The Role of True Fir Species in the Silviculture of British Forests: past, present and future

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Abstract

There are no true fir species (*Abies* spp.) native to the British Isles: the first to be introduced was *Abies alba* in the 1600s which was planted on some scale until the late 1800s when it proved vulnerable to an insect pest. Thereafter interest switched to North American species, particularly grand (*Abies grandis*) and noble (*Abies procera*) firs. Provenance tests were established for *A. alba*, *A. amabilis*, *A. grandis*, and *A. procera*. Other silver fir species were trialled in forest plots with varying success. Although species such as grand fir have proved highly productive on favourable sites, their initial slow growth on new planting sites and limited tolerance of the moist nutrient-poor soils characteristic of upland Britain restricted their use in the afforestation programmes of the last century. As a consequence, in 2010, there were about 8000 ha of *Abies* species in Britain, comprising less than one per cent of the forest area. Recent species trials have confirmed that best growth is on mineral soils and that, in open ground conditions, establishment takes longer than for other conifers. However, changes in forest policies increasingly favour the use of Continuous Cover Forestry and the shade tolerant nature of many fir species makes them candidates for use with selection or shelterwood silvicultural systems. Supporting evidence is provided by analysis of the regeneration in a long term study of transformation of first rotation conifer plantations. The need to adapt forests to climate change has identified some other silver fir species from southern Europe and Asia as having potential to help increase the resilience of British forests against the impacts of a warmer climate. This paper is the first review of experiments, operational experience with, and the potential role of silver firs in British forestry for more than 20 years. It suggests that previous reviews of the potential role of *Abies* species have been unduly pessimistic and that there should be an expanded place for silver fir species in British forestry in the future.

Keywords: *Abies*, Silviculture, Provenance, Continuous cover forestry, Climate change

Introduction

The four countries of the United Kingdom (England, Northern Ireland, Scotland and Wales) fall within the Atlantic zone of north-western Europe with a native woodland cover composed mainly of temperate broadleaved species (e.g. *Quercus* spp., *Fraxinus excelsior*, *Betula* spp.), although there are outliers of the boreal forests in the Scots pine (*Pinus sylvestris*) dominated areas of northern Scotland. Apart from Scots pine, no other European conifer of commercial importance (e.g. Norway spruce – *Picea abies*; European silver fir – *Abies alba*) is native to the British Isles. All four countries share a similar history of centuries of deforestation and unsustainable forest management (e.g. Smout, 2003) so that at the beginning of the twentieth century forest cover was very low, being less than five per cent in Great Britain (Forestry Commission, 2011a). However, by the early years of the seventeenth century, there was increasing interest in the creation of woods and forests to improve the landscape and provide domestic supplies of timber (House and Dingwall, 2003). This interest included the trialling of species that were not native to the British Isles and which were introduced from continental Europe, from North America or from other parts of the world. The early years of the last century saw the start of concerted attempts to restore forest cover through afforestation of marginal agricultural lands. The expansion of the forest area has continued until the present day so that the forest area of the United Kingdom now amounts just over three million hectares or 13 per cent of the land area (Forestry Commission, 2011a). The primary aim of the early decades of the afforestation programme was to produce a timber resource for industrial purposes and the programme was based on the use of fast growing and mostly non-native conifer species which could tolerate the exposed sites and impoverished soils where planting was concentrated. The result has been the transformation of the

British forest resource from broadleaves to conifers in around 50 years (Mason, 2007). Thus the non-native conifer Sitka spruce (*Picea sitchensis*) is now the major tree species in Britain, particularly in Scotland, and accounts for a substantial proportion of the domestic timber supply.

