors to tourist attractions, 1973* (various). Cardiff: Wales Tourist Board. **Wales Tourist Board.** 1985, 1986. *Tourism trends in Wales.* (Annual report 1985, 1986.) Cardiff: Wales Tourist Board.

Landscape design of forestry

O W R LUCAS
Forestry Commission Headquarters, 231 Corstorphine Road, Edinburgh EH12 7AT

Summary
The landscape impact of afforestation is distinct from consequences for water, soils, wildlife and the economy in that the effects are relatively immediate and obvious to the layman. No specialized knowledge or assessment is required to realize that landscape change is taking place and, by its very nature, forestry is an activity which produces sudden periods of change—at ploughing, establishment and, later, clear-felling and replanting. The health and appearance of the countryside are of great concern to many of our population today. Most foresters now realize that these aspects must be considered carefully as the cycle of planting, felling and restocking continues. The reasons for public reaction to afforestation, the nature of sympathetic and unsympathetic landscape change, the communication of specific future changes and the effective implementation of good landscape design are all essential parts of the planning of forestry operations, such as planting, felling and replanting.

1 Public attitudes
Although public reactions to landscape change are very complex, there are certain factors which are particularly important to an understanding of the response to afforestation. First, the long history of deforestation in this country left Britain with predominantly bare hills by the latter part of the 19th century. At about the same time, the rapid expansion of the urban population and the advent of rail travel made the hills more accessible, and they were extensively visited as a relief from a noisy and polluted working environment. These open areas were and still are perceived as natural, and there is therefore a strong association in perception between valued wild areas and open space. As a result, extensive afforestation has been perceived as a threat to unencumbered access and the beauty of our upland landscapes.

It is also likely that criticism of afforestation has arisen from a dislike of sudden and extensive change in the environment, over which the individual feels he has no influence or control.

The third factor which stimulated vociferous criticism of afforestation was the appearance of many of the plantations established in the 1920s and 1930s. Although the work was well done in the context of the policies of the time, there was little or no thought of their appearance. Characteristically, the plantations were laid out in geometric shapes which bore no relationship to their surroundings or the underlying ground. The rich detail of crags, vegetation change, streams, etc, usually became hidden by trees and, as a result, the plantations often appeared not only uninteresting by comparison with their surroundings, but also too large.

Not all of the results of the early plantings were so unattractive—for example, in Gwydyr, where an existing pattern of estate woodlands and the planting of more varied species, often related to vegetation change, produced forest landscapes of recognized quality. Other notable examples of good forest landscapes exist at Coed-y-Brenin, at Grizedale in the Lake District, and at Achray and Dunkeld in Scotland.

Landscape design is therefore concerned with the nature of change, and its principles take account of all the elements in the landscape, as well as the attitudes of society that prevail at the time. The perception by the public that the countryside is 'natural' (even though they may know that it is not), the appreciation of open space and dislike of unsympathetic change are all factors that influence the principles of forest landscape design.

2 Principles of landscape design
In 1963, with criticism of afforestation in the landscape continuing to increase, the Forestry Commission appointed Dame Sylvia Crowe as landscape consultant and she established principles of forest landscape design which still form a sound basis for the discipline today.

The main principles of forest design are to:
— contrast the appearance of the forest landscape with that of the town, and blend with natural qualities of the landscape;
— relate forest shapes to landform;
— reflect the scale of the landscape in the forest;
— create as much diversity as possible.

Underlying these principles is the objective of finding a balance between the environmental and timber production objectives of the forest. This objective is now enshrined in the Wildlife and Countryside Amendment Act 1985 and the subsequent Forestry Act as a requirement to seek a balance between timber production and management of the forest on the one hand, and the protection and enhancement of natural beauty, fauna and flora and features of physiological or geological interest, on the other.

2.1 Contrast of the forest landscape and the town
Why should the forest landscape contrast with the

town? Our wilder countryside provides an important relief for the 90% of the population living amongst the noise, hard materials and geometry of the town—characteristics which are in sharp contrast to the landscape of Snowdonia, for example. Yet, whenever man unthinkingly changes the landscape, its appearance is modified towards that of the town. Like the town, the patterns of agriculture are highly geometric and in contrast to the irregularity and diffuseness of the wilder landscape. The contrast of the countryside with the urban landscape will be reduced, if the geometric shapes of agriculture are repeated at a larger scale on the steeper slopes of the hills. We should adopt a more irregular and naturalistic layout for the forest shapes.

2.2 Shape

The second principle of landscape design is that forest shapes should reflect landform. Shape is the most powerful and evocative factor in our perception of the environment. It is concerned with boundaries: between mass and space or areas of different colour and texture or between the forest and open ground, different species, etc (see Plate 11).

Natural shapes contrast strongly with man-made shapes. Artificial shapes are more geometric, straight-edged, symmetrical and well defined than natural shapes which tend to be irregular, curved, asymmetric and diffuse. However, a complete range of shapes exists between these 2 extremes.

2.3 Relating forest shapes to landform

Generally speaking, the eye tends to be drawn downwards on spurs and convex slopes and upwards in gullies, hollows and concavities. The power of these visual forces increases with the strength and size of the spur or hollow. Forest shapes superimposed on landform, so that their boundaries rise in hollows and fall on convexities, respond visually to the shape of the ground in a direct and satisfying way. Whether the forest is above or below, the edge can be shaped in the same way.

This approach can be applied at any scale to unify landform and layout of forest edges, species margins and any other lines which occur. This approach to forest design has been successfully used in the Forestry Commission for a number of years. A similar effect occurs naturally where trees survive in fertile, moist, sheletered hollows at a higher level than on dry, exposed ridges (see Plate 12).

2.4 Scale

The third principle of forest design is that the scale of the forest should reflect that of the landscape. Scale is

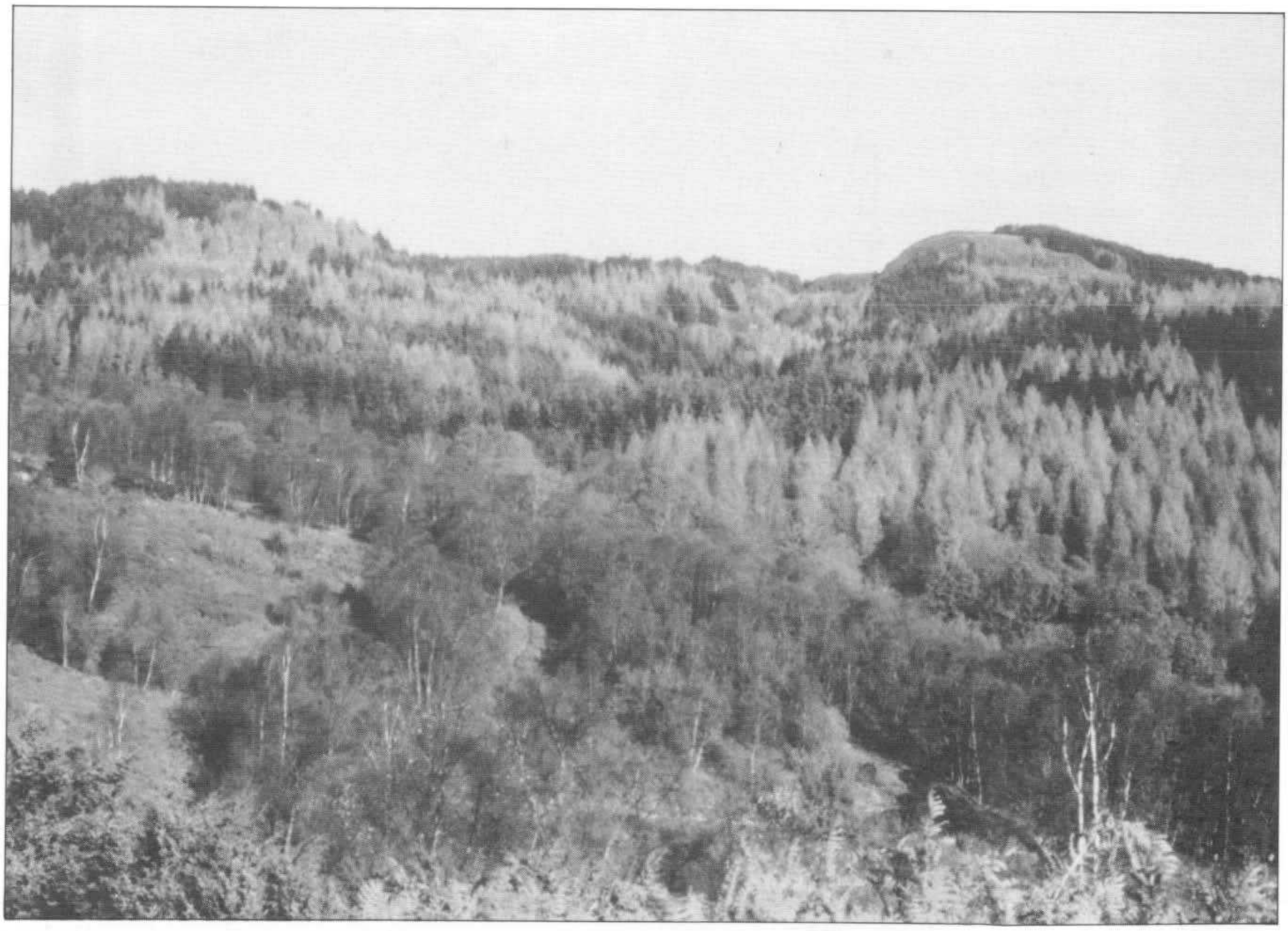

Plate 11. A diverse forest landscape with irregular larch shapes reflecting bracken patterns on open land—Achray (Photograph Forestry Commission)

