Providing the evidence base to diversify Britain's forests: initial results from a new generation of species trials.

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Summary:
Forestry in Britain is reliant on a small number of tree species, and is facing the challenges of climate change and an increasing number of new pests and diseases; this narrow palette of species increases risk. After a 40-year gap in large scale species trials a new series was established in 2012. This paper examines the initial results with the aim of increasing knowledge and understanding to evaluate species potential for wider use. Two series of trials have been established amounting to 42 species and 116 provenances on five sites across England, Scotland and Wales. To be concise, results are only reported at the species level. Of the species assessed: seven exceeded expectations (holm oak, incense-cedar, oriental beech, cork oak, Weymouth, loblolly and stone pines), fifteen did as expected and nine performed below expectations. The results so far do not tell the full story and it is important that poorly performing species are not summarily dismissed as a variety of factors will have had an impact.

Introduction

The British climate suits many trees and around 500 introduced species have been grown, with many trialled for forestry. Species trials were an important function of Forest Research until the late 1960s when, mainly driven by economics, large scale trials stopped. The few species selected for operational use now dominate British forestry. Current woodland cover is around 2.65 million hectares divided 50:50 between conifer and broadleaves (Forestry Commission, 2019). Approximately 96% of coniferous forest consists of nine species; Sitka spruce, makes up 52% of that forest cover. Similarly, oaks, birch and ash make up 46% of all broadleaved woodland (Figure 1). This lack of diversity puts British forests at risk.

Pests and diseases already impact Britain's forests (e.g. Dutch elm disease and great spruce bark beetle) but from the mid-1990s there has been a considerable increase with over 20 new pests and diseases including Dothistroma needle blight (DNB), *Phytophthora ramorum*, 'Chalara' ash dieback and acute oak decline. Excluding elm, the above mentioned together could potentially affect 50% of the forest area of Britain.

Climate change is having an increasing impact on Britain's trees and forests. Recent reports (Met Office, 2020;

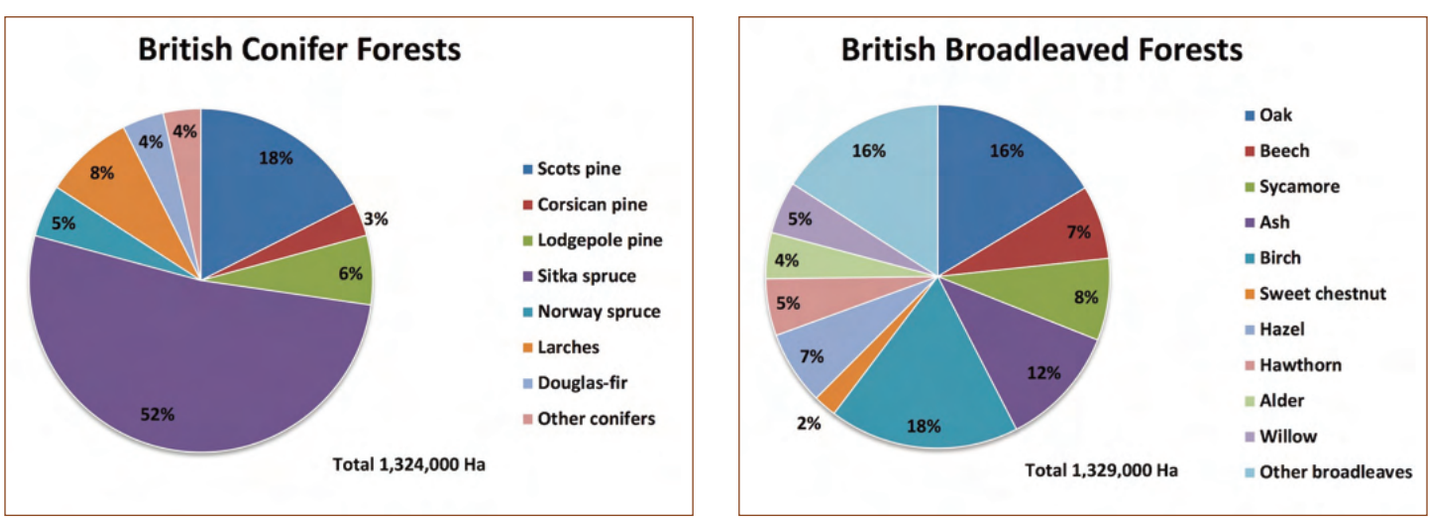

Figure 1. Composition of forests in Britain.

