Forestry Commission

Research Note

Natural regeneration in western hemlock plantations on ancient woodland sites

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During the 20th century large areas of ancient semi-natural woodland were converted to conifer plantations, creating sites now termed PAWS (Plantations on Ancient Woodland Sites). Restoration of these sites to native woodland is a current objective of forestry policy throughout Great Britain. Natural regeneration is often regarded as the preferred method for restocking PAWS but it is a generally unpredictable process and some native species are very difficult to regenerate. A survey of western hemlock PAWS, carried out to identify which species were regenerating and how much of each was present, found a wide range of species either as seedlings or saplings, but at many sites the regeneration was predominantly birch. There were significant relationships between some site characteristics and the occurrence of regeneration, with the presence of nearby parents being especially important. Although there were often large numbers of seedlings present, most were small and patchily distributed, and the proportion of each site stocked with natural regeneration was low. A simple method for determining the proportion of a site stocked is described. While timber species such as oak and beech were regenerating, both seedling numbers and the areas of each site stocked were low. This indicates that natural regeneration may be an inadequate method of restocking and that planting may be required if an objective of management is to produce a good final crop of timber.

Introduction

During the middle of the 20th century substantial areas of ancient semi-natural woodland were converted to plantations, often of non-native conifers, creating sites known as plantations on ancient woodland sites, or PAWS. These occupy around 200 000 ha about 60% of which are conifers. At the present time, restoration of these sites to native woodland, with the aim of improving their biodiversity value, is an important objective of forestry policy throughout Great Britain.

It is generally recommended that restoration of PAWS should take place by progressive removal of non-native canopy, either by thinning or some form of continuous cover forestry (Thompson *et al*., 2003). However, clearfelling may be acceptable if remnant features are not adversely affected, or regeneration of the introduced species is likely to be prolific. Stands of western hemlock will often fall into the second category. Natural regeneration is the preferred method for restocking PAWS but it is a generally unpredictable process and some species are very difficult to regenerate.

This Research Note reports the results of a survey of natural regeneration in western hemlock PAWS (Box 1) which aimed to:

- determine the numbers and species of tree seedlings regenerating;
- estimate the amount of each site that was restocked;
- assess the effect of site characteristics such as canopy cover, parent trees and vegetation cover on tree seedlings;
- identify a general sampling method to assess the proportion of a site that is stocked.

Survey method

Twenty-one sites were selected for survey from those managed by the Forestry Commission in southeast England. They were classified into three stand types according to the current crop:

Western hemlock felled

- Broadleaved sites comprising a number of hardwood species that were originally mixtures of hardwoods and western hemlock from which the latter had been largely or completely felled.
- Open sites derived by clearfelling stands originally described in sub-compartment records as pure western hemlock.

Western hemlock standing

- Hemlock sites at which no recent felling has taken place and there is a crop of western hemlock either pure or in mixture with hardwoods.

During summer 2007 a systematic procedure based on that described in Kerr *et al*. (2002) was used to assess the following characteristics on a maximum of fifty 2 × 2 m quadrats at each site. Full details are given in Harmer *et al*. (2011).

Results

All sites, even those which had been clearfelled, had some overstory and understorey trees remaining. A total of 26 species were recorded during the survey, seven of which were non-native conifers. Birch, oak, beech and western hemlock were most common. Shrubs were generally infrequent and only eight species were seen, with holly, broom and gorse being most common. Bramble was the predominant vegetation and there was little difference between stand types. In contrast, grasses, rushes and shrubs were more abundant on open sites than those with tree cover.

Regenerating trees

Saplings or seedlings were recorded on all sites, but most species were uncommon, occurring on less than 10% of sample quadrats and less than half of sites surveyed. Birch, hazel and western hemlock were the most common of the 10 species of saplings; ash, beech, birch, oak and western hemlock were the most common of the 21 species found as seedlings (Table 1). At any site there were between 3 and 11 species regenerating. Many of the seedlings were small, with the tallest seedlings of most species being less than 50 cm in height.