The most authoritative account of the species trialling in the early decades of the afforestation programme was provided by MacDonald et al. (1957) who proposed that an introduced tree species has to go through three stages before it can recommended for widespread operational use in forestry. These stages are, in turn: the planting of a candidate species as individual trees in arboreta and parks where the specimens can be given careful attention; the establishment of small plots of more promising species in forest gardens where comparative performance can be evaluated; and finally the creation of trial plantations of the best species on a wider range of sites to determine performance under more testing conditions. Amongst the genera covered in that review was the *Abies* genus where the performance of 34 members of the genus was discussed with three (European silver fir - *A. alba*, grand fir - *A. grandis*, and noble fir - *A. procera*) being considered of silvicultural importance for British forestry while four more (*A. amabilis*, *A. concolor*, *A. nordmanniana*, and *A. veitchii*) were thought to have commercial potential (MacDonald et al., 1957). They considered European silver fir to be 'an example of an exotic [species] of some importance in its day which is no longer planted' due to the serious damage caused by the aphid *Adelges nordmannianae*. However, the high productivity of grand fir was felt likely to encourage the use of this species on better quality sites while noble fir's tolerance of exposure would find it a place in the silviculture of upland regions of Britain.

These findings resulted in an increase in the planting of grand and noble fir so that by the mid 1960s there were over 4000 ha of these species in British forests (Aldhous and Low, 1974). Therefore, a further review of these operational trials was carried out to compare the performance of and financial return from plantations of grand and noble fir (also western red cedar - *Thuja plicata*, and western hemlock - *Tsuga heterophylla*) with more widely used species such as Sitka spruce and Douglas fir (*Pseudotsuga menziesii*) (Aldhous and Low, 1974). The results suggested that both *Abies* species, but particularly grand fir would grow as fast as or faster than Sitka spruce, especially on more fertile and sheltered sites in western Britain. Grand fir was found to be the fastest growing commercial conifer in the British Isles with an estimated productivity of 32 m^3 ha^{-1} yr^{-1} on favoured sites (Aldhous and Low, 1974; Table 1). However, these benefits were offset by concerns over higher establishment costs because of slow initial height growth and over the relatively low density of the timber of both species, which was compounded by a comparatively high incidence of drought cracks.

Partly as a consequence of these concerns and also because of the increasing availability of genetically improved strains of Sitka spruce (Lee and Matthews, 2004), interest in the use of *Abies* species in British forestry has remained at a relatively low level since the 1970s. This is despite information becoming available (Lines, 1979) to suggest that correct provenance choice could speed up early height growth and so reduce establishment costs, while Kerr (1999) argued that using European silver fir as a shade tolerant component of mixed species stands should reduce the risks of damage to this species from *Adelges nordmannianae*. More recently, there has been interest in increasing tree species diversity as part of a strategy of adapting forests to projected climate change (Read et al., 2009). Thus a number of *Abies* species (*A. alba*, *A. amabilis*, *A. borisii-regis*, *A. bornmuelleriana*, *A. cephalonica*, *A. cilicica* and *A. nordmanniana*) have been specifically mentioned as having a potential role in an adaptation strategy for British forests (Read et al., 2009; Tables 6.5 and 9.1). There is also greater recognition of the potential role of a wider range of alternative silvicultural systems to clear felling in support of multifunctional forestry (Mason, 2007). These trends have resulted in increasing interest in the potential role of *Abies* species as a component of the future forests in

Britain (Wilson, 2011). However, much of the information to support the case for an increased use of *Abies* species in British forestry is scattered and anecdotal: the purpose of this short review is to try to bring together some of the key experimental evidence and to suggest areas where further research or information is needed.

Materials and Methods

Information on the current area of Abies species within British forests was obtained from the 2010 National Forest Inventory for Great Britain (Forestry Commission 2011b). The data were searched to distinguish between grand fir, noble fir, European silver fir, and all other *Abies* species.

The history of a range of *Abies* species in British forestry was derived from a variety of sources. The date of introduction of a particular species into Britain and its current distribution in parks and arboreta was based upon accounts in Mitchell (1972), supplemented by personal knowledge where appropriate. Performance in Forestry Commission arboreta was based upon reports by Danby and Mason (1998) and Mason et al. (1999) supplemented by other information in Forest Research files. Information on the extent of experimental trials with *Abies* species was derived from Forest Research experimental databases (Mason et al., 2008) while details of provenance trials were found in Lines (1979 and 1987) and in Samuel (1996).