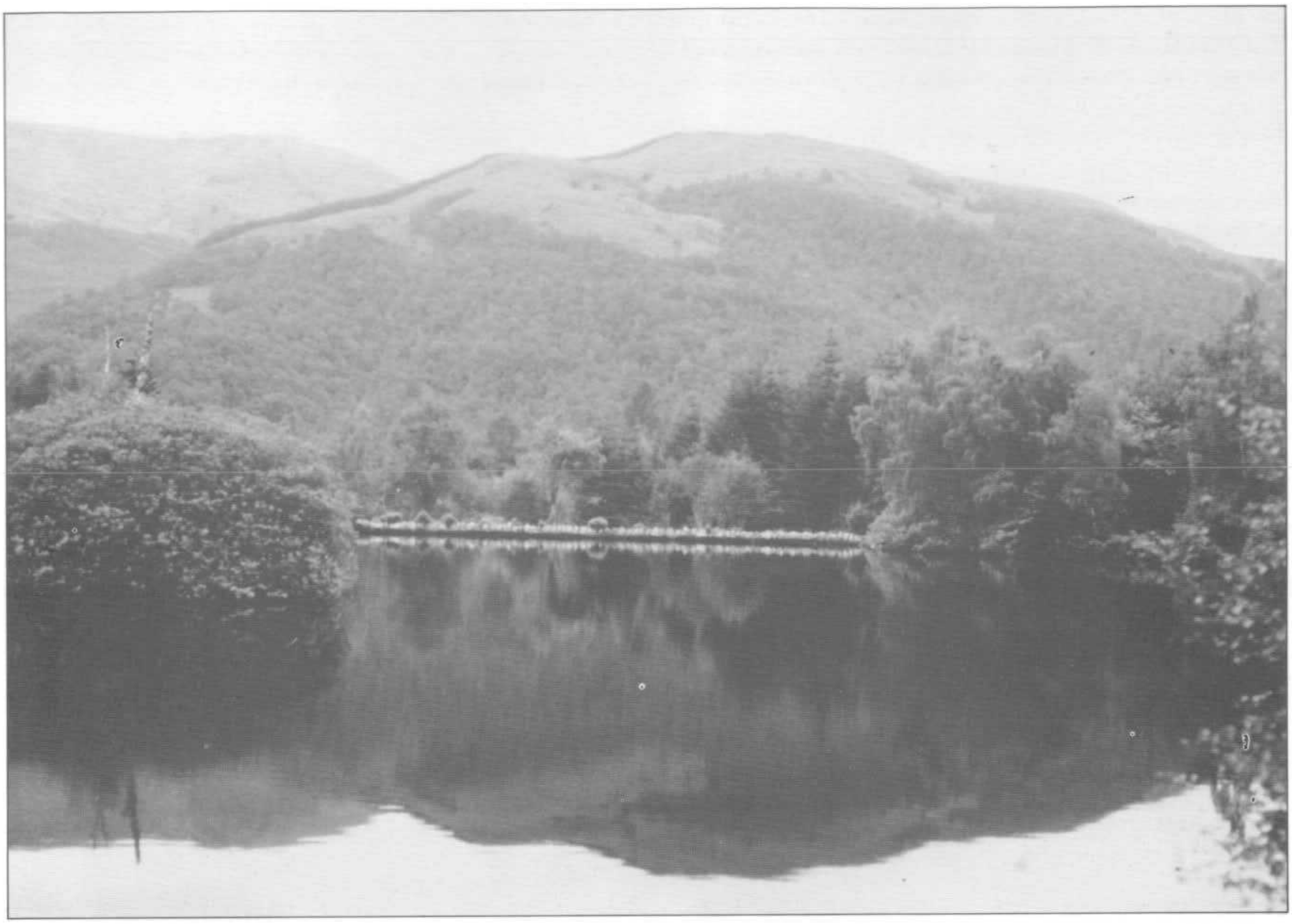

Plate 12. Semi-natural oak woodland in Glencoe running up depressions with ridges left bare (Photograph Forestry Commission)

concerned with the size of the elements in a composition, both proportionally and in absolute terms. The scale of the landscape can be identified by the extent which is visible. If one can see a great breadth of view and a long way, as shown in the open views of the Denbigh Moors, then the scale is large. It would, therefore, be more appropriate to plant fewer larger sweeps of forest in this area than numerous small woodlands.

Similarly, the scale of the landscape increases if one can see larger differences in elevation. Medium-scale landscapes often occur where views are contained by valleys, eg in parts of Rheidol Forest. *In the small-scale views within the forest, detail becomes far more important and this is often the landscape of recreation.* Scale also affects perception of shape—what appears to be an irregular edge from a short distance may look like a straight line from further away. It is therefore important to resolve forest shapes boldly before adding edge detail. Scale also changes in a fairly consistent way with topography. Generally, it is smaller in the lower parts of valleys where views are more confined, and increases further up slopes and towards the summits of hills. So, where a forest extends from a valley to a hill, the actual size of felling coupes would be smaller on the lower slopes and increase in size further up the slopes, and the scale of forest layout would change gradually from one part of the landscape to another.

2.5 Diversity

The final principle of forest design is to create as much diversity as possible. Diversity is the degree and number of differences in a design, and can give a high quality of landscape. Diversity in the forest landscape is developed by keeping major features open to view and by increasing forest diversity by varying species and age and introducing open space. Some landscape assets cannot be replaced by stand diversity, and so it is particularly important not to obscure:

— water, with its qualities of reflection and movement.
— views, especially those up valleys with their focal qualities.
— rocks—planting should be kept clear.
— vegetation—large, old broadleaved trees down to rare herbs and even the mundane ivy can give an exceptional landscape quality.
— sites providing a good environment for recreation, which need to be conserved and enhanced, even if not for immediate development. The environment of walking routes is increasingly important.
— habitats where viewing of wildlife can be developed to provide a potentially outstanding aesthetic component.

— the archaeological landscape, which is so rich it is not only worth conserving in its own right, but also because of its great value as an interpretive resource and as a contributor to forest diversity. The interest in forestry and archaeology is likely to increase rapidly in the next 5 years.
— in extensive forests, open areas such as agricultural holdings or failed crop to provide contrast.
— with modern streamside management, more open space as it is introduced along watercourses.

Inevitably, some detail is lost under the tree canopy, but this loss can be offset by planting larch (*Larix* spp.), especially to highlight the subtleties of morainic landform. The added component of broadleaves produces another contrast of texture and colour, and is being used to increasing effect as a result of the new broadleaved policy.

The contrast of open space within the forest can be further enhanced by carefully phased felling coupes at an appropriate shape and scale (see Plate 13). In the same way, the contrast of textures of different crop ages is also developed in the second rotation into a permanent structure, within which the dynamics of the forest cycle can proceed, but with a few areas of trees retained to grow to physical maturity.

3 Practice of forest landscape design—Beddgelert case study

The integration and implementation of the varied principles previously described require an organized process of planning and design. The process can be illustrated showing the various stages applied to a section of the Beddgelert main block. The Beddgelert project was carried out from 1981–83 in an area of high landscape sensitivity—near to the heart of Snowdonia, an intensive recreation interest with camp site and car parks. As a result of the approach applied, Beddgelert now is representative of what may happen more generally in the future. There may be differences of degree, but the same ingredients will be represented in many forest landscape plans.

3.1 The landscape design process

The application of these 4 main principles of forest design requires careful balancing one with another, and against the efficient, economic and timely management of the forest. At Beddgelert, this balance was further complicated by a need to improve the internal landscape for recreation, which is small scale, without creating intrusive effects in the larger-scale views from outside the forest. Areas of value to nature conservation also needed to be identified and included within the design. This requirement demands an organized

Plate 13. A small felling well related to a small-scale landscape—Gwydyr Forest (Photograph Forestry Commission)

Plate 14. Diversity of tree size, framed views and open space created as part of long-term forest structure—Beddgelert Forest (Photograph Forestry Commission)

process of design which would produce a good appearance in the long view, and a good environment for recreation and wildlife.

This process can be simply illustrated with reference to the southern part of Beddgelert Forest. (It is essential to illustrate forest design on an accurate photographic base. The Forestry Commission generally uses photocopies of photographs known as photosketches, with coloured pencil applied to illustrate proposed changes.) As a first step, all the information which might affect the design is collected and that which is most relevant is illustrated on a landscape appraisal sketch (see Plate 15). This sketch includes the visual forces in landform on main ridges and hollows, visual problems of the external shape, elements of diversity such as rocks or water features, and areas of conservation value which will grow larch. In view of the very extensive external edge to the forest and its very high visual impact, the improvements to the external edge were designed first.

3.2 Long-term forest structure

This redesigned edge provides a context for the design of the long-term forest structure. The long-term forest structure consists of a series of long narrow areas running through the forest which are subject to a much smaller scale of management to provide an attractive environment for walkers and a good environment for wildlife (see Plate 14). It is generally located along main watercourses because:

— there is a good relationship to landform, in the broader view;
— its small scale looks appropriate when seen from outside the forest;
— water provides an important aesthetic and wildlife conservation resource.

The components of the long-term forest structure are open space, broadleaved trees and eventually large conifers (where they will stand).

The potential benefits are:

— a diverse small-scale environment for recreation;
— a permanent landscape element, around which successive changes of felling and replanting can take place with less impact on those using walking routes;
— more framed views from open space to mountains beyond the forest.

The redesigned external edge and the long-term forest structure together provide the context for the design of a series of felling shapes covering the whole area. The shapes are related to visual forces in landform. The coupes on the upper slopes are much larger than

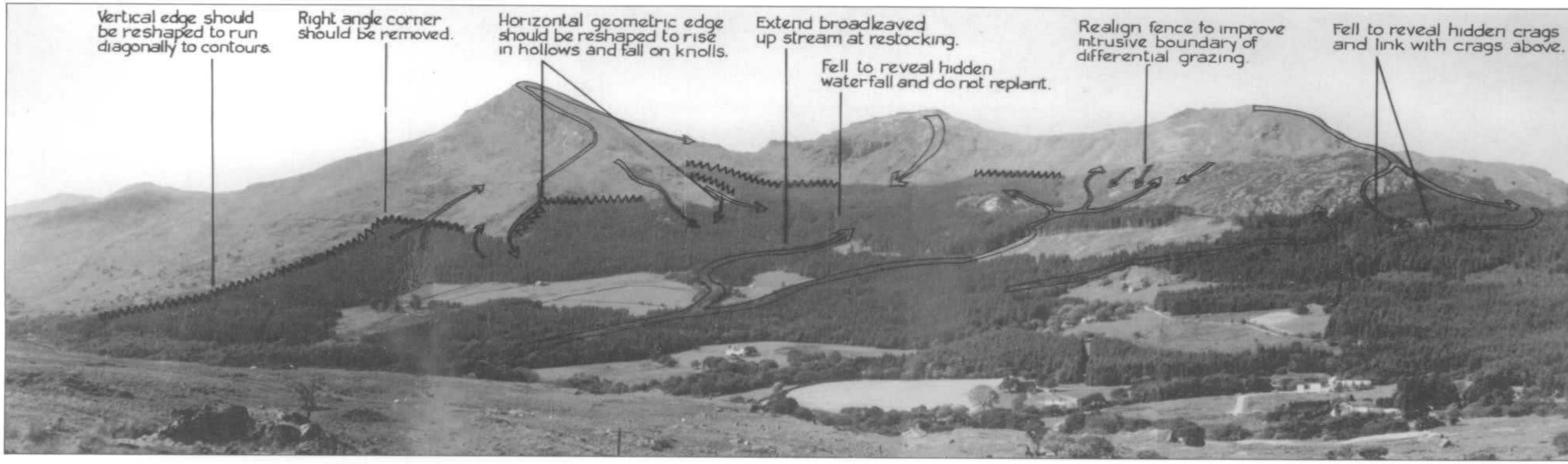

Plate 15. Landscape appraisal sketch for the southern part of Beddgelert Forest

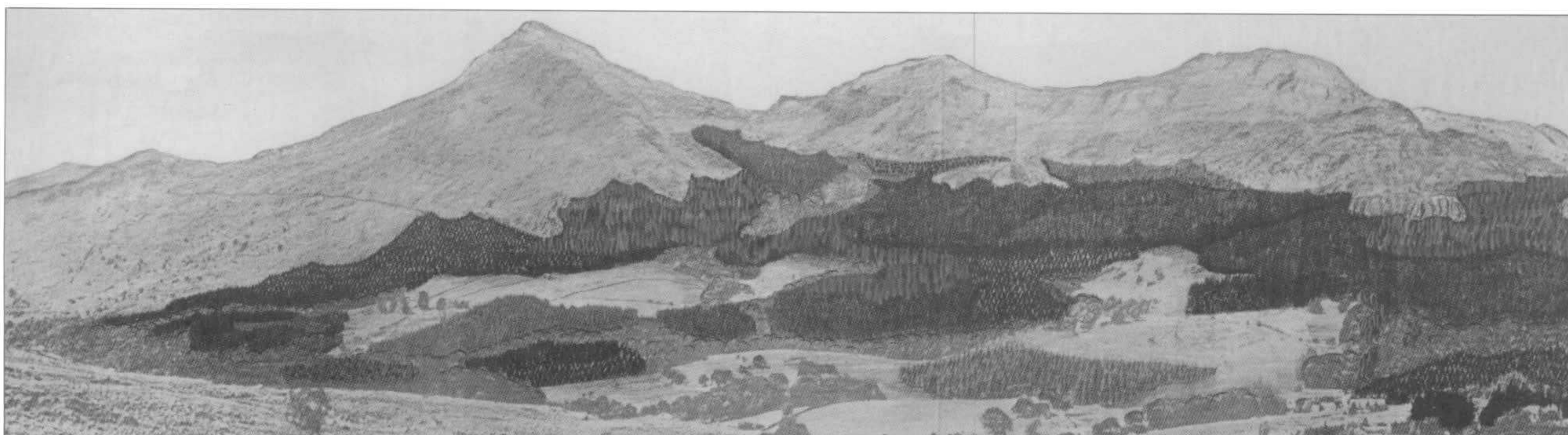

Plate 16. Landscape design for the southern part of Beddgelert Forest, species and age class diversity are indicated by different shadings

those further down. Once the pattern is complete, the timing of successive fellings is affected by the economic maturity of the crop and the scale and balance of the landscape composition. It is also planned on the map at the same time. Depending on site factors, adjacent coupes should generally be separated by 7–10 years to allow for establishment. Where forest goes over skylines and ridges, these areas should generally be felled later in the sequence, once the changeable nature of the forest landscape has been established.