Quantity of regeneration on each site

The amount of regeneration present was estimated from the number of saplings and seedlings present on the sample quadrats. Estimates were also made for a group of timber producing species, including ash, beech, oak, sweet chestnut and sycamore.

Natural distribution and characteristics

Western hemlock is found naturally in the Pacific coastal area of north-western North America in forests where it is often associated with Sitka spruce, Douglas fir and western red cedar. Although it can be a pioneer species, it is very tolerant of shade and is regarded as a climax species. It grows well on a variety of soil types but growth may be less good on sites with poor drainage or high water tables. Western hemlock forests are amongst the most productive in the world, on the best sites old-growth trees often attain heights of 50–60 m and diameters of >100 cm, with typical maximum ages of 400–500 years. A wide variety of damaging agents can have adverse effects on western hemlock including: windthrow due to shallow rooting; frost damage; foliage-eating insects; and butt-rot caused by *Heterobasidion annosum*. Stem fluting is common in some areas.

Use in Great Britain

Although it was first introduced in 1851, the widespread use of western hemlock in forestry developed slowly. It was first planted as a forest tree in 1888 and 50 years later there were about 250 ha of plantation. During the middle of the 20th century, when there was significant interest in expanding the variety of non-native conifer species used in plantation forestry, western hemlock was regarded as a species that:

- had no marked climate preferences;
- showed good productivity in areas of relatively low rainfall;
- grew well on acidic mineral soils and better peats;
- was useful for under-planting;
- was difficult to establish on exposed, open ground;
- established poorly when in competition with heather;
- was susceptible to butt rot.

Use of western hemlock in plantations increased during the middle to late 20th century, but it remained a relatively minor species accounting for about 1% of the total area of conifers occupying a maximum of *c.* 11 000 ha. In many of these plantations western hemlock was used for the under-planting or enrichment of derelict and poor quality, uneconomic broadleaved woodland which today would probably be classified as valuable ancient semi-natural woodland (Figure 2). A decline in the use of western hemlock began in the 1970s following the publication of a comparative study which showed that for many sites it was unlikely to be the best choice of species.

Figure 2 12-year-old understorey of western hemlock developing beneath an overstorey of oak (taken in 1973).

Biological characteristics and restoration

During the period when the use of western hemlock was expanding, several of its biological characteristics were found to have potential silvicultural value. These included:

- shade tolerance, which would enable its establishment beneath a tree canopy;
- rapid growth and ability to cast dense shade that could reduce the need for vegetation management;
- good seed-producing capacity and ease with which it regenerates.

Fifty years ago these were regarded as beneficial as they would aid the establishment, management and perpetuation of the crop, and be especially attractive when converting unproductive/derelict broadleaved woodland to conifer plantation. At the present time these attributes are likely to be viewed as being unfavourable for the Planted Ancient Woodland Sites on which the species occurs, for example the intense shade produced has adverse effects on the ground flora and the species often regenerates freely in surrounding areas of woodland. Consequently stands of western hemlock are often important targets when considering restoration of PAWS to broadleaved woodland (Figure 3).

Figure 3 The western hemlock canopy creates deeply shaded conditions and the forest floor typically comprises leaf litter with only a sparse ground flora.

Table 1 Number of sites with saplings and seedlings of each species, and the frequency with which they occurred.

Species	Sites		Frequency	
	Saplings	Seedlings	Saplings	Seedlings
Native				
Ash[a]	-	16	-	22
Beech[a]	1	12	<1	10
Birch	9	20	9	39
Blackthorn	-	1	-	<1
Field maple	3	2	<1	<1
Hawthorn	3	4	<1	<1
Hazel	8	9	2	3
Hornbeam	1	4	<1	2
Oak[a]	-	17	-	17
Poplar[b]	4	5	<1	1
Rowan	-	3	-	<1
Sweet chestnut[a]	-	4	-	<1
Sycamore[a]	2	7	<1	2
Wild cherry[a]	-	1	-	<1
Willow	4	9	<1	2
Yew[a]	-	4	-	<1
Non-native				
Douglas fir	-	1	-	<1
Fir	-	3	-	<1
Lawson's cypress	-	1	-	<1
Pine	-	5	-	2
Western hemlock	9	17	3	16

Frequency = percentage of total sample quadrats observed on which the species occurred; *Castanea sativa* and *Acer pseudoplatanus* are considered to be native; a = timber species; b = includes aspen; as the sites surveyed were outside of the natural range of *Pinus sylvestris* it is not considered to be native.