Since much of the conclusions of previous reviews (e.g. MacDonald et al., 1957; Aldhous and Low, 1974) on the comparative performance of *Abies* species were based on plots that were established in the first half of the last century, summary data were extracted from a younger series of species trials established in the 1980s on five sites in northern England and Scotland. These trials were located in Kielder (55^0 11'N, 3^0 3'W; peaty gley soil; second rotation site), Nithsdale (54^0 58'N, 3^0 41'W; surface water gley; first rotation site), Inverliever (56^0 11'N, 5^0 23'W; upland brown earth; first rotation site), Speymouth (57^0 35'N, 3^0 10' W; ironpan soil; second rotation site) and Shin (58^0 2'N, 4^0 56'W; deep peat; first rotation site) forests. Each experiment contained between 9 and 14 different species and species mixture combinations in a randomised block design with three replicates of each treatment and a plot size of 0.05 ha. Treatments were planted in a deer fenced enclosure at 2 m spacing after standard site cultivation for the particular soil type. Sitka spruce, grand fir, noble fir and Pacific silver fir (*Abies amabilis*) were common to all experiments while information on the performance of Scots pine and Norway spruce (*Picea abies*) was also extracted to provide further indication of comparative growth. Information on height growth after 10 years (i.e. the completion of the establishment phase) was available from all experiments together with subsequent growth data for four of the five sites. Analysis of the data followed standard analysis of variance procedures. The comparison between treatments covers all the species planted in these experiments and not just the *Abies* and standard species that are discussed in this paper.

There is comparatively little information on or experience with the performance of *Abies* species as a component of alternative silvicultural systems within British forests. However, some guidance can be gained from an experiment undertaken to monitor the effect of enrichment planting with 25 different species to increase the productivity of a first rotation stand of Scots pine. These included a number of *Abies* species (*A. grandis*, *A. procera*, *A. concolor*, *A. nordmanniana*, and *A. veitchii*). Part of this site has been thinned since 1996 under a Continuous Cover Forestry (CCF) approach to explore aspects of transforming even-aged stands to an irregular structure while an adjoining control area has remained unthinned (Mason, 2006). This experiment is located in Wykeham forest in north England (54^0 15'N, 0^0 35'W) on an ironpan soil with a 'poor' soil nutrient regime and 'slightly dry' soil moisture status (terminology follows Pyatt et al., 2001). A full history of the experiment and details of assessments up to 2001 can be found in Mason (2006) while a further assessment of tree growth, stand structure and regeneration was carried out in autumn 2006. a number of operational trials of irregular silviculture were established in the 1950's as part of an attempt to transform first rotation plantations to more varied structures (Anderson, 1960) and summary reports from some of these trials are now becoming available (Kerr et al., 2010). In addition,

Results

The area of British forests made up of *Abies* species was slightly more than 8,000 ha in 2010 (Table 1) which represents a two fold increase from the time of the last British review of the genus (Aldhous and Low, 1974) which used data collected at the time of the 1965 census of woodlands (the precursor to the current National Forest Inventory). This represents about 0.3 per cent of the British forest area which is about the same as at the time of the 1965 census. Grand fir (62 per cent) and noble fir (36 per cent) are by far the largest components of the resource with European silver fir representing a small proportion. Noble fir is mainly found in Scotland and Wales whereas grand fir is present in all three countries. The relatively small area of European silver fir is mainly confined to Scotland. Most of the resource is in private sector woodlands, although in Wales there is a comparatively even split between private and public forests. The age class distribution (data not shown) suggests that there has been a decline in the planting of *Abies* species since the beginning of the 1980s.