The pattern of replanting then follows the felling pattern quite closely, with some coupes being completely planted with larch or broadleaves and groups of broadleaves distributed irregularly around the edges of the felling coupes.

The appearance of the design should also be checked from subsidiary viewpoints and adjusted as necessary. It then needs to be accurately mapped and set out.

The design of a well-shaped landscape pattern of varying scale forms an essential basis for more detailed treatment of edges by means of thinning, planting of broadleaved groups, positioning of rides, etc. All the elements should be co-ordinated as closely as possible with the overall design, if a diverse but integrated landscape is to be realized. When the varied textures and colours of different-aged crops and species are brought together, we can demonstrate the opportunities of achieving more diverse and interesting forest landscapes (see Plate 16).

4 Conclusion

With such plans extending well into the next century, modifications will be needed as circumstances change. However, the landscape plan will provide a useful framework against which successive decisions can be taken, as our perception of the scale and form of the landscape remain relatively constant.

It must also be recognized that the wide-ranging demands placed upon our forests are now so diverse that no one individual can be totally competent in all the disciplines required, but that each needs to understand something of the other's problems. Complex landscape plans of a professional standard are produced by team-work between forest managers, landscape architects and nature conservationists, with the forest manager as project team leader. An understanding of shape, scale, visual force, diversity and unity will encourage more rational debate between landscape designer and forest manager. This debate, in turn, allows more flexible reconciliation of the beauty of the landscape with the economic demands placed upon it. It must be accepted that visual requirements may often conflict with function and that, in balancing the 2, some cost should be carefully calculated and related to the sensitivity of the landscape in question. The principles, practice and techniques described above allow a comparison between cost and aesthetic benefit in a rational qualitative way, always remembering the underlying choice: to conserve, to improve or to despoil the landscape.

Opportunities for vegetation management in plantation forests

M O HILL
Institute of Terrestrial Ecology, Monks Wood Experimental Station, Abbots Ripton, Huntingdon PE17 2LS

Summary
Vegetation of upland forests is mostly found in the unplanted parts. There are few truly woodland species even under trees. Ferns, grasses, sedges and rushes predominate. In lowland areas there is more bramble; woody plants are far more vigorous. People certainly value wild vegetation in woodland, and complain if they see too much bare ground. Vegetation provides variety of colour and height. Rare plants are found chiefly in the lowlands, with dune forests pre-eminent. One management option is introduction of species, but is rarely justifiable, except for native trees and shrubs. The general environment of the forest can be improved by increasing the amount of ground vegetation. Whole-tree harvesting is advantageous in this respect, as are pines and larches. Scrub should be tolerated along roads and streams; but open areas, which may require mowing, are equally valuable. Roads should be allowed to become grassy where not in heavy use.

1 Introduction

1.1 Vegetation and habitat

Vegetation, for the purposes of this paper, is defined as wild vegetation. In strict logic, a crop of trees is vegetation; but crops are managed quite differently from other vegetation. Plantations of uneconomic broadleaves are also not considered to be vegetation, although their self-sown or suckering progeny are.

Wild vegetation varies greatly according to the habitat in which it is found. In a production forest, the main vegetation habitats are forests blocks, rides, streamsides, road verges and road surfaces. There are always other unplanted habitats, such as quarries, rock outcrops and the vicinity of buildings.

Sceptics and green activists often say that there is no vegetation in forest blocks. If the crop is unthinned Sitka spruce (*Picea sitchensis*) older than 15 years, then the sceptics are right. Careful searching will, in fact, always reveal a few patches of greenery; but, except for finding out what may increase later, there is little point in looking for vegetation under unthinned spruce. Even bracken (*Pteridium aquilinum*) is killed. The chief survivor is bilberry (*Vaccinium myrtillus*). After thinning, there is always some invasion of rosette-forming ferns, though not of bracken. Heavily thinned spruce (*Picea* spp.) on favourable sites does eventually develop typical woodland ground vegetation; but, on most sites, the crop is felled or blown down before this development can happen.

Thus, the least favourable type of silviculture for vegetation is short-rotation Sitka spruce in the uplands. There is a period of only 15 out of 55 years during which non-crop plants can thrive. Heavy deposition of brash may shorten this period still further.

At the other extreme are pine (*Pinus* spp.) and larch (*Larix* spp.) grown on fertile lowland or semi-upland sites. Typically, the vegetation under mature crops is bracken and bramble (*Rubus fruticosus*) in the field layer, with a storey of bird-sown woody plants such as elder (*Sambucus nigra*) and rowan (*Sorbus aucuparia*). Here, we can indeed look for vegetation to manage. It will rapidly become dense when the trees are felled, and may compete with the next crop. Only during the rather brief thicket stage is it temporarily in abeyance.

Unplanted ground is always vegetated. Here, the main ecological characteristic of the forest environment is the low intensity of mammalian grazing. There is also appreciable shading along roads and rides when the trees are mature. In the absence of much grazing, small plants are rapidly crowded out, and there is a general ecological succession towards tussock grasses, ericoid shrubs, thorny scrub and seral woodland.

1.2 Species of the forest

Many plant species that are found in woodland are not specifically woodland plants. The vascular plants of Cwm Ddu in Beddgelert Forest number only 47 species (Table 1); bryophytes are more numerous. Of 12 grasses, only creeping soft-grass (*Holcus mollis*) is at all a woodland plant. It is also frequent on moorland. There are 9 sedges (*Carex* spp.) and rushes (*Juncus* spp.); none is a woodland plant, in the sense that it normally grows in shade, or is more likely to be found in a wood than elsewhere. Of the 12 herbs, only rosebay willowherb (*Chamerion angustifolium*) and foxglove (*Digitalis purpurea*) are woodland plants. The 5 ferns (which do not include bracken) are all strongly favoured by woodland. All the woody plants, except heather (*Calluna vulgaris*) and gorse (*Ulex europaeus*), are characteristic of woodland.

With the possible exception of holly (*Ilex aquifolium*), bramble and willowherb, all of which have excellent dispersal, the Beddgelert flowering plants would all have been present in the basin before afforestation. One of the ferns, scaly male-fern (*Dryopteris pseudomas*), may perhaps have been absent; the rest would certainly have occurred in small quantity on steep banks. Thus, afforestation has resulted in little immigration of new species to the site. Small plants,

Table 1. Vascular plants of Cwm Ddu, Beddgelert Forest

WOODY PLANTS		
Betula pendula	Birch	Scattered seedlings
Calluna vulgaris	Heather	Scattered seedlings
Ilex aquifolium	Holly	Scattered seedlings under spruce
Picea sitchensis	Sitka spruce	Much natural regeneration
Rubus fruticosus	Bramble	Scattered plants, not abundant
Salix cinerea	Sallow	Scattered seedlings
Sorbus aucuparia	Rowan	Scattered plants
Ulex gallii	Gorse	Steep south-facing slope; some adults, much regeneration from buried seed after clearfelling
Vaccinium myrtillus	Bilberry	Very common under trees
GRASSES		
Agrostis capillaris	Common bent	Abundant, especially soon after clearfelling
A. vinealis	Brown bent	Abundant but less than *A. capillaris*
Anthoxanthum odoratum	Sweet vernal-grass	Common, especially on verges
Deschampsia cespitosa	Tufted hair-grass	Common and locally abundant
D. flexuosa	Wavy hair-grass	Abundant after clearfelling
Festuca ovina	Sheep's fescue	Frequent in clearcuts
F. vivipara	Viviparous fescue	One plant found in a clearcut
Holcus lanatus	Yorkshire fog	Widespread in grassy places
H. mollis	Creeping soft-grass	Very locally abundant, mainly reliant on vegetative spread
Molinia caerulea	Purple moor-grass	Frequent
Nardus stricta	Mat-grass	Scattered individuals
Poa annua	Annual meadow-grass	Common on roads, rare elsewhere
SEDGES AND RUSHES		
Carex binervis	Green-ribbed sedge	Abundant regeneration from buried seed
C. echinata	Star sedge	Frequent, especially in moister places
C. ovalis	Oval sedge	Scattered regeneration from buried seed
C. pilulifera	Pill sedge	Frequent
Eriophorum vaginatum	Hare's-tail cotton-grass	Germinating from buried seed, scarce
Juncus bulbosus	Bulbous sedge	Frequent in wetter places
J. effusus	Soft rush	Abundant in grassy places
J. squarrosus	Heath rush	Frequent regeneration from buried seed
Luzula multiflora	Heath woodrush	Very scarce
HERBS		
Cardamine flexuosa	Wood bittercress	Roadside ditch in one place
Cerastium fontanum	Common mouse-ear	Roadsides
Chamerion angustifolium	Rosebay willowherb	Frequent, not abundant
Digitalis purpurea	Foxglove	Frequent, especially by roads
Epilobium brunnescens	New Zealand willowherb	By road
Galium saxatile	Heath bedstraw	Abundant in grassy places
Montia fontana	Blinks	Roadsides and damp old quarry floor
Potentilla erecta	Tormentil	Scattered in grassy places
Rumex acetosella	Sheep's sorrel	Abundant on bare ground
Sagina procumbens	Common pearlwort	Roadside and ditches
Stellaria alsine	Bog stitchwort	Wet roadside
Veronica serpyllifolia	Thyme-leaved speedwell	Roadside
FERNS		
Athyrium filix-femina	Common lady-fern	Scattered in basin
Blechnum spicant	Hard fern	Frequent throughout plantations
Dryopteris pseudomas	Scaly male-fern	Scattered
D. dilatata	Broad buckler-fern	Abundant
D. filix-mas	Common male fern	Scattered

such as sundew (*Drosera* spp.) and bog asphodel (*Narthecium ossifragum*), would doubtless have been present in flushes before afforestation, and have now gone.