Native species

Most sites had saplings of some native species, but the total number only exceeded 1000 ha^{-1} at six sites and only three sites had any saplings of timber producing species (Table 2).

Seedling numbers were usually much greater than those for saplings, but the predominant species on many sites was birch. The number of seedlings of timber species was almost always lower than the total for all species. For both saplings and seedlings the differences between numbers of timber and all species was due to the large numbers of regenerating birch. (Figure 4)

Removal of western hemlock increased the amount of birch and reduced the amount of western hemlock, but had no effect on ash, beech or oak seedling numbers (Figure 5).

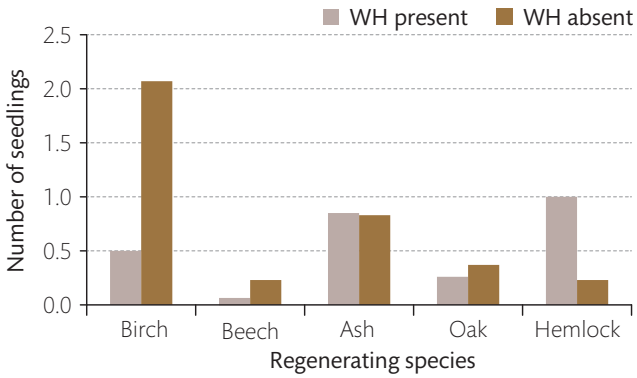
Table 2 Estimated numbers (ha^{-1}) of saplings or seedlings of native species present on a site and the percentage of the area stocked.

	Saplings		Seedlings		% stocked	
	Timber	All spp.	Timber	All spp.	Timber	All spp.
Western hemlock felled						
Bushey leaze	0	0	12 206	12 206	6	6
Bushey leaze	60	119	6 369	10 060	7	10
West Wood	200	250	5 650	5 800	24	26
Chiddingfold	0	345	4 655	15 862	0	45
Shabbington	0	259	5 000	16 293	3	7
Whitley Block	0	13 158	658	7 105	0	79
Chiddingfold	0	76	1 288	4 545	0	6
Micheldever	0	0	1 146	1 771	0	0
West Walk	0	5 583	2 750	7 667	0	60
Ampfield	0	50	1 150	11 950	4	40
Ampfield	0	5 786	929	9 000	0	63
Micheldever	0	0	1 100	12 600	0	72
Whitley Block	0	6 000	417	13 917	0	93
Western hemlock standing						
Home Hut	0	66	1 974	6 382	3	11
Stoke Park	0	0	3 000	3 571	6	9
Ampfield	0	147	6 912	9 779	0	6
Ranmore	71	143	2 000	3 071	3	6
Chiddingfold	0	1 121	10 517	14 052	0	34
Chiddingfold	0	1 310	4 762	7 857	0	43
Alice Holt	0	147	1 397	4 265	3	9
Redlands	0	0	83	167	0	0

All spp. = total number of seedlings of all species.
= removal of all western hemlock from mixtures but with broadleaves remaining.
= clearfelled sites that had been pure western hemlock.
= no recent felling of western hemlock.

Figure 4 A dense area of birch regeneration has developed in the five years since the western hemlock was clearfelled from this site. Broom, gorse, bracken, grasses and herbs typical of acidic soils have established, but despite the presence of some parent trees on and around the site few oak seedlings are developing.

Figure 5 Mean number of seedlings in each 2 × 2 m quadrat on sites with or without western hemlock.



Non-native species

The non-native saplings present were all western hemlock and there were often more western hemlock saplings than those of native species. In contrast to saplings there were always fewer seedlings of non-native species than there were of native species (Figure 6).

Figure 6 Following removal of underplanted western hemlock a dense ground flora has developed beneath this 80-year-old stand of oak which also has saplings of western hemlock developing in the understorey.