A large number of species in the *Abies* genus have been planted in Britain (Appendix 1), but there has been greater emphasis upon the species from western Northern America than upon those from eastern Asia, southern Europe, or Mexico and Central America. The earliest introduction was of *Abies alba* in 1603, but most species were introduced in 1800s and early 1900s. While most species are represented tree collections and in the Forestry Commission's main arboreta, the experimental trials are dominated by grand and noble firs which respectively comprise 34 and 30 per cent of the experiments with this genus. Otherwise, only European silver fir (eight per cent), Pacific silver fir (seven per cent) and *Abies concolor* (five per cent) make up a substantial proportion of these experiments. The remainder of the experiments contain 10 other species, namely *A. balsamea*, *A. cephalonica*, *A. delavayi*, *A. firma*, *A. homolepis*, *A. lasiocarpa*, *A. lowiana*, *A. magnifica*, *A. nordmanniana*, and *A. veitchii*. Comprehensive provenance trials have only been carried out for four of the species which are grand fir, noble fir, European silver fir, and Pacific silver fir. There are estimates of productivity available for 14 different species. Grand fir and noble fir have proved the most productive of the species trialled, but individual plots of Pacific silver fir, *A. lowiana*, and European silver fir have all shown good productivity.

After ten years growth in five experiments in northern Britain, the three *Abies* species trialled were appreciably smaller than Sitka spruce at four out of the five sites (Table 2). These differences were either highly or very highly significant. The only exception was at the Speymouth site where competition from heather (*Calluna vulgaris*) affected the growth of all species and there was little difference between the various treatments. Subsequent development in the experiments appeared to depend upon soil moisture and site fertility. Thus at the most fertile site in Inverliever, with a 'fresh' soil moisture status (after Pyatt et al., 2001), basal area growth of the three *Abies* species was comparable to or better than that of Sitka spruce after 22 years. By contrast, on a very moist and nutrient poor soil at Kielder, basal area production was a third or less than that found in Sitka spruce. Similarly, on a wet and very poor fertility soil at Shin, height growth continued to be much poorer than was found for the spruce. After 25 years at Speymouth, on a slightly dry although nutrient poor soil, the performance of grand fir was notably better than that of Sitka spruce, that of noble fir was similar to the spruce, while Pacific silver fir was less productive.

In the Wykeham experiment, ten years after the start of the transformation process, the *Abies* species provided about 20 per cent of the basal area in both treatments (Table 3). Apart from noble fir, only grand fir and *Abies veitchii* have successfully contributed to the development of the enriched Scots pine stand. Noble fir provided the largest diameter (67 cm dbh) and tallest (30.7 m) trees in the experiment. The natural regeneration cohort was dominated by *Abies* species which were 65 per cent of seedlings and saplings in the thinned plot and 97 per cent in the unthinned plot. In the thinned plot both seedlings and saplings were present in nearly equal proportions and *Abies* species comprised over 60 per cent in each category. By contrast, in the unthinned plot, hardly any saplings were present.

Discussion

The last four decades have seen an increase in the absolute area of British forests comprised of *Abies* species but the relative area has not increased. Indeed, the apparent reduction in planting of species like grand and noble fir in the last two decades suggests that the proportion of *Abies* in British forests may decline in the current century if measures are not taken to increase the rate of planting and promote the use of regeneration where it occurs. This is despite the evidence that species of this genus are amongst the most productive conifers that can be grown in Britain (Aldhous and Low, 1974), evidence which is supported by the fact that the tallest tree (64.28 m) in the British Isles is a grand fir growing in Argyll in western Scotland. The reasons for this potential decline are probably driven by three main features, first the limited tolerance for the moister, poorly drained soils which have been typical afforestation sites in recent decades, second the relatively slow growth in the establishment phase and hence higher establishment costs than for other species like Sitka spruce and Scots pine, and third concerns over the quality of the timber produced especially in relation to drought crack and failure due to brittleness (Aldhous and Low, 1974; Wilson, 2011).