Cwm Ddu is on a peaty podzol and the flora is small. For comparison, a single quadrat on brown earth in a clearfelled part of Gwydyr Forest contained 32 kinds of vascular plants; a square kilometre in Clocaenog Forest contained 108 vascular plants; and from 42 sampling stations in Newborough Forest, 160 vascular plants were recorded. At Newborough, the crop was pine, and a distinctively woodland flora was beginning to develop 30 years after planting, including rosebay willowherb, foxglove, creeping soft-grass, red campion (*Silene dioica*), white bryony (*Bryonia dioica*), black bryony (*Tamus communis*), wood sage (*Teucrium scorodonia*), dune helleborine (*Epipactis dunensis*), common twayblade (*Listera ovata*), honeysuckle (*Lonicera periclymenum*), ivy (*Hedera helix*) and elder. The majority of the non-woodland plants were common species of wayside and dune.

1.3 Structure of forest vegetation

In an upland forest such as Beddgelert, the structure of the ground vegetation is simple. In forest blocks, there is abundant grass, rush and sedge during the later part of the light phase between clearfelling and canopy closure. Woody plants are poorly represented unless there is nearby standing birch (*Betula* spp.), which seeds itself abundantly into clearcuts. Bramble and rosebay willowherb do not flourish. The only colourful herbs of any note are bedstraw (*Galium* spp.) and foxglove, with just a smattering of tormentil (*Potentilla erecta*).

In the lowland parts of Gwydyr Forest, by contrast, there are always nearby broadleaved trees. In the quadrat mentioned above, there was no ground vegetation when the Douglas fir (*Pseudotsuga menziesii*) crop was still standing. Five years after clearfelling, it was dominated by bramble, gorse, birch and willowherb, which formed a tangle so dense that walking was difficult.

Duneland is an exception to the general trend towards complex structure in the lowlands. In Newborough Forest, planted blocks on young dunes are very poor in species, and are notable chiefly for their abundance of moss, with scattered dewberry (*Rubus caesius*) and willowherb. As the dunes get older, the soil gradually becomes more fertile, and lime is leached out. At this stage, the ground becomes suitable for bramble; ferns become more prominent; and there are the beginnings of a woody understorey.

The same general structure is found on verges of forest roads. These are heathy, grassy or mossy in the uplands, brambly in the acid lowlands, often with much bracken, and grassy or mossy in young duneland.

2 Influence and value of vegetation

2.1 Effects of vegetation

One effect of vegetation is to suppress growth of young trees. In the uplands, the main weed problem is perhaps natural regeneration of Sitka spruce. I do not know whether heather presents a serious second-rotation weed problem anywhere in upland Wales. Much of the area was grassy before afforestation, so that the overall quantity of heather is quite small. On brown earth soils, bramble and bracken can create difficulties if replanting is delayed. Although bracken often delays the invasion of broadleaved trees on unforested ground, it is regarded by Brown (1975) as a relatively friendly species, which may benefit young transplants by suppressing other competitors such as grasses.

After clearfelling, ground vegetation takes up nutrients from the soil, and certainly has the effect of reducing nitrogen losses. Phosphorus is much less soluble, and is unlikely to be lost even without vegetation. Whether potential nitrogen losses are ever likely to represent a significant economic loss in the British climate is an open question. Certainly, no-one has yet recommended sowing grass seed at clearfelling in order to get a quicker rate of greening up. In the United States, grass is sometimes sown after forest fires to reduce erosion; but not, so far as I know, to retain nutrients.

Vegetation has a major influence on animals, by providing food and shelter. The effect of the crop cycle on birds is now relatively well documented (Bibby *et al.* 1985). Thomson (1986a) demonstrated a rapid increase of field voles (*Microtus agrestis*) following clearfelling in Beddgelert Forest, doubtless in response to an increase in ground vegetation, even though greenery formed less than 50% of their diet (Thomson 1986b). Being sheltered from predators by brash, they could perhaps forage more widely than in grassland, and reached an estimated density of 31 animals per hectare when ground vegetation was still sparse.

In the lowlands, the vegetation of rides and verges sustains viable populations of numerous invertebrates. Butterflies are the most valued, and require chiefly shelter, warmth and the right food plants.

2.2 Value of vegetation

Through its effect on crops, soils and animals, forest vegetation has value, sometimes negative, to many people. It also has value in its own right. Almost all of us will agree that a forest without wild vegetation would be a dreary prospect. Indeed, one of the delights of forest landscapes compared with those of intensive agriculture is the abundance of wild plants.

It is pertinent to enquire what we value most in such landscapes. As with all aesthetic questions, people's responses will differ in detail. Let me list some of the things that I like to see in vegetation: accents of colour, variety in height, vistas into enclosed worlds, and a sense of the abundance and force of nature. Smells are also to be valued, but the best ones are normally produced by the crop itself.

Colour accents can be produced by flowers, foliage, and, in a few species such as Japanese larch (*Larix kaempferi*), by twigs. It is a sad fact that British flowers are really less colourful than those of many other countries, as a result of our dull, moist summers. Colourful flowers are an advertisement to pollinating insects, and are most effective on still days in bright sunshine. Thus, our forests lack many of the pretty herbs that one can see in Sweden and Switzerland. In Beddgelert Forest, we have to make do with foxglove, willowherb, bedstraw, tormentil, and little else. Heather, especially bell heather (*Erica cinerea*), and gorse are major contributors of colour elsewhere. Only in the warmest lowlands are verges adorned with really abundant herbs. Even there, some of the most beautiful effects, such as viper's bugloss (*Echium vulgare*) and evening primrose (*Oenothera erythrosepala*) along roads in Newborough Forest, are achieved by deliberate cultivation.

If floral colour is generally poor in the uplands, foliage accents are often beautiful. Birch trees are perhaps the most generous contributors, providing brilliant pale greens in spring and fine yellows in autumn. Rowan and holly berries are almost as good. Even bracken is a fine sight in autumn, commemorated as 'goch' in countless Welsh place names.

Vegetation does not always provide variety in height; there may be little except grass and sedge. However, woody plants such as bramble, broom (*Sarothamnus scoparius*) and sallow (*Salix cinerea*) always provide interesting height contrasts. This is especially true if they are arranged like a good shrub border, with the taller elements at the back, and herbaceous plants in front.

Vistas into enclosed worlds are not entirely the result of vegetation. No doubt speleologists also delight in such sights. Nevertheless, small clearings among tall forest, gaps in high banks of bushes, sunny verges alongside twisting forest roads, mossy ravines with rushing water, and well-illuminated ferny undergrowths beneath widely spaced columns of trees are just the sort of scenes that are most pleasant to meet in forest country. It is their enclosure that makes them delightful, and their vegetation is an essential part of their attraction.

A sense of the abundance and force of nature is provided by carpets of herbaceous plants and thickets of young trees. On the whole-tree harvested plots where I have studied vegetation for many years in Beddgelert Forest, there was in 1986 a splendid display of flowering wavy hair-grass (*Deschampsia flexuosa*). Waving in the wind, the ripe grass flowers were almost like a cereal crop in appearance, only more elegant. Likewise, in Newborough Forest, a sheet of wild pansies (*Viola tricolor*) flowering on ground from which turf had been stripped in an unplanted dune slack created a remarkable visual effect. Young broadleaved trees regenerating vigorously into forest clearcuts are certainly pleasing to the layman's eye, even if they spell future weeding for the forester.

In addition to its aesthetic value, which is great, vegetation also has some value as a product. Brambles yield blackberries, at least when they get plenty of sun; bilberries are best where grazing is light, as along roads in Clocaenog Forest; raspberries (*Rubus idaeus*) are pleasant to find, if rarely numerous; some woodlands produce moss for lining baskets; and edible fungi are cherished by some enthusiasts. Yet, although these products are not negligible, they are small in value compared with aesthetic and animal products of forests.

2.3 Nature conservation

In production forests, nature conservation is necessarily not the main objective. Indeed, there is generally little vegetation that is of special value. Most conservationists prefer fragments of the past that carry a long history, such as peat bogs and ancient woodland. These are, so to speak, ancient monuments. If they are turned over to production forestry, then the link with the past is cut, and they become modern ecosystems. When some of our production forests have themselves seen a long history, then they too will come to acquire features that are interesting to conservationists.

If the vegetation of various forests is compared for nature conservation value, then dune forests must rank high, and Culbin Forest highest. Here, there is a remarkable selection of rare northern flowers, including the wintergreens, one-flowered wintergreen (*Moneses uniflora*), serrated wintergreen (*Orthilia secunda*) and common wintergreen (*Pyrola minor*), and the orchids, coralroot orchid (*Corallorhiza trifida*), creeping lady's-tresses (*Goodyera repens*) and lesser twayblade (*Listera cordata*). According to McCallum Webster (1977), they become abundant for a while, but, owing to thinning and felling of the pines, are never permanent.

This description emphasizes an important feature of production forests, which makes them a difficult habitat for some plant species, namely that they are constantly changing, and plants may lack a means of survival through the dark phase of the crop cycle. Forests are not permanent like grazed meadows. It is notable that both wintergreens and orchids are dispersed by minute dust seeds, and are dependent on mycorrhizal associations for survival. Here in Wales, two species, the common wintergreen and the round-leaved wintergreen (*P. rotundifolia*), have invaded Newborough Forest on Anglesey. The dune helleborine (*Epipactis dunensis*), possibly not present before afforestation, has now become abundant. These events have occurred in less than 40 years.

Another important feature of dune forests is that they are planted with pines. There is almost no opportunity for a good woodland flora to develop under spruce and fir (*Abies* spp.) in the uplands, because they are windthrown too soon. Indeed, so far the only colonists of note have been ferns, aided by their windblown spores. In principle, forest blocks with a short crop rotation ought to be a good habitat for flowering plants with long survival of buried seed. For, if there is not too much brash, and if there is little vegetation on the forest floor at the time of clearfelling, then the floor makes a good seed bed. In Beddgelert Forest, foxgloves, sedges and rushes have benefited from this fact, most notably after whole-tree harvesting, but no formerly rare species have spread in clearfelled spruce forests. They show none of the propensity of dune pinewoods to develop a specialist flora.

The fact that forest blocks in spruce woods do not develop an interesting flora does not mean that areas of upland forest are lacking in interesting plant species. It does mean that such plants should be looked for in unplanted parts of the forest, or perhaps in parts that are reserved for larch, pine or broadleaves. Even in a dune forest such as Newborough, most of the interesting plants are found on verges or in unplanted dune slacks. Likewise, in Gwydyr Forest, old quarries and lead mines are valuable habitats, as are lake margins and crags.

I wish that I could say more about vegetation in relation to conservation of animals. The existence of scrubby areas with plenty of bramble must surely improve the habitat for many animals by providing cover and alternative sources of food. On the other hand, some small mammals can exist in the darkest spruce plantations, where vegetation other than moss is lacking. In unfelled parts of Beddgelert Forest, Thomson (1986a) found densities of 6 wood mice (*Apodemus sylvaticus*) and 16 bank voles (*Clethryonomys glareolus*) per hectare. These creatures lived chiefly on spruce seeds, with an admixture of some arthropods. In autumn, fungi formed a large part of their diet (Thomson 1986b). The existence of this alternative seasonal diet must be providential for these rodents, because the season of seedfall runs from October to April, but the main seedfall often does not start until December (Mair 1973).