Proportion of each site stocked

Estimates of stocking were calculated separately for timber, native and non-native species. For any site the percentage stocked was equivalent to the percentage of stocked 2 × 2 m quadrats. A stocked quadrat was defined using the following criteria:

(a) 1 sapling/quadrat;
(b) either two seedlings where the median height of seedlings was ≥100 cm or four seedlings where the median seedling height was ≥36 cm.

Most sites were at least partly stocked with native species, but this was frequently ≤20% of the area and exceeded 50% on only five sites. Fewer than half of the sites had any of their area stocked with timber species and for all except West Wood it was <10% of the site's area (Table 2). Overall the percentage of a site's area stocked with non-native species was less than that for native species and for most sites was ≤10%.

A general survey method to determine the proportion of a site which is stocked is described in Box 2.

Relationships between tree seedlings and site characteristics

Relationships between site characteristics and the presence and abundance of seedling regeneration were investigated separately for ash, beech, birch, oak and western hemlock. Although the range of significant factors varied with species there were some obvious trends:

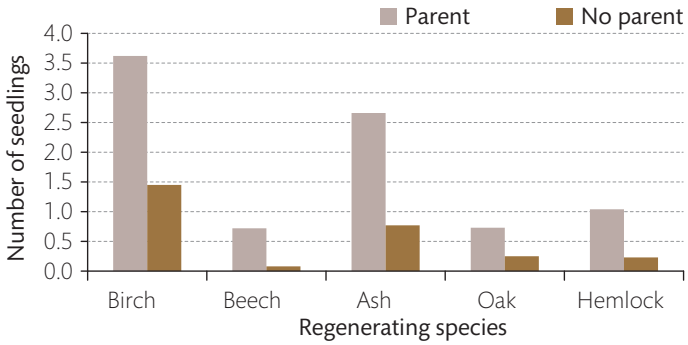
- The presence of a parent within *c.* 15 m was significant and positive for all species which indicates that nearby parent trees are an important influence on regeneration. Mean seedling numbers were between 2– and 20–fold greater when parent trees were within the 30 × 30 m area surrounding the quadrat (Figure 7).

- The amount of canopy cover was a significant factor but with varying effect. It had an adverse effect on the number of birch seedlings which may be related to birch's light demanding nature. Conversely it had a positive on ash and beech which may be due to their ability to withstand shade.

- The effect of bramble cover was generally negative indicating that it has an adverse effect on seedling number.

- Overall bramble, bracken and grass had little effect on the presence of seedlings but affected their numbers.

Figure 7 Mean number of seedlings in 2 × 2 m quadrats with or without parent trees in the 30 × 30 m plot.



Box 2 – Method for estimating proportion of a site that is stocked with naturally regenerating trees

Natural regeneration is an unpredictable process with new trees often being patchily distributed in clumps of variable density and estimation of stocking can be difficult. Examination of the survey results indicated that the data had a binomial distribution and that standard binomial sample sizes can be used to determine the number of samples needed to estimate the proportion of a site that is stocked.

Before carrying out the field survey at any site two factors need to be decided:

1. Size of the temporary sample plots that will be used. These must be constant within a site and for ease of assessment their size should be in the range 2 × 2 m to 4 × 4 m. They are temporary and do not need to be marked, but can be estimated visually.
2. The criteria that determine whether or not a plot is stocked need to be fixed. These criteria may vary with plot size, site, species and objectives, examples of possible criteria include:
   - the presence of one sapling in a 2 × 2 m plot;
   - 10 unbrowsed seedlings greater than 80 cm tall in a 3 × 3 m plot;
   - 60 of seedlings more than 1-year-old that are taller than 20 cm in a 4 × 4 plot;
   - four oak saplings present in a 4 × 4 plot.

A wide variety of other criteria are possible and they may depend on local experience and forestry knowledge.

The sample plots must be distributed across the site. This is probably simplest to achieve using the systematic method described by Kerr *et al.* (2002) in which plots are placed on transects distributed evenly across the site.

