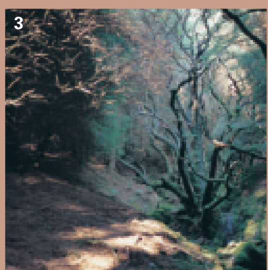
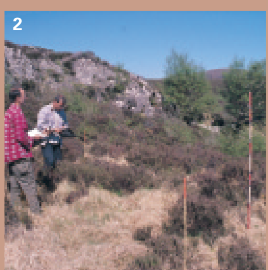
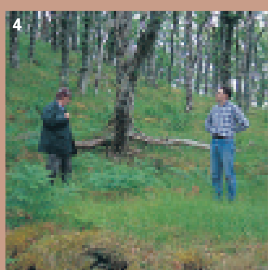
Richard Thompson, Colin Edwards and Bill Mason

Silviculture of upland native woodlands

Recognition of the value of native woodlands, particularly Ancient Woodlands, has been increasing in recent years. At an international level the importance of such natural habitats was emphasised at the Rio Earth Summit in 1992 and in the resolutions of the Ministerial Conferences on Protection of Forests in Europe at Helsinki in 1993 and Lisbon in 1998.







1. Improvement: management for natural regeneration, upland oakwood, mid Wales.
2. Expansion: predicting colonisation of upland birchwoods, Wester-Ross.
3. Restoration: remnants of a former ancient woodland within a Sitka spruce plantation, Argyll.
4. Woodland history: assessing the impact of charcoal production on oakwood structure, Argyll.

INTRODUCTION

The improvement, restoration and expansion of native woodlands is a prominent element in the *UK Biodiversity Action Plan* (Anon., 1994). This is reflected in the recent English, Welsh and Scottish forestry strategies and complying with these objectives forms one of the preconditions for certification under the UK Woodland Assurance Scheme.

These initiatives have generated a renewed interest in the management of native woodlands. Some 50 000 hectares of new native woodland were established in the uplands during the 1990s through natural colonisation and planting. The majority of these new woodlands were created in the Scottish Highlands (Anon., 2000). In addition, there have been extensive schemes where the aim has been to restore native woodlands on Ancient Woodland sites previously planted with non-native conifers. Habitat Action Plans (HAPs) have been published for the main upland native woodland types (see Table 1) with targets for expanding the current area of each type. This rapid development of native woodland management in the uplands has generated a series of questions on the most appropriate management techniques to use and improved guidance is needed. However, as Box 1 shows, there are a range of issues to be considered and guidance needs to be

Table 1

Native woodland types in the uplands.

Habitat	FPGs[a]	NVC[b]	Approximate area (000 ha)
Upland oakwoods	5	W11 W17 W10e	70–100
Native pinewoods (+ juniper woods)	7	W18 (+W19)	16
Upland birchwoods	6	W11 W17 (W4a & b)	40–64
Upland mixed ashwoods	4	W9 W8d-g (W7c)	65
Wet woodlands	8	W1–3, W5–7	50–70[c]

[a] Forest Practice Guides for the management of semi-natural woodlands. [b] National Vegetation Classification. [c] Includes lowland wet woodlands.

Box 1

Some of the issues that influence research in upland native woodlands.

- The uplands of Great Britain range from the cool boreal north-east to the oceanic western seaboard. The range of climatic and edaphic conditions has resulted in a diversity of woodland types which generates a need for a range of management options.
- Many upland native woods experienced a period of intensive management, particularly in the 17th to 19th centuries. A variety of stand structures can be observed depending upon management history. Appropriate management will depend on inherited stand structures, from minimum intervention to managed high forest for a range of objectives including production of timber.
- Traditionally, upland native woodlands were used to shelter low numbers of livestock (usually cattle). Today, there are frequently high numbers of sheep and cattle found in these woodlands. The deer population has also increased dramatically in the last 30 years, e.g. 185 000 red deer in Scotland in 1969 compared with 350 000 today (MacKenzie, 1989; Deer Commission for Scotland, 2000). Regeneration of existing woodlands is often very difficult to achieve, not only due to the direct impact of grazing animals but also to their effect on the quality of ground conditions for seedling germination (e.g. lack of leaf litter in upland oakwoods and competitive grasses in upland birchwoods).
- High grazing pressure and regular burning of upland heaths and mires has significantly impoverished soil conditions for establishment of new native woodlands. Sufficiently robust establishment techniques are needed which will cause minimal impact to the site and the wider environment.
- Between the 1930s and the early 1980s approximately 40% of ancient semi-natural woodlands were converted into plantations of predominantly non-native coniferous species. The understorey of many broadleaved woodlands have been gradually colonised by invasive species such as *Rhododendron ponticum*.

appropriate to a particular site and woodland type. In order to deliver practical solutions we need to improve our understanding of underlying processes influencing the development of native woodlands in the uplands of Britain.

Until the early 1990s, with the exception of some intermittent studies in native pinewoods (see Nixon and Edwards, 1997), very little applied silvicultural research had been undertaken in upland native woodlands. This article presents recent findings from three areas of our work with emphasis on the native pinewoods and the upland oakwoods. In the first section we discuss stand dynamics in a range of minimum intervention stands, in the second we consider natural regeneration within existing woodlands as a consequence of site treatments, and lastly we consider some results from experiments on the planting of native woodlands.

NON-INTERVENTION RESERVES

Age structure of upland oakwoods

This study was undertaken to highlight the influence of woodland history on inherited stand structures and the consequences for future management.