3 Management

3.1 Introduction of species

Foresters are no strangers to making species introductions, but often restrict themselves to crop species and a few ornamentals dotted along the forest edge. Newborough Forest was exceptional. Well over 100 species were deliberately introduced to the site, most of which failed immediately. Some, such as *Yucca gloriosa*, thrived where they were planted, but did not spread; this species is not truly naturalized nearer than northern Italy (Tutin *et al.* 1964–80). Of many herbs tried, white stonecrop (*Sedum album*) and evening primrose are now locally abundant, but most planted herbs died out. Broom (*Cytisus scoparius*) and Himalayan cotoneaster (*Cotoneaster simonsii*) have spread to a small extent, and may eventually become fully naturalized. Sea buckthorn (*Hippophae rhamnoides*) was introduced from south Wales, and has proved so successful that efforts are now being made to control it. It is a native British plant in its right habitat, regarded by many as dangerously invasive. There is no reason to be too sentimental about our native flora; exotics may often be preferable.

In retrospect, it would probably have been better if nothing had been deliberately introduced to the Newborough dunes. Sea buckthorn is a threat to the nearby nature reserve. Likewise, in the uplands, foresters would be ill advised to plant rhododendron (*Rhododendron ponticum*) for ornament along verges. Species that are likely to invade nearby lands should be avoided.

On the other hand, there can be no objection to introducing plants that are already present in the vicinity, provided that they have a valuable contribution to make. On the barer uplands, deliberate planting of birch and rowan should enable populations of these trees to increase more quickly, so that they should soon become a permanent part of the forest scene. Why wait? They would get there in the end.

Likewise, if a woodland flora is urgently desired in a new forest, there should be no objection to introducing local species that are thought suitable. Purists will object, saying that species should be allowed to find their own way in over the course of time. However, it is absurd to regard all forestry plantations as experiments in island biogeography. If a species is really needed, then it should be brought in, but let us be clear about what we want.

3.2 Crop management

In the present state of knowledge, it is difficult to be sure about long-term effects of crop regimes on vegetation. The first rotation is only the beginning. Ellenberg (1978) says that, in central Europe, it generally takes 3 rotations of pine forest before a woodland flora is properly developed, but that with spruce only one rotation is necessary. Certainly, spruce in Britain has the effect of killing out the existing ground vegetation more effectively than pine during the thicket stage; but, with our short rotations, spruce forest scarcely develops any flora at all.

To promote woodland plants, some areas permanently devoted to species other than spruce can help to act as a reservoir. In valley bottoms, spruce grown on long rotations with heavy thinning may also be a possibility. But we should remember that, in the western uplands, even the native woodland flora is poor. Western forests may be beautiful, but they will not develop a rich, specifically woodland, flora except on dry soils in the lowlands.

Not only are species other than Sitka spruce likely to be more favourable for the woodland flora, but they also produce less brash, so that there is more open ground to support vegetation regrowth after clearfelling. Even more effective at opening up ground is whole-tree harvesting. Observations in Beddgelert

Forest suggest that whole-tree removal results in about 5 years' advancement of the greening-up process. The forest floor under larch is already green by the time the crop is felled, and the amount of brash is small. A similar or even larger advancement of the greening process may result.

If the 'light window' between rotations is 15 years, and if it takes about 2 years to green up with whole-tree harvesting (Hill *et al.* 1984), then this gives 13 green years with whole-tree harvesting, as opposed to only 8 years if the brash if left on the ground. In walking about a normal forest, the difference will be substantial, with perhaps 60% more vegetation found in clearcuts from larch and whole-tree harvesting than after brashy Sitka spruce.

The size and arrangement of felling coupes must also have some effect on the vegetation within them. Invasion of plants from outside is not negligible, especially of trees such as birch and sallow. Most plants, however, have poor dispersal, over only a few metres, so that edge effects are small. True woodland plants with poor dispersal are the most likely to benefit from small felling coupes. On the other hand, winter-greens and orchids are well dispersed by small seeds, and are probably indifferent as to coupe size.

3.3 Vegetation management

The most ambitious form of vegetation management, now being implemented in Beddgelert Forest, is the designation of parts of the area to 'permanent forest structure'. Here, the rotational clearfelling regime will be abandoned, and the forest will be allowed to regenerate naturally. There can be no doubt that this practice will create visual interest, though because of the general floristic poverty of western woodland, the ground flora will not necessarily develop any intrinsic conservation value.

Less ambitious but also achieving good visual effects is to tolerate scrub along roads and streams, and not to 'clean' planted crops too assiduously. These relatively lax management practices will surely lead to a great enhancement of the visual interest of forests, by providing the colour accents and height variation that strictly regimented verges and forest blocks lack.

Another form of laxity that certainly creates attractive vegetation for the visitor is reduced attention to road maintenance. Grassy roads are really very pleasant, but are often eliminated by frequent regrading. Clearly, roads should not be so bad as to damage the vehicles that drive along them, but, from the point of view of vegetation, they are better with a minimum of maintenance.

On roads, maintenance is normally frequent enough to suppress woody vegetation and coarse grasses. On verges, however, mowing may be necessary to suppress scrub. Wide mown verges are a special and interesting type of habitat. They encourage flowering herbs and thereby promote a valuable element of colour. In Newborough Forest, not only mowing but also cultivation is used to sustain diversity.

Rivers and streams perhaps present more of a problem than roads, in that, if left unmanaged, their banks will all become scrubby. Their plant life is certainly diminished if there is uniform shade along them. Also, intermittently grassy streamsides are more pleasing to the eye than totally scrubby ones. Both here and on roads, zones of scrub suppression should help to avoid the impression that the forest is closing in on the visitor from all sides.

4 References

Bibby, C.J., Phillips, B.N. & Seddon, A.J.E. 1985. Birds of restocked conifer plantations in Wales. *J. appl. Ecol.*, **22,** 619-633.

Brown, R.M. 1975. *Chemical control of weeds in the forest.* (Forestry Commission booklet no. 40.) London: HMSO.

Ellenberg, H. 1978. *Vegetation Mitteleuropas mit den Alpen.* 2 ed. Stuttgart: Ulmer.

Hill, M.O., Hornung, M., Evans, D.F., Stevens, P.A., Adamson, J.K. & Bell, S.A. 1984. The effects of clear-felling plantation forests. *Annu. Rep. Inst. terr. Ecol. 1983,* 9-11.

McCallum Webster, M. 1977. *A check list of the flora of the Culbin State Forest.* Privately printed.

Mair, A.R. 1973. Dissemination of tree seed: Sitka spruce, western hemlock and Douglas fir. *Scott. For.*, **27,** 308-314.

Thomson, A.G. 1986a. Anomalies in estimations of small mammal abundance in conifer plantations. *Notes Mamm. Soc.*, **52,** 287-290.

Thomson, A.G. 1986b. The diet of forest-dwelling mice and voles; papain as an aid to faecal analysis. *Notes Mamm. Soc.*, **52,** 290-293.

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M. & Webb, D.A. 1964–80. *Flora Europaea*, Vols 1-5. Cambridge: Cambridge University Press.

Effects of management of commercial conifer plantations on birds

C J BIBBY
Royal Society for the Protection of Birds, The Lodge, Sandy, Bedfordshire SG19 2DL

Summary
Rather than repeating in detail the well-established adverse impact of afforestation on birds, this paper deals with means of maintaining and enhancing the beneficial aspects of forestry. For some species, conifer forests are either the major habitat in Britain or provide part of the requirement of a scarce bird living on woodland margins. Management in commercial forests could have a major impact on these species. The effects of geographical locality, tree species, vegetation structure, plot size and edge effects on bird diversity and abundance are discussed. The value of small groups of broadleaves in large conifer plantations is highlighted.

1 Introduction
The afforestation of open land has a major effect on birds. Species of open country are first replaced by those favouring scrub conditions, which in turn are replaced by species of more mature woodland. Three fairly distinct bird communities follow in this succession, though individual species may rise to their most abundant and then decline at different stages.

By a rationale that is only partially objective, nature conservationists do not regard all species or habitats with equal importance. Dwarf shrub heaths and blanket bogs are relatively uncommon in the world. In Europe, they reach their most extensive and varied development in the oceanic climate of Britain and Ireland. On them occur bird species, particularly the waders and birds of prey, for which Britain supports numbers of international significance. Threat to upland birds from forestry is currently felt most acutely in Sutherland and Caithness, where Britain's largest boglands also support the greatest range of moorland breeding bird species.

This paper will not give further consideration to the impact of afforestation on birds and ways of alleviating it. Given the continued need for and existence of forestry, how can its benefits to birds be maintained and enhanced? It is important to maintain the distinction between these 2 questions because the problem of conservation of open moorland birds is not diminished by the nature of the forest that replaces them.

What should be the criteria for success of management for birds in forests? One possible answer is the maximization of diversity or richness of species. For a fixed (reasonably large) area, a forest with more breeding species might be considered more successful. The most difficult of several problems with diversity is that it treats all species as of equal quality. Open ground is likely to be poorer in bird species diversity than a forest of any kind. In one case the birds may include several scarce and threatened species, while the forest bird community is going to include many of Britain's most numerous and widespread song birds. In this extreme example, diversity is clearly not a good measure of nature conservation quality. A walk through a wood will, however, be more interesting, if there are more bird species and the variety of habitats that support them. For song birds, diversity is therefore a criterion of some value, but it has probably been over-used.

Most woodland song birds are more abundant in broadleaved woods than conifer plantations. This statement is especially true of those species not present in all conifer plantations. Efforts to diversify a plantation and add species may thus make only a small contribution to the status of the species concerned. For some species, however, conifer forests are either the major habitat in Britain or provide part of the requirement of scarce bird living on woodland margins (Table 1). Management in commercial forests could have a major impact on the long-term future of these species in Britain. There are some more scarce species, especially amongst birds of prey, where

Table 1. Species for which British status is much dependent on management of commercial forestry

Forest type	Species	
Lowland, especially pines on sandy soils	Nightjar	*Caprimulgus europaeus*
	Woodlark	*Lullula arborea*
Native pinewoods and similar plantations in Highland Scotland	Capercaillie	*Tetrao urogallus*
	Crested tit	*Parus cristatus*
	Scottish crossbill	*Loxia scotica*
Typical upland conifer forests	Black grouse	*Lyrurus tetrix*
	Crossbill	*Loxia curvirostra*
	Siskin	*Carduelis spinus*

conifer forests are not the major habitat but might support enough pairs to make a significant contribution to future status.

This paper will concentrate on typical upland forests. In the lowlands, nightjar (*Caprimulgus europaeus*) and woodlark (*Lullula arborea*) are declining in numbers and increasingly concentrated on restocks, whose management could influence status considerably. Woodlarks are presently the subject of a joint study by the Royal Society for the Protection of Birds (RSPB) and the Forestry Commission (FC) and a British Trust for Ornithology (BTO) census. Nightjars deserve more attention. The native pinewoods and some similar plantations support 3 characteristic species including Britain's only endemic bird (by current taxonomic view of the Scottish crossbill (*Loxia scotica*)). Habitat requirements of capercaillie (*Tetrao urogallus*) are quite well understood (Jones 1982, 1984), of Scottish crossbill can be guessed to some extent (Nethersole-Thomson 1975), and of crested tit (*Parus cristatus*) are the subject of a study started in 1986.