The method assumes that the percentage of a site stocked is one of three levels 70, 80 or 90% and in order to assess whether this has been achieved use the following procedure:

1. Decide the percentage stocking required.
2. Choose the number of plots that need to be assessed from Table 3.
3. Make a systematic survey of the site counting the number of plots that are stocked according to the criteria identified.
4. Determine whether the site is stocked by comparing the number of plots counted as stocked with the numbers in Table 3.
5. Resample sites where the number of stocked plots falls within the uncertain category. To do this survey another set of plots and add the number of stocked plots to that found in the first survey to create a combined total of stocked plots. Then compare the total number of stocked plots with those for the **resampled site** in Table 3.
6. When resampling a site, either place the additional plots on the same transects between the plots initially assessed, or assess plots on new transects placed between the original transects.
7. After resampling some of the sites may have an **intermediate** number of plots stocked and a decision on whether these sites have a sufficient area stocked should be made on the basis of experience gained after surveying the site and forestry knowledge.

As an example, for 80% stocking a sample size of 30 plots is taken for the first survey. If 25 or more of the plots are stocked according to the criteria chosen then it can be assumed that the site is stocked. If 19 or fewer plots are counted as stocked then it can be concluded that less than 80% of the site is stocked. If there are 20 to 24 plots stocked then the result is uncertain and a second sample of 30 plots should be assessed.

Table 3 Number of plots to assess to determine whether a site is stocked.

		Assessment of first survey			Assessment of resampled sites			
% of site stocked	Number of plots	Stocked	Uncertain	Not stocked	Total sample size	Stocked	Intermediate	Not stocked
70	35	≥26	20–25	≤19	70	≥49	43–48	≤42
80	30	≥25	20–24	≤19	60	≥48	43–47	≤42
90	25	≥23	20–22	≤19	50	≥45	42–44	≤41

% of site stocked = desired level of stocking; **Number of plots** = number of plots that must be assessed; **Stocked** = the number of individual plots which are stocked that indicates that the percentage stocking is achieved; **Not stocked** = the number of individual plots which are stocked that indicates that the percentage stocking is not achieved; **Uncertain** = the number of plots stocked which indicate resampling is necessary; **Intermediate** = the site managers experience will be necessary to decide whether the site is adequately stocked.

Conclusions

Use of natural regeneration may be inappropriate for restocking sites where there are few parent trees of the species desired, especially if these are not well distributed across the site or produce heavy seeds with poor long-distance dispersal.

Although there were more than 10 000 seedlings ha^{-1} of native species at some sites they were usually small; birch was the most common species with other desirable timber species being much less abundant. The number of saplings was usually lower than that for seedlings, with saplings of timber species being absent at most sites. Few sites had more than half of their area restocked with native species and estimates of the area stocked with timber species were very low. However, the area judged to be restocked is likely to be an underestimate at some sites due to the relatively short time since felling and the criteria used to define stocking.

At sites where western hemlock had not been felled there were greater numbers of western hemlock seedlings reflecting the reproductive potential of the species. This indicates that clearfelling is probably a good option for restoring western hemlock PAWS as it will reduce both the potential for the species to re-establish on and around the site, and the costs of remedial work to remove unwanted natural regeneration.

A simple systematic survey of a site which assesses small plots can be used to determine the proportion of an area that is stocked.

On felled sites where there are currently few seedlings or saplings, any further regeneration is likely to be severely hindered by competing vegetation unless further disturbance takes place. The interventions needed to promote further regeneration will vary with site, but are likely to include: ground preparation to create conditions suitable for germination and establishment; vegetation management to reduce the effects of competitive vegetation; and reduction of canopy cover to promote seedling growth.

Manipulation of site conditions may increase the total amount of natural regeneration present and the proportion of a site stocked, but it may have relatively little effect on the proportion stocked with desirable timber species. Beech and oak are masting species with heavy seed that does not disperse far and is a favoured food of small mammals. Similarly the wind-blown seed of ash are moderately heavy and disperse poorly relative to birch.