Records suggest that many upland oakwood stands were worked intensively for coppice production, some of these having been planted originally. Other stands retain large trees which appear to be relics of pastoral management systems. Work has been undertaken in the past on the historical ecology of upland oakwoods, particularly in Scotland and Wales (e.g. Lindsay, 1975; Linnard, 2000), but the relationship between past management and current conservation value has not always been fully recognised in the development of management recommendations.

A study was carried out (partly funded by LIFE Nature) to determine age structure profiles in a number of Atlantic oak stands, i.e. upland oakwoods on the western seaboard. Results are presented from two stands in western Scotland (Duntaynish and Barr Mor) and from Coed Cymerau in north-west Wales which illustrate contrasting structures and woodland histories. In each case a plot of around 1.0 ha was established and cores taken from trees within the stand.

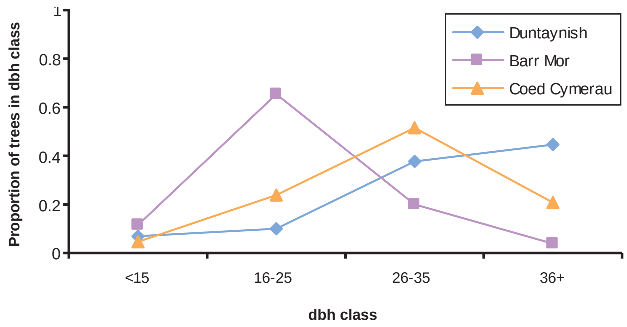
Results

Diameter distributions: comparison of the three sites

Trees were classified into four dbh classes: <15 cm, 16–25 cm, 26–35 cm and >36 cm. Data were analysed as a two-way contingency table with site and dbh class as the two factors. There was a highly significant ($p<0.001$) difference in the distribution of trees among dbh classes between sites. Duntaynish has a higher proportion of trees in the two larger dbh classes, with Barr Mor reaching a peak in the 16–25 cm class and Coed Cymerau in the 26–35 cm class (Figure 1).

Figure 1

Proportion of trees in four dbh classes at three sites.



Duntaynish stand description

This stand at Duntaynish (Plate 1) has a very irregular structure and an open canopy with a basal area of 19.5 m^2 ha^{-1} in 1999. Oaks are composed of old coppice and maiden trees with a range of diameters. The stand also contains frequent birch, rowan and hazel, many of which are senescent. There is a well-developed lichen flora on the larger maiden trees (>40 cm dbh) including a range of lichens characteristic of old growth stands, e.g. three species of *Lobaria*. Smaller maiden trees (< 35 cm) had poorer lichen communities, suggesting that they have seeded in after coppicing ceased.

Plate 1

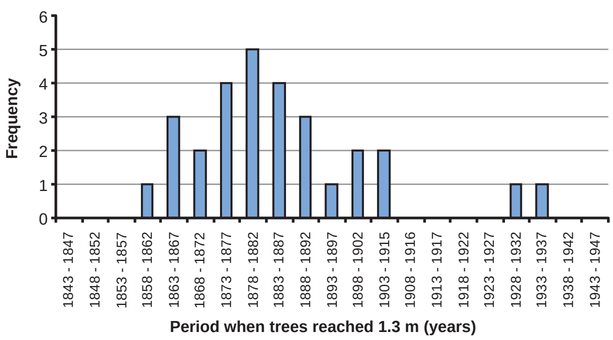
Upland oakwood stand at Duntaynish, western Scotland.

The age-class profile (Figure 2) indicates a 55-year regeneration period from 1860 to 1915. Some of the older trees have smaller diameters and these probably originate from coppiced stems. The small number of younger trees probably regenerated due to relaxation of grazing in the 1920s and 1930s.

The plot contains an old trackway and boundary walls which appear to date from an early period. There are no archeological features to suggest intensive woodland management which, combined with the irregular stand structure, indicate that this stand was not managed as intensive coppice. Some of the plot appears to have been managed as wood pasture with other areas subject to informal exploitation of coppice material.

Figure 2

Histogram of oak age classes – Duntaynish.



Barr Mor stand description

There are striking differences between Barr Mor and Duntaynish, despite both occurring in the same woodland complex. This stand at Barr Mor (Plate 2) has a uniform structure with a closed canopy of singled oak coppice and a basal area of 30.6 m^2 ha^{-1}. There are few maiden stems and no veteran trees. There is a complete lack of *Lobaria* lichen species within this plot which (in the context of Taynish) indicates a lack of ecological continuity. Other lichens are largely limited to species characteristic of early successional habitat.

The age profile (Figure 3) indicates that coppicing declined from around 1850 to 1860, with the majority of coppice regrowth reaching 1.3 m by 1900. However, there was continued recruitment to the stand until the 1940s.

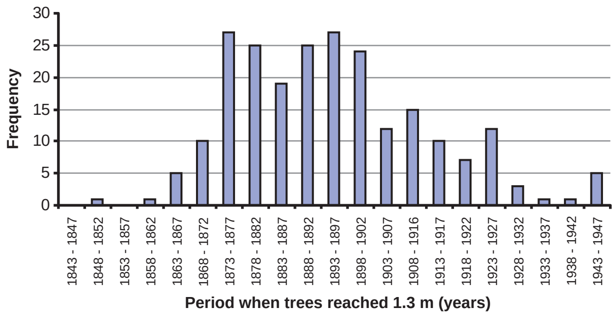
Archeological features suggest a history of intensive woodland management with a number of very obvious charcoal hearths or platforms and interconnecting pony tracks seen within the stand. The uniformity of the stand, lack of veteran trees, relatively poor lichen flora and archeological remains suggest that this stand developed after a period of intensive coppice management when ecological continuity was lost.