The first two of these concerns are largely supported by the results from the recent species trials reported in Table 2. Thus on the better drained soils at Inverliever and Speymouth, growth of both grand and noble fir was comparable to or better than Sitka spruce 20-25 years after planting. By comparison, on wetter soils at Kielder and Shin, even after intensive site drainage, growth was generally much poorer than for Sitka spruce. These results suggest that the classification of species suitability by soil moisture regime in the Ecological Site Classification (ESC) system (Pyatt et al., 2001; Figure 13) may be overoptimistic when it suggests that soils in the 'wet' soil moisture regime (e.g. better drained peaty gleys and peats) may be suitable for grand fir and Pacific silver fir. It appears that the maximum wetness that these species are predicted to tolerate should be limited to the 'very moist' category which is similar to noble fir. Similarly, it is possible that the drier limit of all three species can be extended into the 'slightly dry' soil moisture regime, particularly if the species were to be planted in mixture and subject to regular thinning so that growing season demands upon available soil moisture were limited.

Despite the 1980s trials using the best available provenances of grand, noble and Pacific silver fir, early growth in the trials was less than that for Sitka spruce on most of the sites. The differences were generally between 1-2 m which represents around 2-3 years delay in growth for most sites in upland Britain. These differences are similar to those which were reported by Aldhous and Low (1974; Table 8). Given that these newer experiments were established under research conditions with regular maintenance and protection against browsing from deer, it is possible that these results underestimate the growth differences that might occur in operational practice. Such effects might also occur because of the apparent greater sensitivity of some Abies species such as noble fir to root desiccation and weed competition after planting (e.g. McKay et al., 1997). The results from the Speymouth experiment are the only ones where early growth of the Abies species is similar to that of Sitka spruce, but performance on this site is confounded by the effects of heather competition. Taken overall, the safest finding continues to be that the establishment phase of *Abies* species is likely to be longer, and potentially more expensive, than that of standard conifer species grown in Britain when planted or regenerated under open conditions, whether in afforestation or after restocking.

Aldhous and Low (1974) concluded that concerns over the timber qualities of grand

and noble fir, coupled with the relatively small areas planted meant that these species were unlikely to be important components of the future forest estate in Britain, despite their high productivity on better sites. There have been no systematic studies of the timber properties of any *Abies* species in Britain since their review, but Wilson (2011) has summarised anecdotal evidence from growers in various parts of Britain who have marketed timber from mature silver fir stands. These findings suggest that small dimension roundwood can be placed in similar pulp and industrial markets as spruce and Douglas fir. Larger dimension material can be more problematic, partly because of the poor load bearing ability of grand fir timber. However, for both grand and noble fir, there is evidence of local speciality markets being identified which allow growers to market large dimension timbers satisfactorily. A new study on the timber properties of several 'minor' conifer species including noble fir may add further information in due course (pers. comm., Elspeth Macdonald, Forest Research).

Although concerns over establishment success and costs cast doubt on the potential role of *Abies* species in the conventional patch clear felling systems currently used in much of British conifer forests (Mason, 2007), it is likely that the increased role proposed for CCF in new policy documents (e.g. Forestry Commission Scotland, 2006; Forestry Commission, Wales, 2009) should result in a potentially expanded role for species in this genus. This is because the move to implement CCF through the greater use of shelterwood or selection systems will rely on natural regeneration in small gaps or under a canopy, where the shade tolerant properties of many *Abies* species may prove advantageous (e.g. Kerr, 1999; Malcolm et al., 2001; Wilson, 2007). The potential ability of silver fir species to regenerate under such conditions is shown by their domination of the regeneration cohort in the Wykeham experiment reported above while other British examples of grand, noble and European silver fir regeneration were cited by Hart (1995). However, the palatability of *Abies* species to deer browsing is a factor which may limit the potential recruitment of natural regeneration of these species into the canopy. Thus in the long running transformation trial at Glentress (Kerr et al., 2010), the original aim of establishing European silver fir as a component of the transformed forest proved impossible because of pressure from deer and sheep browsing. Partly as a result, after 40 years, Abies species remain only a small proportion of the growing stock.