Most sites surveyed were inadequately stocked and had either insufficient natural regeneration or only small amounts of desirable timber species that were patchily distributed. If timber production is an important objective then choosing a suitable method of restocking that leads to successful establishment of a suitable crop is a critical management decision.

The use of natural regeneration for satisfactory restocking of PAWS with timber species such as oak and beech is likely to be unreliable especially when there are few good seed-producing parent trees remaining in the stand. Under these circumstances positive management action will probably be required to establish sufficient quantities of desirable timber species across the site. This could entail repeated interventions to try to stimulate further natural regeneration or the use of artificial means of establishment such as direct seeding or planting. However, if the timescale for establishment of such timber species is of low priority, then it is currently assumed that these species will arrive by natural processes but it may take many decades.

Whilst direct seeding has been used successfully to create new woodland on farmland (Willoughby, *et al*., 2004), further research is required to adapt the methods for use on restocking sites.

At present planting remains much the most reliable method of restocking to establish predictable amounts of any species and it is probably the most appropriate method if production of a final crop from a desirable timber species is a definite objective of management. It may not be necessary to plant the entire site at recommended densities (2500 stems ha^{-1}) and establishing small groups of trees at final crop spacing may be sufficient if natural regeneration of other species is present or will take place. However the trees are distributed, best practice (e.g. suitable planting stock, vegetation management, protection) must be followed to ensure that trees establish, especially where small groups are planted and a dense stand of birch or other fast growing species is likely to develop (Figure 8).

Figure 8 Regeneration at this site was initially sparse and consisted mainly of birch. After mulching to remove remaining brash, groups of species including oak, ash and cherry were planted to enrich natural regeneration.

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References

ALDHOUS, J.P. and LOW, A.J. (1974). *The potential of western hemlock, western red cedar, grand fir and noble fir in Britain*. Forestry Commission Bulletin 49. HMSO, London.

ANDERSON, M.L. (2002). *The selection of tree species* (2nd edition). Castlepoint Press, Dalbeattie.

ANON. (1952). *Census of woodlands 1947–1949*. HMSO, London.

BARNS, R.M. and HONKALA, B.H. (eds) (1990). *Silvics of North America volume 1: Conifers.* USDA, Washington.

EDLIN, H.L. (ed). (1964). *Forestry practice* (8th edition). Forestry Commission Handbook 6. HMSO, London.

HARMER, R., MORGAN, G. and BEAUCHAMP, K. (2011). Restocking with broadleaved species during the conversion of *Tsuga heterophylla* plantations to native broadleaved woodland using natural regeneration. *European Journal of Forest Research* 130, 161–171.

KERR, G, MASON B, BOSWELL R, POMMERENING A (2002). *Monitoring the transformation of even-aged stands to continuous cover management.* Forestry Commission Information Note (FCIN45). Forestry Commission, Edinburgh.

LINES, R. (1987). *Choice of seed origins for the main forest species in Britain*. Forestry Commission Bulletin 66. HMSO, London.

LOCKE, G.M.L. (1970). *Census of woodlands 1965–1967*. HMSO, London.

MACDONALD, J., WOOD, R.F., EDWARDS, M.V. and ALDHOUS, J.R. (1957). *Exotic forest trees in Great Britain.* Forestry Commission Bulletin 30. HMSO, London.

THOMPSON, R., HUMPHREY, J., HARMER, R. and FERRIS, R. (2003). *Restoration of native woodland on ancient woodland sites*. Forestry Commission Practice Guide. Forestry Commission, Edinburgh.

UKWAS (2006). *UK woodland assurance standard.* UKWAS.

WILLOUGHBY, I., JINKS, R., GOSLING, P. and KERR, G. (2004). *Creating new broadleaved woodland by direct seeding*. Forestry Commission Practice Guide. Forestry Commission, Edinburgh.

WOOD, R.F., MILLAR, A.D.S. and NIMMO, M. (1967). *Experiments on the rehabilitation of uneconomic broadleaved woodlands.* Forestry Commission Research and Development Paper 51. Forestry Commission, London.

WOODLAND TRUST (2006). *The conservation and restoration of plantations on ancient woodland sites*. Woodland Trust, Grantham.

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