Table 1. Category definitions for species of potential interest for British forestry in the trials reported in this paper.

Species category definitions[1]	Species examples[2]	Planted[3] FR	Planted[3] REIN.
Principal tree species are defined as species that are currently widely used for timber production and will continue to be dominant species unless affected by a new pest or disease or become adversely affected by climate change. The **species in bold** are already affected by disease and use has become restricted. However further work on provenance is still justified to define their place in British forests.	Common beech (*Fagus sylvatica* Linnaeus)		●
	Corsican pine (*Pinus nigra var. laricio* (Poir.) Maire.)	●	●
	Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco)	●	●
	European larch (*Larix decidua* Miller)	●	●
	Hybrid larch (*Larix x marschlinsii* Coaz)	●	
	Pedunculate oak (*Quercus robur* Linnaeus)	●	●
	Sessile oak (*Quercus petraea* (Mattuschka) Lieblein)		●
	Scots pine (*Pinus sylvestris* Linnaeus)	●	●
	Silver birch (*Betula pendula* Roth)	●	●
	Sitka spruce (*Picea sitchensis* (Bongard) Carrière)	●	
	Sweet chestnut (*Castanea sativa* Miller)		●
	Sycamore (*Acer pseudoplatanus* Linnaeus)		●
Secondary tree species[4,5] have been planted on a much smaller scale than the Principal species because they are restricted to particular climate zones or have been overshadowed by more popular Principal species. The qualities of Secondary species are reasonably well understood, and they have demonstrated their suitability for forestry under current conditions and so have potential for wider use in future.	Radiata pine (*Pinus radiata* D. Don.)	●	
	Red oak (*Quercus rubra* Linnaeus)	●	●
	Western red-cedar (*Thuja plicata* D. Don)	●	●
Plot-stage species[4] are species that have not been planted commercially on any significant scale but have demonstrated positive silvicultural characteristics in trial plots and have qualities suitable for forestry objectives to justify further testing and development.	Atlantic cedar (*Cedrus atlantica* (Endl.) Manetti ex Carrière)	●	●
	Caucasian fir (*Abies nordmanniana* (Steven) Spach)[6]	●	
	Cedar of Lebanon (*Cedrus libani* A. Richard)	●	●
	Coast redwood (*Sequoia sempervirens* (D. Don) Endlicher)	●	●
	Tasmanian blue gum (*Eucalyptus globulus* Labillardière)		●
	Shining gum (*Eucalyptus nitens* (H. Deane and Maiden) Maiden.)		●
	False acacia (*Robinia pseudoacacia* Linnaeus)		●
	Holm oak (*Quercus ilex* Linnaeus)		●
	Incense cedar (*Calocedrus decurrens* (Torrey) Florin)		●
	Japanese red cedar (*Cryptomeria japonica* (Thunberg ex Linnaeus f.) D. Don)	●	
	Macedonian pine (*Pinus peuce* Grisebach)[6]	●	
	Maritime pine (*Pinus pinaster* Aiton)	●	●
	Oriental beech (*Fagus orientalis* Lipsky)		●
	Oriental spruce (*Picea orientalis* (Linnaeus) Link)	●	
	Pacific silver fir (*Abies amabilis* Douglas ex Forbes)[6]	●	
	Weymouth pine (*Pinus strobus* Linnaeus)	●	
Specimen-stage species are species that have rarely been trialled for forest potential in experimental plots but have demonstrated as specimens in tree collections positive traits of good form, growth rate and hardiness to warrant further testing in plots on a limited scale.	Eucalyptus 'Gundal' (*gunnii* x *dalrympleana*)		●
	Big leaf maple (*Acer macrophyllum* Pursh)	●	
	Chinese fir (*Cunninghamia lanceolata* (Lambert) Hooker)		●
	Liquidambar (*Liquidambar styraciflua* Linnaeus)		●
	Loblolly pine (*Pinus taeda* Linnaeus)		●
	Pyrenean oak (*Quercus pyrenaica* Willdenow)	●	
	Slash pine (*Pinus elliottii* Engelmann)		●
	Shumard red oak (*Quercus shumardii* Buckland)		●
Species included in trials that would not normally have been considered for trials within the UK. These could be species not assessed as suitable for forestry or those that have demonstrated potential for forestry but now excluded as they are known to be badly affected by recognised pest and diseases.	Carob (*Ceratonia silique* Linnaeus)		●
	Calabrian pine (*Pinus brutia* Tenore)		●
	Cork oak (*Quercus suber* Linnaeus)		●
	Italian cypress (*Cupressus sempervirens* Linnaeus)		●
	Ponderosa pine (*Pinus ponderosa* Douglas ex Lawson)		●
	Stone pine (*Pinus pinea* Linnaeus)		●