Plate 2

Upland oakwood stand at Barr Mor, western Scotland.

Figure 3

Histogram of oak age classes – Barr Mor.



Coed Cymerau stand description

The age of the oldest trees at Coed Cymerau (shown in Plate 3) is greater than at either of the Scottish sites (Figure 4). Reduction in grazing pressure following fencing in the 1960s has resulted in a substantial change in vegetation since extensive swards of *Deschampsia flexuosa* have been replaced by *Vaccinium myrtillus* (W. Shaw, personal communication). There has also been the recruitment of natural regeneration on an area at the top of the bank (known to have been treeless in the early 1960s) and the development of an understorey in much of the wood. Stems on the middle bank are competing for space and going through a stem exclusion phase (i.e. suppressed and sub-dominant trees are dying due to competition from dominants and co-dominants). At the same time, a substantial recruitment of saplings is taking place in the understorey. In the lower bank (where the slope becomes shallower, soils become moister, light levels and temperatures are lower), several isolated dominant and co-dominant oak trees are dying or dead. Some of these are on the river terrace which occasionally floods. Gaps created are filling with rowan from the understorey. There were no signs of *Lobaria* lichen species either within the plot, on trees around the edge of the wood or elsewhere within the woodland.

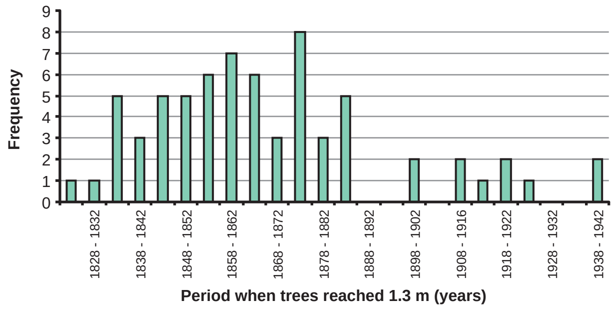
The only archeological features observed within Coed Cymerau were dry stone walls thought to date back to the enclosure period. Timber from the local Maentwrog oakwoods is known to have been used largely for ship building from the late 1700s until 1820. A photograph in Linnard (2000) shows a merchant vessel being constructed from Maentwrog oak at Porthmadog, with the bark being used at a tannery on the southern edge of Coed Cymerau. Other records show that timber from the estate went to the Pembrokeshire collieries and that some was used for charcoal. Many of the woodlands in the Vale of Ffestiniog may have been planted since 1807. Merioneth Quarter Sessions records indicate that local landowners were encouraging new plantations (Gwyn, 2001). The local estate owner was recognised for the active management of his woods, and there was a tree nursery 1 mile east of the wood. Records suggest that trees from here were used to plant up clearings after felling. It is possible that planting was restricted to the more accessible sites with better soils and that poorer sites were left for grazing or to regenerate naturally after felling. Further work is required to discover the extent to which planting or regeneration determined the current overstorey structure in this woodland.

Plate 3

Upland oakwood stand at Coed Cymerau, north-west Wales.

Figure 4

Histogram of oak age classes – Coed Cymerau.



Age structure and development of native pinewoods

Natural regeneration is the preferred method for increasing the area of existing pinewood stands. Managers are looking for more information on the natural recruitment rates and dynamics of pinewood stands, and the effect management operations have on speeding the establishment of future cohorts of seedlings. Some guidance can be obtained from a series of non-intervention pinewood reserves established between 1930 and 1950 (Edwards and Mason, 2000).

The Black Wood of Rannoch is an 800 ha Native Scots pine reserve situated on the southern shores of Loch Rannoch in Perthshire. Felling operations and disturbance events are known to have occurred regularly from the 17th century, the last being in 1940/41 by the Canadian Forestry Corps (Wonders, 1996). Deer browsing is known to be a significant cause of seeding loss (Miles and Kinnaird, 1979a and b). This has been reduced substantially since 1945 by a combination of fencing and rigorous culling (Arkle and Nixon, 1996).

Several 0.81 ha plots were established in Rannoch in 1948 to study structural changes and natural regeneration succession. Plots were assessed in 1948, 1956, 1983/84 and 1993/94 when tree and seedling establishment or mortality was recorded. Tree height, dbh, crown depth and crown width in two directions were recorded. Trees >10 cm dbh were aged by taking increment cores. Seedling (<10 cm dbh, <1.3 m in height) positions and species were also recorded. The research focus has been to examine whether the pinewood could recover and regenerate sufficiently without management intervention and the speed of the recovery process.

Results

Recruitment of both Scots pine and birch exceeded mortality between 1948 and 1994 (Figure 5), resulting in substantial increases in tree population size. New seedlings (<1.3 m tall) were recorded in all plots in 1994 at a density of around 170 seedlings ha^{-1}, showing that recruitment is still continuing. Over 90 per cent of seedlings were of Scots pine, with the balance being made up by birch, rowan and willow.