A question that is related to the potential increased role for *Abies* species as part of CCF management is whether trees of this genus may be more resistant to wind damage. European silver fir has a reputation for being less vulnerable to storm damage (Collin et al., 2009) than other conifers including spruces. Aldhous and Low (1974) reported no evidence that grand or noble fir were more resistant to overturning than Sitka spruce and this subject has not received much attention in recent times in British silvicultural thinking. However, a recent reanalysis of extensive British tree pulling data by Nicoll et al. (2006) revealed that, both on freely draining and gleyed mineral soils, grand fir had significantly better anchorage than Sitka spruce ($p<0.001$ and <0.05) respectively. However, on peaty mineral soils the anchorage of grand fir was poorer than for Sitka spruce ($p<0.001$). The few comparisons between noble fir and Sitka spruce showed no significant difference in anchorage. While the practical implication of these results still requires further analysis, they are at least indicative of the possibility that, on mineral soils in Britain, developing mixed species stands with a significant silver fir component may be a way of increasing the stability of CCF stands against windthrow.

Given that seven *Abies* species (see introduction) were cited by Read et al. (2009) as potentially contributing to a climate change adaptation strategy for British forests, it is pertinent to ask whether there is adequate experimental or other trial information to advise on wider deployment of these species at the present time. Unfortunately, examination of Appendix 1 suggests that, with the partial exception of *Abies alba* and *A. amabilis*, experimental data on the other species which come from south-eastern Europe and Asia Minor are lacking. Even for *A. cephalonica* and *A. nordmanniana* which have been planted in a few experiments and trials, the seed sources used were often not from the native range. For instance, the plot of *A. cephalonica* at Kilmun was derived from a older stand in northern Scotland (Mason et al., 1999) while another stand of the same species at Brechfa probably obtained from the same source shows some trees of distinctly different habit (WLM, pers.obs.). Therefore, there appears to be a pressing need to establish new trials of these species in sites where their potential contribution to an active adaptation strategy can be thoroughly tested.

In summary, at the present time, we have good to adequate data on the silvics, growth potential and provenance choice for four species in the *Abies* genus, namely grand fir, noble fir, European silver fir, and Pacific silver fir. The information available suggests that the main future role of these four species should be as a component of the implementation of CCF on suitable soils throughout Britain. These species could be introduced through under planting where no suitable seed sources are available. The potential benefits to stand stability from incorporating these species into CCF stands need further investigation. The only additional role may be for the use of noble fir as a component of planting on freely drained mineral soils in upland Britain, because of its capability of withstanding wind exposure (Aldhous and Low, 1974; Wilson, 2011). There is clearly the possibility of using a wider range of silver fir species in British forests, but at present we lack the experimental evidence to suggest where and how these species might best be deployed. Nevertheless, it seems clear that the rather pessimistic conclusions of Aldhous and Low (1974) about the potential importance of grand and noble fir, and by implication other silver firs, in British forestry need to be discarded. On the right sites and with appropriate silviculture, these species can make an important contribution to the future diversification of British forests to meet policy objectives and increase resilience to climate change.

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Table 1. Area (ha) of the main *Abies* species grown in British forests in 2010 by country and the proportion in private forests

Country	Species				Total	Percentage in private forests
	Grand fir	Noble fir	European silver fir	Other silver firs		
England	1674	443	55	18	1866	71
Scotland	2597	1756	334	23	4709	80
Wales	936	810	13	16	1775	46
Great Britain	5207	3008	402	57	8350	71

Notes:

1. Data sources are the 2010 National Forest Inventory for private forests and the sub-compartment database of the Forestry Commission for public forests.
2. Figures may not add up because of rounding errors.
3. Other silver firs are not identified separately in the inventory data.

Table 2. Comparative height at 10 years and other early growth parameters (generally expressed as a percentage of Sitka spruce) of three *Abies* and three standard species in 5 species experiments in northern Britain