1. The category definitions are from Kerr and Jinks (2015).
2. Species name authorities; Conifers – www.Conifers.org; Broadleaves – Mitchell, A (1974) and Eucalyptus species – www.anbg.gov.au
3. Species planted in the two-trial series. FR (Forest Research); REIN (REINFFORCE) – highlighted with black dot if planted.●
4. 'Emerging species' is a collective term including Secondary tree species and Plot-stage species.
5. There are many more potential Secondary Species but only 3 were include in these trials.
6. Species not included in results as planted from 2014 onwards – highlighted with light grey dot.●

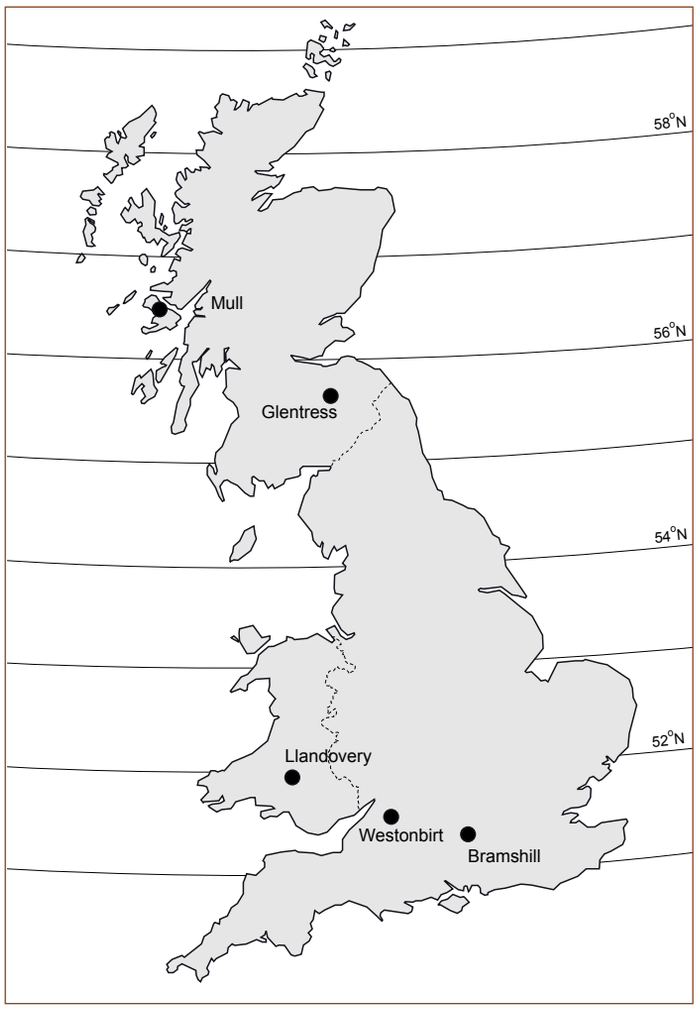

Figure 2. Species trial sites and latitudinal positions.

Committee on Climate Change, 2020) highlighted that the ten warmest years from 1884 for Britain have occurred since 2002. Future projections are hotter, drier summers in central, south and eastern England and milder winter conditions for areas in the west and north. This suggests 2080s conditions analogous to a Mediterranean climate in the New Forest, and the current climate of central France for the highly forested areas of Britain such as the west coast of Scotland. There is also a likely increase in the frequency and intensity of extreme weather events. These projected changes will impact species choice and selecting the right species now may help to alleviate future climatic issues.