The age distribution pattern for plot 4 differs markedly from the other plots in the study (Figure 6). There is a peak of individuals in the 120 years age-class with lower frequency in all younger age-classes. In addition, plot 4 has a greater basal area than any of the other plots (Table 2) and is the only plot where mortality exceeds recruitment (not shown). In plots 5, 6 and 7 there is a higher frequency of individuals in the youngest age classes (Figure 6). Recruitment probably occurred as stands recovered from disturbance during felling operations in the period 1940–1942. Either advance regeneration was released by the felling operation or new seedling germination occurred, or both.

In parts of the Black Wood reserve, seedlings established following ground disturbance and canopy removal have taken an average of 16 years to reach 1 m height in good growing conditions (Edwards, unpublished). Scott *et al.* (2000) predict Scots pine saplings will require 22 years to grow from <10 cm height to >1.5 m in good conditions, and > 50 years on poor sites. This is in general agreement with seedling growth at Rannoch.

Figure 5

Mortality and recruitment rates for Scots pine and birch in all plots (1948–1994). Values indicate mean number of trees ha^{-1} present on each assessment date, and the mortality and recruitment rates between each successive assessment date.

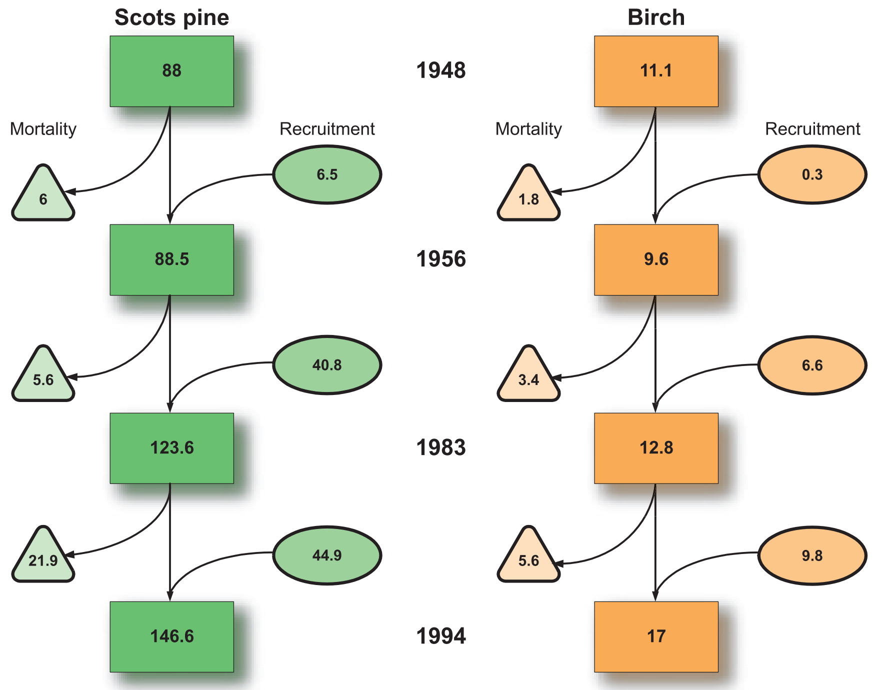


Table 2

Tree species data from the four permanent assessment plots in the Black Wood of Rannoch (excluding areas disturbed by fences and power lines).

	Number of Scots pine trees in 1994 (>1.3 m height, >10 cm dbh)	Basal area[a] (m^2 ha^{-1})	Mean height (m)	Mean age[b] (yr)	Age range (yr)
Plot 4	130	27.3	15.7	119	23–263
Plot 5	58	21.2	14.4	80	13–204
Plot 6	81	14.9	11.0	37	9–140
Plot 7	114	25.7	14.3	57	14–153

[a] Basal area calculation includes birch, rowan and pine trees.

[b] Age is taken from cores at 1.0 m height above ground level.