Site	Kielder		Inverliever		Speymouth		Shin		Nithsdale
Species	Height (m)	Percentage basal area (m^2 ha^{-1}) @ 15 years	Height (m)	Percentage basal area (m^2 ha^{-1}) @ 22 years	Height (m)	Percentage basal area (m^2 ha^{-1}) @ 25 years	Height (m)	Height (m) @ 15 years	Height (m)
Sitka spruce	4.4	100	5.7	100	3.1	100	2.6	3.8	5.6
Scots pine	4.1	87	-	-	2.9	125	1.4	3.0	4.4
Norway spruce	2.5	43	3.4	73	-	-	-	-	3.1
Grand fir	1.9	27	3.9	99	3.3	138	0.9	1.4	2.1
Noble fir	1.4	31	3.1	120	2.8	99	1.4	2.4	2.7
Pacific silver fir	1.8	34	3.3	92	3.2	78	0.9	1.2	3.1
Significance	P<0.001	P<0.001	P<0.01	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001	P<0.001
5% LSD	0.8	-	1.6	-	0.6	-	0.5	0.7	1.0

Table 3. Development of over ten years of the thinned and unthinned plots in the Continuous Cover Forestry trial at Wykeham forest, north England (see text and Mason (2006) for more details)

Species group	Basal area (m^2 ha^{-1})						Natural regeneration 2006 (numbers ha^{-1}) [2]	
	Thinned area			Unthinned control [1]			Thinned	Unthinned
	1996	2001	2006	1996	2001	2006		
Scots pine	17.6	11.9	11.7	14.7	15.5	26.4	-	-
Larches	4.1	5.1	5.7	8.4	9.0	6.3	157	-
Noble fir	2.6	3.7	3.4	6.0	8.1	7.6	6076	13804
Other firs [5]	3.4	3.6	4.2	3.2	3.7	1.9		
Other conifers [3]	2.9	3.3	4.7	7.7	9.5	3.9	2234	232
Beech	1.1	1.3	1.7	0.8	1.1	1.8	-	-
Other broadleaves [4]	2.6	3.0	3.5	0.7	0.9	1.0	860	232
Total	34.3	31.9	34.9	41.5	47.8	48.9	9327	14268

Notes:

1. The size of the unthinned plot was doubled in size between 2001 and 2006 which explains apparent changes in species proportions.
2. These data are for seedlings (< 1.3 m tall) and saplings (> 1.3 m tall, < 7 cm dbh) combined. Because of the difficulty of distinguishing between regeneration of *Abies* species, these have been classed as one species.
3. Other conifers are: *Picea orientalis*, *Cryptomeria japonica*, *Picea omorika*, *Tsuga heterophylla*, *Thuja plicata* and *Pseudotsuga menziesii*.
4. Other broadleaves are: *Betula pendula*, *Betula lutea*, *Alnus rubra*, *Quercus petraea*, *Quercus rubra*, *Sorbus aucuparia*, and *Ilex aquifolium*.
5. Other firs are *Abies grandis* and *A. veitchii*.

Appendix 1. A summary of the status of experimental knowledge on the performance of *Abies* species in Great Britain