2 Methods of study of woodland song bird communities

There have not been many studies of song birds in British conifer plantations. The results of many of them are difficult or impossible to interpret for methodological reasons. Problems in study design occur in selecting methods to count birds and to describe vegetation, and then in extracting general conclusions.

Three bird counting techniques have been used: line transects, point counts and territory mapping. Territory mapping (Enemar 1959) has been standardized and widely used in Britain for the BTO Common Birds Census. Single plots, generally of about 10 ha, are visited 8–10 times during the breeding season and bird registrations plotted on a map. Analysis involves plotting all the registrations for a species and recognizing clusters as bird territories. There is not much time in the year to conduct such studies. Most recording has to be done during the 2 months when birds sing, during the morning when birds are most active, and avoiding bad weather. As a result, most studies only report results from a single study plot. The largest such study (Moss *et al.* 1979) covered 292 ha in 20 plots over 3 years.

Line transects were used by Simms (1971) and Yapp (1952). In this method, the observer walks a route of known length at uniform pace and records all the birds detected. Point counts involve the observer standing at a set of predetermined points for a fixed period and recording all bird contacts. Two such studies have been conducted in British conifer forests (Bibby *et al.* 1985, 1987). These 2 studies averaged about 1700 detections of different birds per observer per field season (in 50 days).

The usual way to describe the vegetation of a mapped plot has been to ascribe the whole plot to one or a few simple categories of tree, shrub or ground cover. With point counts, it is possible to measure vegetation in a circle centred on the recording point. This method can be done with varying degrees of measurement, as against estimation where the trade-off is between precision and cost of time. The resulting data match the presence or absence of individual bird species at a point to the set of measured vegetation attributes. Vegetation on transects can be measured by dividing them up into fixed lengths and taking spot measurements. Transects are more efficient in number of birds detected per unit effort, because time is not wasted walking between recording points. In general, transects are to be preferred if vegetation is homogeneous on a scale of about 500 m:1 km. In Britain, this is rarely the case (except on moorland), and point counts give a better match between occurrence of particular birds and the vegetation in which they were recorded. Mapping studies could, in theory, compete with this power if analysis related the size and dispersion of territories to vegetation, but this relationship has rarely been attempted. In forests it would require quite extensive effort to measure vegetation on a grid basis.

The combination of an inefficient bird counting method and the use of rather vague vegetation description has meant that most mapping studies have little power beyond description of a small number of plots. Bird attributes may be confounded by any number of site-specific habitat features, aside from those described as representing the plot.

As generally conducted, the mapping method makes it difficult to study the effects of features that cannot be found in representative plots of sufficient size. Point counts, by contrast, can be given a wide geographic spread and can be stratified and replicated across the range of habitat features under study. The larger sample sizes with birds matched to habitats extend the range of multivariate methods available for analysis.

A problem with all studies of bird communities and the habitats of individual species is that the scarcer species are poorly represented. If community diversity, and hence the habitats of the scarcer species, is of concern, this is a serious deficiency. In the case of mapping studies, sample sizes are usually too small even to register many of the species that potentially occur in the vegetation type. Even with point counts, many of the scarcer species may occur at too few points for analysis of their habitats. This problem can be overcome by locating such birds in the study area but outside the points surveyed and by describing the vegetation in the same manner. The vegetation of a set of points with the birds present can then be compared with that at the points where the species did not occur. This valuable methodological device has no equivalent in mapping or transect studies.

The majority of studies of woodland bird communities and habitats in Britain have, therefore, handicapped themselves by using methods less powerful than the best known. Many general principles affecting woodland song bird communities have been studied more thoroughly in the United States and elsewhere in Europe. Only one mapping study has reported on more than a few upland conifer plantations in Britain (Moss *et al.* 1979). Two point count studies have looked at restocks (Bibby *et al.* 1985) and older stands (Bibby *et al.* 1987) in Wales. The following sections draw primarily on these 3 sources, with reference to smaller or more distant studies for topics not thus covered.

3 General factors influencing woodland bird communities

Four major classes of factor influence woodland bird communities. These classes suggest some of the management operations with potential to benefit birds, though the constraints of economic reality necessarily narrow the options. At the moment, knowledge is rather poor on detail of converting generality into realistic and practical advice.

3.1 Geographical locality

A set of plots planted in a similar way throughout Britain would not all acquire the same bird communities. There are more woodland species in the south-east, with numbers declining to the west and north. As species reach the limits of their range, they generally become scarcer and often more restricted in their choice of habitats. Thus, the south-easterly distributed nightingale (*Luscinia megarhynchos*) occurs in a range of habitats sometimes including conifers in Kent. In central England, the species is rare and more obviously selective for broadleaves with a dense understorey. In Wales or Scotland, no amount of management would secure the nightingale as a breeding species. Many woodland species do not occur in Ireland and Scotland. Such range limitations are often broadly explained in climatic terms.

Altitude has a similar effect on range of bird species, though in Britain, of course, the higher altitudes do not occur in the more species-rich south and east. Soil fertility probably influences bird numbers, as in the sparrowhawk (*Accipiter nisus*) (Newton 1986). It is difficult to separate the effects of latitude and longitude, climate, altitude, soils and vegetation types to recognize the influence of each separately, though, in practical terms, this is not an important problem. At a given locality, there are well-known constraints from these sources on the commercially viable crops. The ground flora and non-crop trees likely to develop or suitable for planting also vary. The location of a forest thus determines the range of birds which could be attracted potentially. It will be least at high latitudes or altitudes with infertile soils and a more oceanic climate.

3.2 Tree species

Very few birds in Britain have strong or exclusive links to a single tree species. Communities of birds do, however, vary between stand types; most obviously between conifers and broadleaves. An example from Wales is shown in Figure 1. Conifers generally have fewer species and lower densities. A smaller number of species are very abundant and dominate the community, though in this case, where the conifer forests included some broadleaves, the total number of species in each was very similar. A higher proportion of conifer forest birds are sedentary, perhaps because of smaller seasonal variation in food supplies on evergreens.

Far less is known about the effects of species of tree and this aspect is difficult to study because of confounding factors. Redstart (*Phoenicurus phoenicurus*), wood warbler (*Phylloscopus sibilatrix*), pied flycatcher (*Ficedula hypoleuca*) and tree pipit (*Anthus trivialis*) are well known to be characteristic of upland sessile oaks (*Quercus petraea*). Lowland pedunculate oakwoods (*Quercus robur*) do not have these species as abundant or even present, but some other species are far more abundant (Simms 1971). These differences are almost certainly not due to tree species. Sessile oaks on poorer soils at higher altitudes in the north and west often have a straggly growth form and poorly developed shrub layers as a result of grazing, while lowland pedunculate oakwoods usually have taller straighter trees and a well-developed understorey. Examples can be found of both species with the location and growth form more typical of the other, so in this case a suitably designed study could resolve the question of how much of the difference is due to tree species and how much to other factors. This study has not been done, but it would almost certainly show that the general trend of difference of bird communities is not caused by the tree species.

Similar problems apply to conifers, though the data are sparser. The species planted is determined by soil and climatic factors and the range of options has been perceived to be small. It would be difficult to find the range of species grown across the range of conditions, in large and frequent enough stands to study the effects on birds of species separated from the confounding site factors likely to be important. Differences might be expected from the effects of fine-scale architecture of the trees and the insects they support providing feeding opportunities for different birds. Growth form and effects on other vegetation might be more important. Larches (*Larix* spp.), with their open and deciduous structure, allow the development of a more diverse shrub and ground flora, and older stands are particularly likely to support birds more typical of broadleaved woods (Currie & Bamford 1982a).

As broadleaves support different birds from conifers, their effects in conifer plantations as planted or retained features are important. As discussed above, it is not yet possible to say anything helpful about the merits of different species. Another important question concerns their dispersion, especially if their retention or planting represents a cost to the primary purpose of the forest, so that their total acceptable area can be deemed to be fixed. Recent opinion (Newton 1983) has argued in favour of large blocks, which implies a presumption that fringes or scattered trees are comparatively less worth keeping. The evidence for this conclusion is not strong (Moss *et al.* 1979; Newton & Moss 1980).

A study in Wales addressed this question (Bibby *et al.* 1987). At least 11 species, including all but one of the migrants, which contributed to the overall variety of birds occurring in the conifer forests, were selective for broadleaves. The incidence of these birds increased with area of patch of broadleaves across the range, from a few tens of square metres (often just a single tree) to a few hectares (Figure 2). The nature of this relationship is such that a fixed area of broadleaves would support more of these species if it was dispersed in many small patches, rather than a single large block. This finding has important implications.

One of the features of mature broadleaved woods compared with commercial conifers is the frequency of hole-nesting birds. The provision of nestboxes can, in part, compensate for the lack of holes in conifers felled at economic rather than biological maturity (Currie & Bamford 1982b). They might be especially beneficial if sited in association with broadleaves either too young or of less good species to provide natural holes. This possibility needs testing.

3.3 Structure of vegetation

Vegetation structure (often expressed as a foliage height diversity index (FHD)) has long been known as a predictor of bird community variety (MacArthur & MacArthur 1961). Moss (1978) provides a British study. It is rarely clear just which of several, often correlated, contributors to FHD is important to birds. Separation of factors correlated with FHD, like shrub cover and tree height, expresses results in more clearly practical language. The structural changes associated with development of the crop, from open ground at planting through to maturity, produce conditions suitable for different birds in succession. In a simple conifer stand, the bulk of foliage is typically in just one band at any time, either as a shrub layer or in the canopy. Two combinations of structure of importance to birds are relatively uncommon and can, in some circumstances, be beneficially promoted.

In the early stages of the second rotation, some birds are favoured by taller elements above the dense low cover from the crop. These elements might be provided by retention of trees at felling. If these are broadleaves, they will grow on to have effects at later stages as well. Rarer, and of importance to a greater range of bird species, is the structure of a mature wood with a high canopy and sufficient light penetration to support ground and shrub layers. Currie and Bamford (1982a) showed the effect of retaining trees beyond economic maturity. The birds gained are those more associated with broadleaved woods, and it seems likely that part of the greater interest of broadleaves is due to their more open nature, leading to greater structural variety than found in pole-stage conifers. A fuller study of the effects of retention of trees beyond economic maturity would be useful. It might not be easy to find sufficient plots for study.