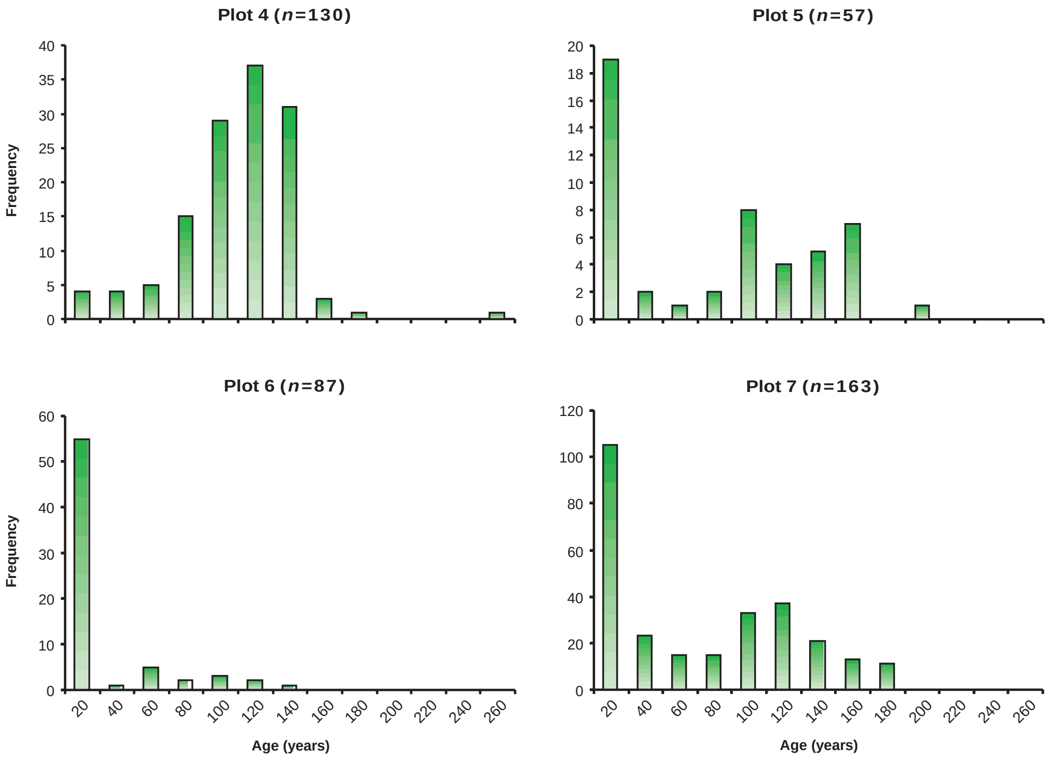
Management recommendations

These stands exemplify the following management recommendations.

- Each stand should be examined and treated as an individual unit. Consider how its structure has developed, the effects of past management, and the interactions between management and site type.
- The most uniform upland oakwood stands tend to be those that have been managed intensively in the past. In such stands, management intervention may be desirable to increase structural diversity, particularly in small woods where natural disturbance is unreliable. Silvicultural operations should avoid large scale disturbance, and aim to maintain woodland conditions.

Figure 6

Age class distribution for pine and birch > 10 cm dbh in the four permanent assessment plots, the Black Wood of Rannoch.



- Before any intervention, assess the conservation value of stems carefully, and do not assume that small trees are of lower value for biodiversity. In some stands, many of the older trees are sub-dominant and have well-developed epiphytic communities, valuable deadwood and associated species of fungi and invertebrates.
- Stands often take a long time to recover from disturbance and it can take 50–100 years or more before new seedlings form part of the forest canopy.

GROUND PREPARATION FOR REGENERATION

Upland oakwoods

A series of experiments was set up during 1991–92 within group fellings in oakwoods in Kilmichael (Argyll), Gilling (North York Moors) and Brechfa (mid Wales). The aim was to assess the effect of different ground preparation treatments on the natural regeneration of oak.

Method

Each site consisted of three group fellings (25 m or about 1.5 tree heights in diameter). A randomised block design was used with six replicates of the treatments described in Table 3. Plots of 0.002 ha were sown with 200 acorns (equivalent to 100 000 ha^{-1}, representing typical acorn densities in a mast year). Seedling counts were carried out in years 1, 5 and 10 for North York Moors 73, years 1, 6 and 10 for Kilmichael 28 and years 1, 5 and 11 for Llandovery 2 (Brechfa). Data from each year were analysed by Analysis of Variance using a square root transformation. Plot layout is shown in Figure 7.

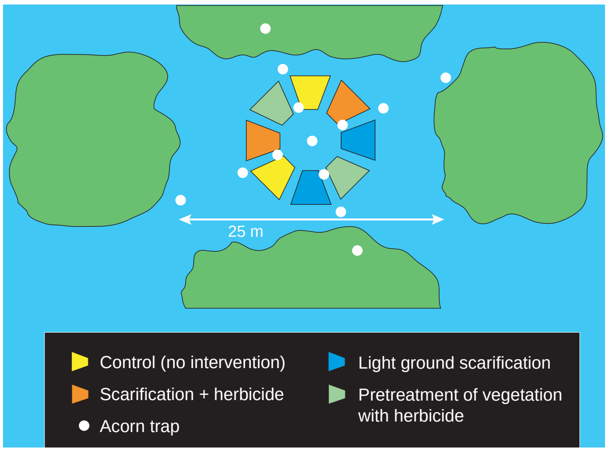
Table 3

List of treatments in the oakwood regeneration studies.

Control (O)	Removal of existing tree seedlings, sowing acorns onto otherwise undisturbed sward.
Scarify (S)	Simulated scarification with hand tools, burying sown acorns 5 cm deep.
Herbicide (H)	Application of herbicide prior to sowing of acorns.
Scarify, herbicide (SH)	Application of herbicide prior to sowing of acorns followed by simulated scarification with hand tools, burying sown acorns 5 cm deep.

Figure 7

Layout of treatments in upland oakwood ground preparation experiments.



Results for Kilmichael

First year results (Table 4) showed significant positive effects of the scarification treatment ($p<0.001$) and the herbicide treatment ($p<0.05$). The general drop in the number of seedlings by year 6 is attributable to development of a dense sward of bracken in 4 out of 6 blocks which negated the initial herbicide effect, so that at 10 years the only significant effect was due to scarification ($p<0.001$). Birch showed a similar response to oak (data not shown), regenerating better on treatments with an element of scarification.

Results for North York Moors

This site suffered severe predation of acorns in the first year which was particularly bad in treatments with herbicide (the herbicide treatment showed a significant negative effect ($p<0.01$; Table 4). There was a good mast year for oak in 1995 and new seedlings established in all plots, but especially where scarification had occurred; however, no effects showed statistical significance. By year 10 scarification alone showed significant improvements over the others ($p<0.05$). There was no advantage from application of herbicide.

Birch regeneration (data not shown) was most abundant where treatments had an element of herbicide application; the addition of scarification (i.e. the SH treatment) showed slight advantages over herbicide alone (i.e. the H treatment).

Results for Brechfa

No effects reached statistical significance in this experiment although a similar pattern of beneficial effects of scarification was observed (Table 4). The increase in seedling numbers by year 6 can be attributed to the 1995 mast year. Year 11 results indicate a general decline in seedling numbers and a lack of treatment effect due to weed competition.