The combination of pests, diseases and climate change present both problems and opportunities for forestry. The policy response has emphasised species diversification and key is an increased palette of species to plant. A comprehensive review of available knowledge, including the 160 non-native species in McDonald et al. (1957), identified a list of candidates. To ensure a logical approach to any research, Kerr and Jinks (2015) defined four categories: Principal, Secondary, Plot-stage and Specimen-stage. Using the available evidence, species were allocated to an appropriate category. Species with immediate potential for wider use in forestry (mainly Secondary and Plot-stage) are the focus of our work under Emerging Species research (Table 1).

In 2009 Forest Research started new species research leading to the planting of two series of trials. The first, an EU project, REINFFORCE, was established to examine forest species adaptability to climate change along the Atlantic coast region of Europe (Orazio et al., 2013). This four-year project established 38 species trials throughout the region from the Azores to the Isle of Mull in Scotland. To complement this project the Forestry Commission funded additional trials to ensure better coverage of different climatic regions in Britain because the geographic focus of REINFFORCE was the western Atlantic areas of the country. This paper summarises the initial results from these trials.

Materials and methods

REINFFORCE trials

The species and provenances selected reflected regional interests of the network; some species are only relevant to particular zones but required planting on all sites. The project enabled assessment of species and provenances not currently planted in Britain at more southerly sites having elements of our future projected climate. Britain has three trial sites: Mull in Scotland, Llandovery in Wales and Westonbirt in England (Figure 2; Table 2).

There were two components to the trials.

- Un-replicated plots – 30 species with each represented by three provenances, i.e. 90 plots in total (Table 1).

- Replicated plots – four species: silver birch, pedunculate oak, maritime pine and Atlantic cedar, each represented by three provenances, replicated three times, i.e. 36 plots in total.

Each of the plots was planted with 12 trees (generally two-year plants) at a density of 1100 stems ha^{-1}, i.e. 3×3m spacing. The plot size will allow one tree to grow to maturity. The un-replicated plots allowed comparison of results across the 38 sites; the replicated plots would provide a measure of within-site variability. The first attempt at presenting the early results can be seen in Correia et al. (2018).

Table 2. Site details for the REINFFORCE and Forest Research trials

Experiment Type	REINFFORCE	FR Trial	FR Trial	REINFFORCE	FR Trial	REINFFORCE	FR Trial	FR Trial
Experiment Name	**Mull 16**	**Mull 17**	**Glentress 96**	**Llandovery 51**	**Llandovery 52**	**Westonbirt 31**	**Westonbirt 32**	**Bramshill 61**
OSGB Grid ref	NM537456		NT303399	SN818371		ST840891		SU852652
Lat, Long	56.32'N: 6.00'W		55.38'N: 3.06'W	52.01'N: 3.43'W		51.36'N: 2.13'W		51.22'N: 0.46'W
Elevation (m asl)	35-70	50-100	170-210	185	175	145	140	95
Aspect	SE	SSE	SE	NW		nil		nil
Slope	Moderate	Steep-gentle	Steep	Moderate		Flat		Flat
Rainfall (mean annual, mm)	1400		892	1351		824		665
Exposure (DAMS score[a])	15		10	10		14		12
Soil nutrient regime[a]	Medium		Rich	Medium		Carbonate		Poor
Soil moisture regime[a]	Fresh		Fresh	Very moist		Moderately dry		Very moist
Soil[c]	Mull Lava group	Basalt	Gala Unit 4 - Wacke	Triwdr Formation - Mudstone and Sandstone		Forest Marble Formation - Limestone		Camberley Sand
Soil[b]	Basic brown earth		Typical Brown Earth	Surface-water gley/ Peaty gley		Argillic Brown Earth/ Typical surface-water gley		Podzolic surface-water gley

[a]See Ecological Site Classification of Pyatt et al., (2001). Records based on default values in ESC4
[b]According to Kennedy (2002)
[c]BGS (British Geological Survey) - Geology of Britain http://mapapps.bgs.ac.uk/geologyofbritain3d/

Forest Research (FR) trials

These trials contained between one and three provenances of 24 species. The choice of species included 14 of those in REINFFORCE of interest to British forestry, eight Emerging Species and two Specimen-stage species. Five trials were established, one at each REINFFORCE site and two others further east in Britain (Figure 2; Table 2). The species tested differed between western and eastern sites to reflect differences in species suitability. Each trial was a randomised block design using 49-tree plots planted at 2×2m spacing replicated three times (Figure 3).