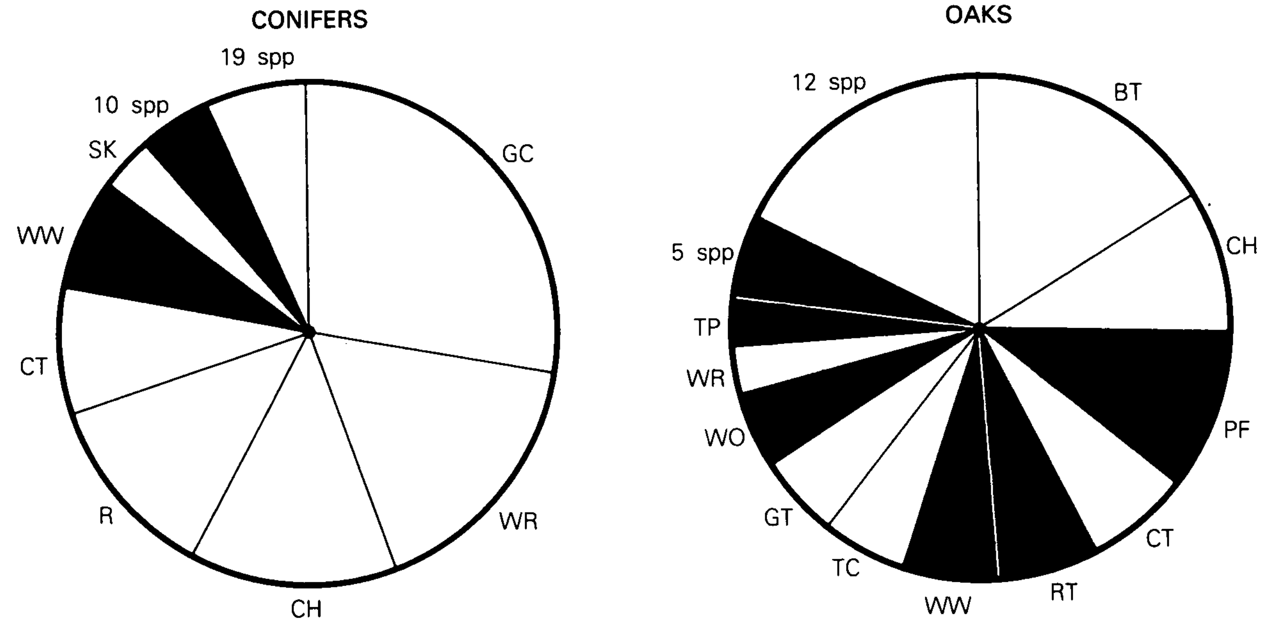

Figure 1. Bird communities of commercial conifer plantations and semi-natural broadleaved woods in Wales (source: Bibby et al. *1987; Bibby, unpubl.). Abbreviations: (conifers) goldcrest, wren, chaffinch, robin, coal tit, willow warbler, siskin; (broadleaves) blue tit, chaffinch, pied flycatcher, coal tit, redstart, willow warbler, treecreeper, great tit, wood warbler, wren, tree pipit. Shaded portions represent long-range migrants*

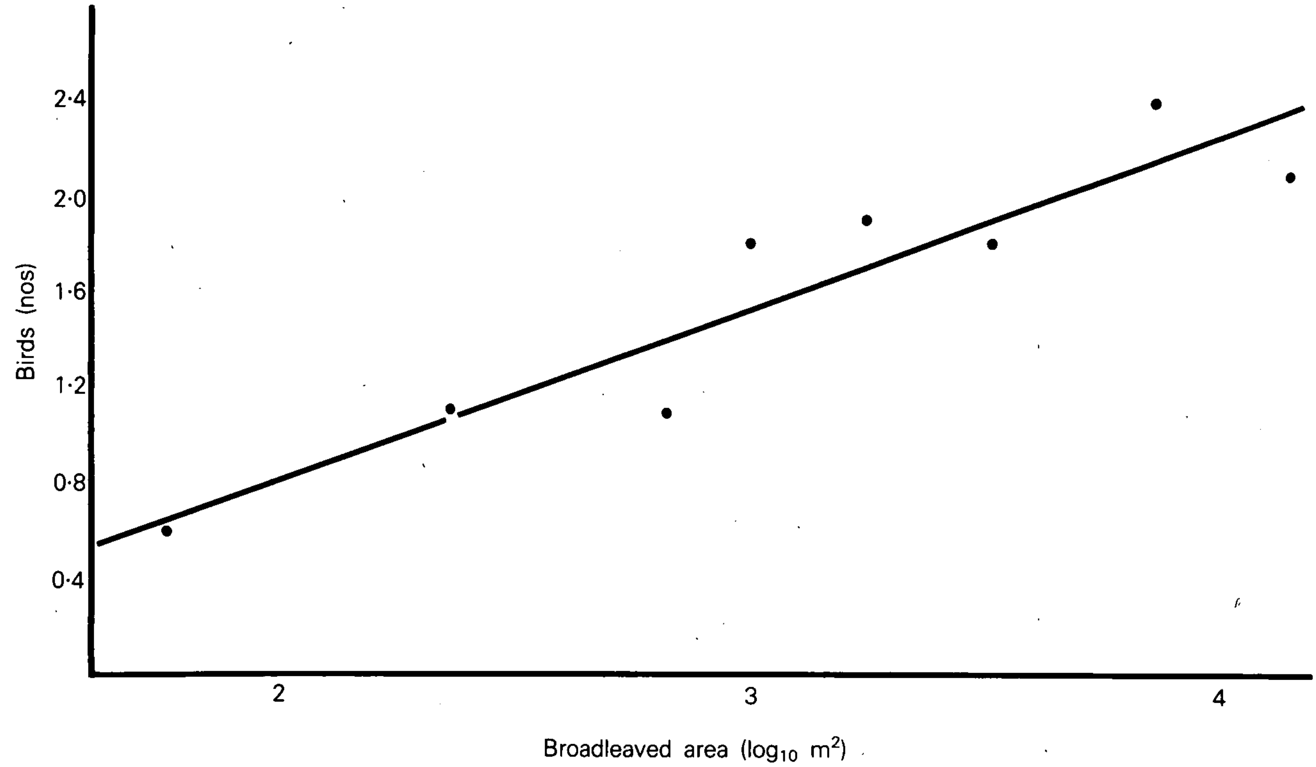

Figure 2. Number of 11 broadleaved-selective bird species detected within 30 m of census points in broadleaved patches of different sizes within conifer forests. Each point represents the mean of observations at 10 points. Note log scale (ie 4=1 ha)

3.4 Plot size and edge effects

Arguments from Island Theory have caused much confusion in being applied to 'habitat islands'. The fact that large plots have more species than small ones can be due to a greater variety of habitats in a larger plot, or simply due to the fact that, drawn from the same species pool, a large plot with more birds will inevitably include more species than a small one. The question of applied importance is whether there is a difference in the birds of a single large area compared with the sum of those from many small plots of the same total area. This question is equivalent to asking whether there are birds which only occur in islands above or below some threshold size. Such considerations are of importance with regard to the ideal size of clearfells or of unplanted islands within forests.

Of unplanted areas within a forest, Rankin and Taylor (undated) provide an analysis flawed by omission of the considerations above. This topic has not otherwise been studied in Britain. Bibby *et al.* (1985) investigated the effects of size of restocked plots on the incidence of individual species. No species was found to be restricted to larger (or smaller) restocks in the range of areas studied (2–50 ha), though it should be noted that few or no data were collected on some of the rare possible birds which might be area-sensitive. At the moment then, there is no reason to believe that the requirements of birds argue for preference for larger clearfells or retained open areas to support species requiring large open areas.

The margins between different habitats, such as that between a clearfell and a pole-stage crop, often support different birds from pure stands of either. Hansson (1983) made the geographically closest study in Sweden. Several woodland species were more abundant at the edge than the interior of old stands, while passerines typical of open areas tended to avoid the forest edges. There has been no comparable study in Britain. If such edge effects occur here, the applied conclusion would depend on numbers of species affected each way and their rarity or other subjective value. If any of the scarcer open country birds are found to avoid edges, this would argue for large clearfells. If not, then the benefits to woodland species would argue for smaller cuts to maximize the diversity of habitats created by edges.

4 Considerations for scarce species

An alternative to looking for factors promoting variety of song birds is to seek to support scarcer species, especially those where such measures could have a significant impact on British population levels. Such species require individual study, being too rare to permit the collection of enough information during census work covering all species. Very few such studies have yet been done.

The bird for which management (as distinct from mere existence) of upland conifer plantations has the greatest potential to benefit is black grouse (*Lyrurus tetrix*). A current study in Wales has shown a total population of no more than 300 males. This species is declining in numbers throughout Europe and is characteristic of the margins of woodland and moors or bogs. A high proportion of displaying males were within or near conifer forests, where birds occur on rides, restocks and newly afforested areas. Study of habitat usage for feeding and breeding should determine the features of value to black grouse, many of which could probably be supported within the established forest. This fact may be particularly important if changes to the open moorland habitats, especially from agriculture, continue to be detrimental. A study in more natural circumstances in Scotland (Picozzi & Hepburn 1984) indicated the importance of features providing good conditions for the chicks which eat invertebrates.

Further study of individual species could beneficially tackle some of those shown in Table 1. Following the species for which management could have a nationally significant effect are several for which important but lesser benefits might accrue. The possibilities for moorland waders and for birds of prey, especially hen harrier (*Circus cyaneus*), in restocks need to be explored. The potential for such studies has only recently dawned as the first major restockings begin. Three bird species, goshawk (*Accipiter gentilis*), crossbill and siskin (*Carduelis spinus*), substantially or primarily occur in conifer forests. The range and numbers of all 3 birds have increased in recent decades, in the last 2 cases solely as a result of afforestation. The goshawk is a recent return to the British avifauna, probably introduced. It is not yet clear what its ultimate range and numbers will be. The trends of all 3 species are upwards, so the urgency for research and possible management is not high. Some of the more selective song birds could also be studied in detail. An ecological approach could throw more light on details of effects of vegetation structure and tree species than can be inferred from census-based studies.

5 References

Bibby, C.J., Aston, N.L. & Bellamy P.E. 1987. Effects of broadleaf trees on birds in upland conifer plantation. *Acta Oecol.: Oecol. gen.* In press.

Bibby, C.J., Phillips, B.N. & Seddon, A.J.E. 1985. Birds of restocked conifer plantations in Wales. *J. appl. Ecol.*, **2,** 619-633.

Currie, F.A. & Bamford, R. 1982a. The value to birdlife of retaining small conifer stands beyond normal felling age within forests. *Q. Jl Forestry,* **76,** 153-160.

Currie, F.A. & Bamford, R. 1982b. Songbird nestbox studies in forests in north Wales. *Q. Jl For.,* **76,** 250-255.

Enemar, A. 1959. On determination of the size and composition of a passerine bird population during the breeding season. *Var Fagelvorld,* Suppl. 2.

Hansson, L. 1983. Bird numbers across edges between mature conifer forestry and clear-cuts in central Sweden. *Ornis scand.*, **14,** 97-103.

Jones, A.M. 1982. Capercaillie in Scotland—towards a conservation strategy. *Proc. int. Symp. Grouse, 2nd, 1981,* edited by T.W.I. Lovel, 60-70. Paris: International Council for Game and Wildlife Conservation.

Jones, A.M. 1984. Nesting habitat of capercaillie in Scottish plantations. In: *Proc. int. Symp. Grouse, 3rd,* edited by D.J. Hudson & T.W.I. Lovel, 301-316. Paris: International Council for Game and Wildlife Conservation.

MacArthur, R.H. & MacArthur, J.W. 1961. On bird species diversity. *Ecology,* **42,** 594-598.

Moss, D. 1978. Diversity of woodland songbird populations. *J. Anim. Ecol.,* **47,** 521-527.

Moss, D., Taylor, P.N. & Easterbee, N. 1979. The effects on songbird populations of upland afforestation with spruce. *Forestry,* **52,** 129-150.

Nethersole-Thompson, D. 1975. *Pine crossbills.* Calton: Poyser.

Newton, I. 1983. Birds and forestry. In: *Forestry and conservation,* edited by E.H.M. Harris, 21-36. Tring: Royal Forestry Society of England and Wales and Northern Ireland.

Newton, I. 1986. *The sparrowhawk.* Calton: Poyser.