Table 4

Mean plot counts from three upland oakwood regeneration experiments. Data were transformed before analysis and values in parentheses are the untransformed means.

Treatment	North York Moors			Kilmichael			Brechfa		
	Year 1	Year 5	Year 10	Year 1	Year 6	Year 10	Year 1	Year 5	Year 11
S	0.87 (1.17)	3.00 (12.50)	2.45 (9.00)	2.83 (8.67)	2.23 (5.67)	1.61 (4.17)	2.53 (7.33)	3.16 (11.50)	1.64 (4.30)
H	0.40 (0.50)	1.48 (2.30)	0.81 (1.33)	2.03 (4.33)	1.04 (1.33)	0.80 (1.00)	1.34 (2.50)	1.87 (3.80)	1.22 (2.50)
SH	0.00 (0.00)	1.45 (3.30)	1.87 (3.83)	3.12 (10.17)	1.94 (5.67)	1.99 (4.50)	2.28 (5.83)	3.21 (14.00)	1.95 (5.80)
O	1.48	1.91	1.49	0.50	0.17	0.00	2.03	2.34	1.53
	(3.00)	(4.00)	(3.17)	(0.83)	(0.17)	(0.00)	(5.33)	(6.80)	(4.20)
SED[a]	0.37	0.71	0.55	0.46	0.52	0.43	0.55	0.74	0.86
LSD (5%)[b]	0.80	1.51	1.17	0.99	1.10	0.92	1.18	1.57	1.83

[a] SED: Standard Error of Difference between mean.

[b] LSD: Least Significant Difference test.

Discussion

The only treatment to provide consistent benefits was shallow scarification, with herbicide effects being very short lived. Ground preparation to encourage regeneration in upland oakwoods will be particularly relevant where high densities of seedlings are desired for timber production objectives.

On all but the most infertile sites and those in northerly latitudes, ground preparation to encourage natural regeneration of oak should be done in a mast year under an intact canopy, with group felling or heavy thinning undertaken later when seedlings are at most 2–3 years old. Group fellings prior to achieving advanced regeneration may develop a dense sward of competitive vegetation before the next mast year.

Native pinewoods

An experiment was established in the 1930s in Glenmore Forest Park in Inverness-shire to test the effects of eight methods of ground preparation or vegetation manipulation upon the natural regeneration of Scots pine. The soils are predominately shallow to deep peaty podzols overlying fluvio-glacial deposits. Topography is generally level with slight hummocks causing changes in micro-topography. A deer fence was erected in 1930 prior to treatments being applied and this fence was maintained until 1972. In 1930, the basal area of the Scots pine overstorey was between 17 and 22 m^2 ha^{-1}, and in 1998 there were 261 trees ha^{-1} with a basal area still at around 22 m^2 ha^{-1}. Rank *Calluna vulgaris* and *Vaccinium myrtillus* and *V. vitis-idaea* now dominate the area with various bryophytes forming a thick mat in the intervening spaces and under the *Calluna* canopy. Early results were reported by Macdonald (1952) who concluded that the best results were obtained after cultivation. This has been confirmed in other studies by Booth (1984) and Low (1988).

Twenty treatment plots, out of 64 originally established, were relocated for assessment in 1999 forming an area approximately 100 m x 80 m. The assessment distinguished between trees (>10 cm dbh), saplings (> 1.3 m tall; < 10 cm dbh) and seedlings (< 1.3 m tall). From each tree an increment core was removed from 1.0 m above ground level, mounted onto wooden holders and used for determination of tree age at that height following the methodology of Stokes and Smiley (1968). We made the assumption that trees aged < 60 years would have been recruited by any of the 1930s treatments. Saplings are considered younger than 60 years. Any trees > 60 years when cored were assumed to have been recruited prior to the 1930s, and have been designated 'mature' to distinguish them from the latter recruitment phase.

Results

In all treatments there was an increase in seedling numbers between 1943 and 1959 assessments (Table 5). The increase was much greater after strip cultivation than for any other treatment. This effect was still evident in 1999 when strip cultivation plots had significantly greater numbers of saplings and seedlings ($p < 0.05$) than all other plots (significance assessed using ANOVA). This treatment also gave rise to a much higher number of young trees. The control treatment eventually resulted in more young trees than patch cultivation, possibly because of reinvigorated vegetation competition in the latter. There are no visible differences in ground vegetation between the various treatments 70 years after the start of the experiment.

Conclusions

Cultivation of the ground in and around large canopy gaps when seed is abundant is the most reliable method of recruiting high numbers of seedlings in pinewoods. Non-intervention can also recruit new trees into a stand, but will only occur in limited numbers over an extended time period and when browsing pressure is controlled.

Table 5

Comparison of mean numbers of seedlings, saplings and young trees of Scots pine in treatment plots in Glenmore in 1943, 1959 and 1999.