General trial information

To ensure consistent planting stock, trees for REINFFORCE and additional plants for Forest Research were raised at a single nursery in France. Other species for Forest Research were grown at our Northern Research Station, Scotland. Differences in species' growth rate and seed availability meant most planting took place over two years (2012 and 2013) with four species only available for planting in 2014. Beating up took place for three years after planting where plants of the same provenance were available.

Figure 3. Westonbirt 32 Forest Research species trial. The image shows the individual species plots containing 49 trees and clearly shows which are performing well. (Photo: © Forestry Commission)

For all trees, heights were measured shortly after planting and each winter thereafter including assessment of survival. All trials were fenced against deer and rabbits, and when required, weeded for a minimum of three years. The conifers at Llandovery were spot-treated for large pine weevil in late spring 2012 and 2013. Operational issues prevented completion of similar treatments on Mull and Glentress.

Data presentation

To present consistent and clear data the following method was used:

- All results are based on the last measurement in 2017/18 of trees planted in 2012 and 2013.
- Data are only presented for species using mean survival and mean height from each site.
- Data from subsequent plantings and any beating-up have not been included to give a fair assessment of initial survival.

Survival and height data were classified using a 'traffic light' colour code detailed in Table 3.

We also used a combination of results, existing knowledge, experience and professional judgement to classify the performance of each species as 'below expectation'; 'as expected'; 'exceeded expectation' (Table 4).

Table 3. Criteria used to classify species performance.

Survival (%) Range	**Description**	**Colour code**
≤ 50%	poor/failed	
> 50% to < 75%	fair to good	
≥ 75%	very good	
Height (cm) Size	**Description**	**Colour code**
0 to <100 cm	not yet established	
≥ 100 to <200 cm	established	
≥ 200 cm	well established	

Results – REINFFORCE trials

Most of the species showed fair/good survival and were considered established 4-5 years after planting. There were 13 exceptions that either showed poor survival or had not yet established (Table 5).

Performance between the sites varied and followed a decreasing success trend; Westonbirt (17) > Llandovery (7) > Mull (2) as shown in brackets by the number of species that had both very good survival and were well established.

The REINFFORCE trial results have been grouped into 'pines', 'other conifers', 'oaks' and 'other broadleaves' (Table 5).

Pines

Corsican, Scots, stone and loblolly pine performed strongly with the first two species doing particularly well (Figure 4). All pine species performed poorly on Mull. Maritime and

Table 4. Summary of evaluation results

Performance[1]	**Existing knowledge of species[2]**		
	Secondary species	**Plot-stage species**	**Specimen-stage species**
Below expectations	Radiata pine	Atlantic cedar Caucasian fir Cedar of Lebanon Coast redwood	Big leaf maple Chinese fir Liquidambar Pyrenean oak
As expected	Red oak Western red cedar	Tasmanian blue gum Shining gum False acacia Japanese red cedar Maritime pine Oriental spruce Ponderosa pine	*Eucalyptus* 'Gundal' Slash pine Carob Calabrian pine Italian cypress Shumard red oak
Exceeded expectations		Holm oak Incense cedar Oriental beech Weymouth pine	Cork oak Loblolly pine Stone pine

[1]Principal species are not included in this list as information on performance is generally well understood.
[2]Judgements based on numerous sources combined with general experience and knowledge.

ponderosa pine showed variable results across the three sites. Calabrian and slash pine showed poor survival and growth at all sites. All the eight pine species were affected by DNB to some degree, but this was not formally assessed. Some species, particularly maritime pine, also suffered issues with wind rock and subsequent socketing in the wet soils and many were subsequently staked.

Other conifers

Several Principal and Secondary Species (Douglas fir,

Table 5. REINFFORCE Trials – mean survival and height after 5 years1. The colours relate to growth and survival as detailed in Table 3.