Newton, I. & Moss, D. 1980. Factors affecting the breeding of sparrowhawks and the occurrence of their song bird prey in woodlands. In: *Forest and woodland ecology,* edited by F.T. Last & A.S. Gardiner, 125-131. Cambridge: Institute of Terrestrial Ecology.

Picozzi, N. & Hepburn, L.V. 1984. A study of black grouse in north-east Scotland. In: *Proc. int. Symp. Grouse, 3rd,* edited by P.J. Hudson & T.W.I. Lovel, 462-477. Paris: International Council for Game and Wildlife Conservation.

Rankin, G.D. & Taylor, I.R. No date. *Changes within afforested but unplanted ground birds.* Unpublished report, Nature Conservancy Council.

Simms, E. 1971. *Woodland birds.* London: Collins.

Yapp, W.B. 1952. *Birds and woods.* Oxford: Oxford University Press.

Summary

L ROCHE
Head of Department of Forestry and Wood Science, University College of North Wales, Bangor, Gwynedd LL57 2UW

We have completed a most successful meeting characterized by the high standards of the 8 papers presented and the depth and scope of the treatment of the subject *Environmental aspects of plantation forestry in Wales.* The meeting has also been notable for the diversity of scientific and management disciplines represented, and the goodwill exhibited during question-time when serious efforts were made to achieve a consensus of understanding of the complex issues discussed.

John Zehetmayr set the scene in the first paper presented. Referring to William Linnard's book, *Welsh woods and forests: history and utilization,* he outlined the principal factors leading to deforestation during the past 500 years. By 1900, the nation had effectively been completely deforested, with a consequent massive reduction in ecological diversity. At that time, with approximately 4% of its land mass under forests, Britain was one of the least forested nations in the world. This was the starting point for modern British forestry which, for reasons outlined in this first paper, gave, in due course, overwhelming emphasis to coniferous plantation establishment.

The remaining 7 papers in their various ways examined the environmental consequences of this great reforestation effort. In addition, these papers have provided guidelines for future forestry development in Wales which will ensure not only the maintenance of environmental quality but its enhancement.

The first of these papers dealt with the effects of reforestation on soil and water and showed that site preparation and logging increase turbidity and siltation in streams and rivers. Improved practices likely to reduce these adverse effects were identified.

Data were presented in the second paper showing considerable increases in acidity and aluminium content of runoff in areas under Sitka spruce (*Picea sitchensis*) plantations. The third paper outlined the effects of changes in the chemical and physical properties of runoff on aquatic fauna, and attributed these adverse changes to reforestation.

The next 2 papers were concerned respectively with landscape design and the recreation potential of production forests. Clear evidence of developing methodologies was presented: methodologies which can be, and are being, incorporated in management regimes for production forests in Wales, and which enhance the aesthetic and recreational value of these forests.

The final 2 papers summed up what we know about the need for greater ecological diversity in our production forests, if we are to provide a greater range of habitats for fauna, particularly avian fauna, and plants. The need for greater ecological diversity in our production forests was a persistent theme struck time and time again, both in the papers and during discussions.

To conclude, perhaps I may be permitted a personal comment. By the end of the 19th century, Britain's forests had been virtually eliminated. The massive adverse ecological consequences of this elimination have never been adequately documented, and, in current ecological studies of the consequences of reforestation, are frequently disregarded. Since deforestation, and following centuries of burning and pastoralism on devegetated hills and mountain slopes, further ecological degradation has taken, and is taking, place over much of upland Britain. Therefore, despite the problems of timescale, the ecological consequences of modern reforestation efforts are properly understood and measured only when placed against this historical background. The writings of Fraser-Darling (1947, 1956), now forgotten by many scientists in this age of extreme specialization, eloquently provide the historical perspective.

References

Fraser-Darling, F. 1947. *Natural history in the Highlands.* London: Collins.

Fraser-Darling, F. 1956. Man's ecological dominance through domesticated animals on wild lands. In: *Man's role in changing the face of the earth,* edited by W.L. Thomas, 778-787. Chicago: University of Chicago Press.

Linnard, W. 1982. *Welsh woods and forests: history and utilization.* Cardiff: National Museum of Wales.

Appendix: List of participants

Mr J F Addie, County Planning Department, Powys County Council, Llandrindod Wells, Powys.

Dr A Agnew, Botany Department, University College of Wales, Aberystwyth, Dyfed, SY23 3DA.

Dr M B Alcock, Department of Agriculture, University College of North Wales, Deiniol Road, Bangor, Gwynedd.

Mr M Anderson, Forestry Commission, Research Station, Alice Holt Lodge, Wrecclesham, Farnham, Surrey, GU10 4LH.

Mr D Archer, Assistant National Park Officer, Snowdonia National Park, Penrhyndeudraeth, Gwynedd.

Professor K Awang, Universiti Pertanian Malaysia, 43400 Serdang, Selangor, Malaysia.

Mr K Bayes, Royal Society for the Protection of Birds, The Lodge, Sandy, Beds, SG19 2DL.

Mr D O Baylis, Forestry Commission, Victoria House, Victoria Terrace, Aberystwyth, Dyfed, SY23 2DQ.

Professor P Beaumont, Department of Geography, St David's University College, Lampeter, Dyfed.

Mr C J Bibby, RSPB, The Lodge, Sandy, Beds, SG19 7DB.

Mr D P Bown, County Planning Department, 40 Spilman Street, Carmarthen, Dyfed.

Mr N H Clayden, Forestry Commission, Clawdd Newydd, Ruthin, Clwyd.

Dr G C Cundale, Redwing Cusop, Hay-on-Wye, Herefordshire, HR3 5RF.

Mr F A Currie, Forestry Commission, Dyfi Forest Centre, Machynlleth, Powys, SY20 9HA.

Dr S Cuttle, Welsh Plant Breeding Station, Plas Gogerddan, Aberystwyth, Dyfed, SY23 3EB.

Mr J B Davenport, Forestry Commission Office, Llanafan, Aberystwyth, Dyfed.

Mr R B Donaldson, Forestry Commission, Llanfair Road, Llandovery, Dyfed.

Professor R W Edwards, Department of Applied Biology, UWIST, P.O. Box 13, Cardiff, CF1 3XF.

Mr David Evans, Forestry Commission, Talybont-on-Usk, Powys.

Mr A M H Filton, Countryside Commission for Wales, 8 Broad Street, Newtown, Powys, SY16 2LU.

Dr J H R Gee, Department of Zoology, University College of Wales, Aberystwyth, Dyfed, SY23 3DA.

Dr J E G Good, ITE, Bangor Research Station, Ffordd Penrhos, Bangor, Gwynedd, LL57 2LQ.

Mr J P Hamilton, Forestry Commission, Ceinws, Machynlleth, Powys.

Dr D M Harding, Department of Forestry and Wood Science, University College of North Wales, Bangor, Gwynedd, LL57 2UW.

Dr D W Henman, Forestry Commission, Brechfa Forest District, Maesygroes, Brechfa, Carmarthen, Dyfed.

Dr M O Hill, ITE, Monks Wood Experimental Station, Abbots Ripton, Huntingdon, PE17 2LS.

Dr M Hornung, ITE, Bangor Research Station, Ffordd Penrhos, Bangor, Gwynedd, LL57 2LQ.

Mr G Howells, Nature Conservancy Council, Penrhos Road, Bangor, Gwynedd.

Mr J A Hudson, Institute of Hydrology (Plynlimon), Staylittle, Llanbrynmair, Powys, SY19 7DE

Mr P M Hughes, Afan Forest District, Forest District Manager, Pontrhydyfen, Port Talbot, West Glamorgan, SA12 9RU.

Mr J Hunt, 'Clevelands', Heol-y-Mynach, Old Ynys-y-Bwl, Pontypridd, Mid Glamorgan, CF37 3PE.

Mr A James, Forestry Commission, Llanfair Road, Llandovery, Dyfed.

Mr D Kay, St David's University College, Lampeter, Dyfed, SA48 7ED.

Mr J O Lazarus, County Planning Department, Gwynedd County Council, County Offices, Caernarfon, Gwynedd.

Mr G J L Leeks, Institute of Hydrology (Plynlimon), Staylittle, Llanbrynmair, Powys, SY19 7DB.

Mr O W R Lucas, Forestry Commission, 231 Corstorphine Road, Edinburgh, EH12 7AT

Mr A J Maisey, Forestry Commission, St David's House, Newtown, Powys.

Dr G J Mayhead, Forest District Manager, Forestry Commission, Gwydyr Uchaf, Llanrwst, Gwynedd.

Mr M A Mclaggan, Merthyr Mawr House, Bridgend, Mid-Glamorgan.

Professor C Milner, ITE, Bangor Research Station, Ffordd Penrhos, Bangor, Gwynedd, LL57 2LQ.

Dr N Milner, Welsh Water District Laboratory, Highfield, Priestly Road, Caernarfon, Gwynedd.

Mr R A Nicholas, Forestry Commission, Town Hall, Temple Street, Llandrindod Wells, Powys, LD1 5DL.

Dr S J Ormerod, Department of Applied Biology, UWIST, P.O. Box 13, Cardiff, CF1 3XF.

Mr T H Owen, 14 Bryn Newydd East, Prestatyn, Clwyd.

Mr A D Parsons, Wentwood, Llanfaches, Newport, Gwent.

Professor T Pritchard, Nature Conservancy Council, Penrhos Road, Bangor, Gwynedd.

Mr T M Proctor, District Manager, Economic Forestry Limited, Pale Estate Office, Llandderfel, Bala, Gwynedd.

Mr C J Radford, Bank Farm Hall, Bank Church, Powys.

Dr O Ratcliffe, Forestry Commission, Alice Holt Lodge, Wrecclesham, Farnham, Surrey, GU10 4LH.

Dr G Roberts, Institute of Hydrology, Maclean Building, Crowmarsh Gifford, Wallingford, Oxon, OX10 8BB.

Professor L Roche, Department of Forestry and Wood Science, University College of North Wales, Bangor, Gwynedd, LL57 2UW.

Mr A H A Scott, Forestry Commission, Victoria House, Victoria Terrace, Aberystywth, Dyfed, SY23 2DQ.

Mr G R Seymour, Pembrokeshire Coast National Park, County Offices, Haverfordwest, Dyfed, SA61 1QZ.

Mr J Skelton, Fountain Forestry Limited, Brecon Road, Hay-on-Wye, Herefordshire, HR3 5DY.

Mr C W Smart, Transport Highways & Planning Group, (Phase 1) Welsh Office, Tŷ Glas Road, Llanishen, Cardiff.

Mr R A Smart, 10 Elizabeth Crescent, Queens Park, Chester, CH4 7AZ.

Mr P A Stevens, ITE, Bangor Research Station, Ffordd Penrhos, Bangor, Gwynedd, LL57 2LQ.

Mr T Thompson, Department of Architecture, Planning and Estates, Clwyd County Council, Shire Hall, Mold, Clwyd, CH7 6NH.

Dr S Teyler, RSPB Wales Office, Frolic Street, Newtown, Powys.

Mr M Watkins, Nature Conservancy Council, 44 The Parade, Cardiff, South Glamorgan.

Mr D M B Yorke, Forestry Commission, Agriculture House, Dolgellau.

Mr J W LL Zehetmayr, 13 Augusta Road, Penarth, South Glamorgan, CF6 2RH.

ISBN 1 870393 02 3
ISSN 0263-8614