Treatments (date of application)	Number of plots assessed	Mean number of seedlings (gross ha^{-1})		Mean number of seedlings and saplings (gross ha^{-1})	Mean number of trees <60 years (gross ha^{-1})
		1943	1959	1999	1999
A Control (1930)	6	0	197	133	104
B Brash cover (1930)	2	0	161	175	50
E Patch burning (1930)	2	111	37	138	62
D Patch cultivation (1930 and 39) D(r) Patch cultivation (1930, 36 and 39)	2	457	284	162	0
J Burning pre-strip cultivation (1930 and 39)	2	1185	1679	1212	225
C Strip cultivation (1930 and 39)	3	1210	1703	1158	242
C(r) Strip cultivation (1930, 36 and 39)	3	2329	3333	1220	467

PLANTING OF NATIVE WOODLANDS

Native pinewoods

Recent guidance to managers on creating new native pinewoods has recommended the use of the minimum cultivation commensurate with satisfactory establishment (Anon., 1994). However, establishment success is known to result from the interaction between cultivation, fertiliser input and plant quality, and it can be difficult to determine what is the appropriate strategy on a given site. An experimental area was established in the mid-1990s on Dava Moor near Grantown-on-Spey to explore some of these aspects.

The site is at 285 m a.s.l. on a sharply defined exposed ridge, with gentle to moderate southwest facing slopes. The soils are podzolic ironpans with various depths of overlying peat, depending on microtopography. There is a heathland vegetation, principally *Calluna vulgaris, Erica tetralix* and *Scirpus cespitosus*. The site was formerly managed as a grouse moor with sheep grazing, and was regularly burnt. The nearest pine seed source is over 1 km distant. Natural regeneration of pine and birch has occurred sporadically, but was suppressed by the grazing and burning. The experimental area was deer fenced before cultivation and planting.

Effects of phosphate at planting at Moray 47 P95

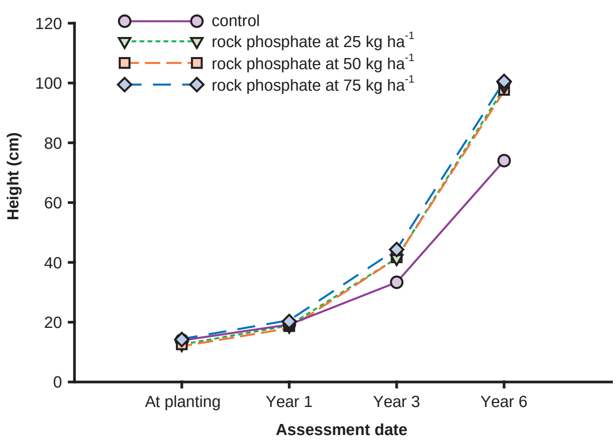
The site was cultivated by a MacLarty continuous mounder in March 1995, and planted with Abernethy origin native Scots pine in May 1995. Fertiliser, as ground rock phosphate, was applied at three rates (25–75 kg ha^{-1}) as spot applications plus an untreated control to an area approximately 1 m^2 round the base of each tree, in July 1995. No herbicide was applied to this experiment. Foliar nutrient concentrations were tested in 1996; 20 needles were collected from sample trees in each treatment and sent to the Foliar Analysis Service, Environmental Research Branch at Alice Holt for standard analysis.

Results

There were no significant differences in plant survival at the end of years 1, 3 or 6 with all treatments having over 95 per cent survival. Foliar N concentrations were significantly (p<0.05) greater in all fertiliser treatments compared with the control (an average of 1.8 vs 1.6 for the control). Plant heights were not significantly different between any treatment up to and including year 3. By year 6 all three fertiliser treatments were significantly taller (p<0.001) than the control, but there was no difference between fertiliser rates (see Figure 8).

Figure 8

Moray 47 P95: height response of native Scots pine to various rates of rock phosphate fertiliser applied at time of planting.



Minimal cultivation at Moray 51 P96

Seven different cultivation treatments (Table 6) were compared. Herbicide in the form of glyphosate was applied once to all treatments that included a weeding component. The site was planted with native Scots pine of Abernethy origin in late April to early May 1996.

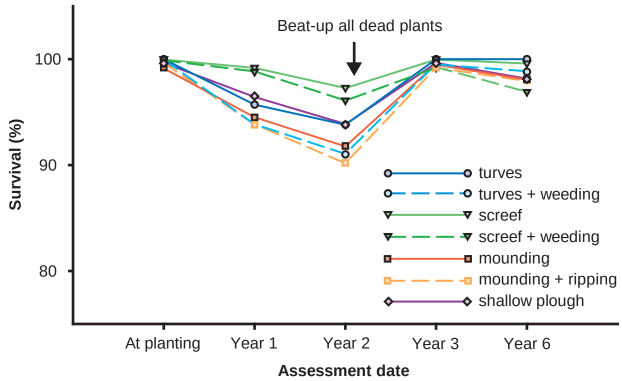
Table 6

Cultivation treatments used in experiment Moray 51.

Code	Treatment description
S	Direct planting into hand-screefed spot
SW	Direct planting into hand-screefed spot plus weed control
T	Direct planting onto hand-cut inverted turves
TW	Direct planting onto hand-cut inverted turves plus weed control
M	Continuous mounding by MacLarty continuous mounder
MR	Continuous mounding by MacLarty continuous mounder with ripping
SP	Shallow double mould board ploughing (D45 T60)

Figure 9

Moray 51: plant survival in difficult cultivation intensities. All dead plants were replaced with native Scots pine 1 + 1s in March 1988.



Results

Survival after 6 years was very good, with no treatment with > 5% mortality (see Figure 9). One year after planting, mean seedling heights in the hand-screefed treatments with and without herbicide were significantly taller (p<0.05) than all other treatments except hand cut turves with herbicide. Plants on hand cut turves were the smallest (Table 7). After 6 years growth, the order had changed with significantly taller plants in the mounding plus ripping and shallow ploughing treatments (p<0.05). The smallest plants were to be found in the hand-screefed treatments with or without herbicide.