Species	Date of first introduction into Britain	Cultivation status [1]	Percentage representation in main Forestry Commission arboreta [2]	Number of species trials [3]	Provenance trials	Recorded growth performance (m^3 ha^{-1} yr^{-1})
Abies alba Mill.	1603	Common	75	42	Yes	18[4]
Abies amabilis Douglas ex Forbes	1830	Infrequent	100	36	Yes	24[4]
Abies balsamea (L.) Mill.	1695 or earlier	Very rare	75	7	No	
Abies borisii-regis Mattf.	1883	Rare	-	-	No	
Abies bornmuelleriana Mattf.	Unknown	Very rare	25	-	No	
Abies bracteata (D. Don) Poit.	1852	Infrequent	50	-	No	
Abies cephalonica Loudon	1824	Uncommon	100	9	No	16[4]
Abies chensiensis Tiegh.	1907	Very rare	25	-	No	
Abies cilicica (Antoine & Kotschy) Carriere	1855	Rare	50	-	No	
Abies concolor (Gordon & Glend.) Lindl. ex Hildebr.	1873	Infrequent	100	26	No	
Abies delavayi Franch.	1901	Widely distributed	100	5	No	
Abies densa Griff.	1822?	NA	50	-	No	
Abies fabri (Mast.) Craib	1901	Rare	50	-	No	
Abies fargesii Franch.	1907	Rare	-	-	No	
Abies fargesii var. *faxoniana* (Rehder & E. H. Wilson) Tang S. Liu	1910	Rare	25	-	No	
Abies fargesii var. *sutchuenensis* Franch.	1911	Rare	-	-	No	
Abies firma Siebold & Zucc.	1861	Very rare	75	8	No	
Abies forrestii Coltm.-Rog.	1910	Rare	75	-	No	
Abies forrestii var. *georgei* (Orr) Farjon	1923	Rare	25	-	No	
Abies fraseri (Pursh) Poir.	1871	Very rare	100	-	No	16[4]
Abies grandis (Douglas ex D. Don) Lindl.	1831	Common	100	179	Yes	Up to 32[5]
Abies guatemalensis Rehder	unknown	NA	25	-	No	
Abies holophylla Maxim.	1904	Rare	50	-	No	
Abies homolepis Siebold & Zucc.	1861	Uncommon	100	5	No	14[6]
Abies kawakamii (Hayata) T. Ito	1919	Very rare	25	-	No	
Abies koreana E. H. Wilson	1913	Frequent	100	-	No	
Abies lasiocarpa (Hook.) Nutt.	1863	Very rare	100	5	No	14[4]
Abies lasiocarpa var. *arizonica* (Merriam) Lemmon	1860s	Very rare	75	-	No	8[4]
Abies lowiana (Gordon) A. Murray	1851	Uncommon	100	16	No	22[4]
Abies magnifica A. Murray	1851	Uncommon	75	7	No	
Abies mariesii Mast.	1879	Rare	50	-	No	
Abies nebrodensis (Lojac.) Mattei	unknown	Very rare	25	-	No	
Abies nephrolepis (Trautv. ex Maxim.) Maxim.	1908	Rare	50	-	No	
Abies nordmanniana (Steven) Spach	1848	Common	100	16	No	16[6]

Abies nordmanniana subsp. *equi-trojani* (Asch. & Sint. ex Boiss.) Coode & Cullen	unknown	Rare	25	-	No	
Abies numidica De Lannoy ex Carriere	1862	Uncommon	25	-	No	
Abies pindrow (Royle ex D. Don) Royle	1837	Rare	75	-	No	
Abies pindrow var. *brevifolia* Dallim. & A. B. Jacks.	Unknown	Very rare	25	-	No	
Abies pinsapo Boiss.	1839	Frequent	50	-	No	14[4]
Abies pinsapo var. *marocana* (Trab.) Ceballos & Bolanos	Unknown	NA	25	-	No	
Abies procera Rehder	1830	Common	100	157	Yes	Up to 26[5]
Abies recurvata Mast.	1910	Rare	25	-	No	
Abies recurvata var. *ernestii* (Rehder) C. T. Kuan	Unknown	NA	25	-	No	
Abies religiosa (Kunth) Schltdl. & Cham.	1838	Extremely rare	-	-	No	
Abies sachalinensis (F. Schmidt) Mast.	1879	Rare	75	-	No	16[4]
Abies sachalinensis var. *mayriana* Miyabe & Kudo	unknown	Very rare	75	-	No	
Abies sibirica Ledeb.	1820	Very rare	25	-	No	
Abies spectabilis (D. Don) Spach	1822	Infrequent	50	-	No	
Abies squamata Mast.	1910	Rare	25	-	No	
Abies veitchii Lindl.	1879	Uncommon	100	18	No	12[6]
Abies vejarii Martinez	1962	Extremely rare	50	-	No	

Notes:

1. Cultivation status refers to the frequency of occurrence in tree collections, parks, etc. and is based on Mitchell (1972).
2. There are four main Forestry Commission tree collections at Bedgebury (southern England), Westonbirt (west England), Brechfa (Wales), and Kilmun (west Scotland).
3. This is the number of all experiments (open and closed) with a particular species on the Forest Research's Experimental database. Note that more than one species can occur in the same experiment.
4. After Mason et al. (1999).
5. After Aldhous and Low (1974).
6. After Danby and Mason (1998).