Conclusions

In the absence of browsing, early survival was very good and not affected by either fertiliser or by cultivation. However, height growth was improved by more intensive cultivation and/or by fertiliser, supporting earlier studies on establishment of trees on heathlands (Zehetmayr, 1960).

Table 7

Mean seedling heights in the different cultivation treatments in Moray 51, assessed at planting and four other dates.

Assessment date	S	SW	T	TW	M	MR	SP	LSD (5%)
				Cultivation treatment				
At planting	10.2	9.0	9.6	9.9	9.5	10.3	9.4	**n.s**[a]
Year 1	18.8	18.2	15.9	17.0	16.3	16.1	16.3	**1.7**
Year 2	21.6	20.7	18.9	19.5	19.6	20.3	20.4	**1.6**
Year 3	26.1	25.3	23.2	24.3	24.4	27.4	28.5	**4.8**
Year 6	38.5	39.3	44.5	44.9	50.3	60.1	59.2	**7.0**

[a] n.s.: no significant differences between the heights of seedlings in any of the treatments at planting.

Restoration of upland oakwoods

In 1996 an experiment was established in Gisburn Forest, northern Lancashire, to examine the comparative performance of a range of broadleaved species for restoring native woodlands following clearfelling of the previous conifer stand. The site is located at 350 m a.s.l on a peaty gley soil. The site is exposed with a Detailed Aspect Method of Scoring (Quine, 2000) score of 16, although the south-easterly aspect provides some topographic shelter. The previous stand was 34-year-old Sitka spruce which was felled in late spring 1995. Site analysis after felling, using guidance in Rodwell and Patterson (1994), suggested that the upper part of the site lay within the NVC W4 native woodland type (birch with purple moor-grass) whereas the lower part fell into the NVC W17 type (upland oak–birch with bilberry).

The experiment contrasts the performance of pure plots of downy birch and of sessile oak with a 1:1 mixture of both species, and with plots containing the species mixtures recommended by Rodwell and Patterson (1994) for creating W4 and W17 types. All species were of local seed sources. Unplanted control plots were also included to examine the potential for natural colonisation. A randomised block design with four replicates was used.

All plots were 0.07 ha in size to allow the possibility of examining long-term stand development. On half of the plots brash from the conifer clearfelling was removed from the site while on the other half it was retained in windrowed strips.

At time of planting there was no ground vegetation as a result of the dense shade cast by the previous Sitka spruce stand. Six years later, although there was still much bare ground, there had been appreciable development of grasses and herbs characteristic of upland sites. Dominant species were *Deschampsia flexuosa*, *Juncus effusus* and *J. squarrosus*, *Molinia caerulea* and *Galium saxatile*. There was very little natural colonisation by trees after 6 years when an assessment of the control plots gave a total count of 39 seedlings (15 birch, 12 rowan, 8 Sitka spruce, 3 holly and 1 Norway spruce). The lack of any adjacent seed sources is the probable reason for the limited colonisation to date.

Five years after planting, the most notable trend was the poorer growth and comparatively low survival of the sessile oak plots compared to the other treatments (Table 8). There was no effect of brash removal upon growth or survival. Most of the minor species planted in either the W4 or the W17 treatments (rowan, silver birch, holly, common alder, goat willow, grey sallow) showed as good survival as the main species; the only exceptions were the two willows where the figures were around 30 per cent.

Although this experiment is still in its early stages, some preliminary conclusions can be drawn from this and sister experiments established in upland Britain since the mid 1990s. Firstly, planting will generally be necessary for rapid restoration of native woodland tree cover on sites that were planted with conifers, if there is no native tree seed source within close proximity. Secondly, the planting of more varied mixtures of native tree species as recommended by Rodwell and Patterson (1994) does not appear to cause major problems in terms of higher establishment costs. Thirdly, it is easy to be overoptimistic about the fertility of a site and to plant species that are not well suited to the location as is shown by the comparatively poor performance of the sessile oak in the Gisburn experiment.

Table 8

Five year height (cm) and survival (%) of a range of native woodland treatments planted in the Gisburn experiment.

Treatment	Height	Survival[2]
Sessile oak	14.9[d]	67.3[c,d]
Downy birch	100.7[a]	78.3[a,b]
Oak/birch mixture	55.0[c]	74.2[b,c]
W4 mixture	66.3[d]	60.3[d]
W17 mixture	83.2[b]	83.0[a]
Significance[1]	***	**
LSD (5%)	13.3	5.7

1. ***p*<0.01; ****p*<0.001.

2. Data were transformed before analysis but are presented here as percentages for ease of interpretation. LSD values refer to these transformed data.

Height and survival responses with common superscript letters are not significantly different.

OVERALL CONCLUSIONS

We believe that some general conclusions can be drawn from these studies:

1. *Management options.* A range of management options is normally available for each native woodland stand and the use of routine prescriptions should be avoided. The options should be carefully evaluated in the light of objectives, management history, practical opportunities and constraints.
2. *Sustaining conditions.* Maintaining woodland conditions (e.g. avoiding the large scale disturbance associated with clearfelling) frequently enhances biodiversity at the stand level and improves the prospects for successful natural regeneration and/or enrichment planting.
3. *Levels of intervention.* With adequate long-term control of browsing pressure, low densities of seedlings sufficient to ensure stand survival can be established with limited inputs. However, wherever timber production is an objective, more intensive site management may be necessary to ensure adequate regeneration.

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