	Llandovery 51			Mull 16			Westonbirt 31			Mean overall	
	Prov[1].	Survival	Height	Prov.	Survival	Height	Prov.	Survival	Height	Survival[2]	Height
Pines											
Scots pine	3	94.4	237.4	3	66.7	117.8	3	100	314.1	87	223.1
Corsican pine	3	80.6	221.7	3	75	97.3	3	97.2	283.9	84.3	200.9
Stone pine	3	91.7	223.4	2	12.5	46	3	94.4	202.2	72.9	171.1
Loblolly pine	2	79.2	308	2	0	0	2	70.8	405.4	50	237.8
Maritime pine	3	47.2	291.4	4	27.1	125.9	3	58.3	386.4	42.5	253.7
Ponderosa pine	2	50	161.2	2	8.3	33	2	66.7	197.1	41.7	130.4
Calabrian pine	3	0	0	2	0	0	3	33.3	205.4	12.5	77
Slash pine	2	16.7	130	2	0	0	2	8.3	142.1	8.3	90.7
Other Conifers											
Western red-cedar	2	100	183.7	2	66.7	176.9	2	91.7	375.3	86.1	245.3
Incense-cedar	1	100	221.2	1	66.7	106	1	91.7	272.5	86.1	199.9
Douglas fir	3	77.8	268.3	2	54.2	187.3	3	83.3	380.1	74	290
European larch	3	52.8	358.6	2	37.5	85.2	3	94.4	537	64.6	357.2
Atlantic cedar	1	41.7	123.3	1	66.7	105.2	1	77.8	242.5	62	157
Coast redwood	3	63.9	119.5	3	55.6	108.4	3	41.7	312.1	53.7	180
Italian cypress	2	41.7	43.7	2	20.8	128.4	2	66.7	264.3	43.1	145.5
Chinese-fir	1	16.7	137	1	16.7	84.5	1	75	271.6	36.1	164.4
Cedar-of-Lebanon	2	33.3	30	2	58.3	48.3	2	0	0	30.6	26.1
Oaks											
Sessile oak	3	88.9	190	3	77.8	120	3	69.4	190.5	78.7	166.8
Pedunculate oak	3	69.4	124.6	5	71.1	103	3	87	252.6	75	149.7
Cork oak	3	97.2	147.7	3	69.4	82	3	52.8	93.1	73.1	107.6
Willow oak	1	91.7	132.8	1	75	52.7	1	50	251	72.2	145.5
Red oak	2	70.8	136.1	2	58.3	91.6	2	83.3	264	70.8	163.9
Holm oak	3	100	127.7	3	50	98.2	3	50	72.9	66.7	99.6
Other Broadleaves											
Eucalyptus 'Gundal'	1	100	586.8	1	100	665.8	1	91.7	1186.4	97.2	813
Oriental beech	3	94.4	189.1	3	88.9	170.9	3	97.2	298.7	93.5	219.5
Shining gum[3]	-	-	-	-	-	-	1	83.3	1193	83.3	1193
Common beech	3	77.8	141.6	2	87.5	151.6	1	91.7	219.1	83.3	157.8
Silver birch	3	70.4	324.5	3	77.8	233.9	3	78.7	603.8	75.6	387.4
Sycamore	3	77.8	70.1	3	69.4	93	3	61.1	330.9	69.4	164.7
False-acacia	3	58.3	100	3	27.8	135.3	2	75	483.4	51	209.1
Sweet gum	2	50	58.7	2	33.3	63.6	2	45.8	94	43.1	72.1
Sweet chestnut	3	38.9	163.4	3	27.8	69.7	3	16.7	85.2	27.8	106.1
Blue gum	1	0	0	1	33.3	375.5	1	0	0	11.1	125.2
Carob	3	0	0	3	0	0	4	0	0	0	0

1 – Prov. – number of provenances of each species planted at site.

2 – Species are listed in order of their mean overall survival in each species group.

3 – Shining gum was planted at all sites. Llandovery and Mull not planted until 2014 so fall outside the scope of this review.

Figure 4. Scots pine at the REINFFORCE Westonbirt 31 trial. Note the difference between the Slovakian provenance (right) and Scottish provenance (left). On average the Slovakian provenance was 1m taller. (Photo: © Forest Research)

western red-cedar and European larch) did well although European larch struggled on Mull. The results for the Plot-stage and Specimen-stage species were variable. Incense-cedar and coast redwood demonstrated fair to good survival and all were established. Of the true cedars, survival and growth of Atlantic cedar was much better than that of cedar of Lebanon; the latter failed completely at Westonbirt. Chinese fir and Italian cypress struggled at Mull and Llandovery but showed good or very good growth and establishment at Westonbirt.

Oaks

Performance of the six species planted differed considerably between sites. At Llandovery all species had good to very good survival and all were established. Survival and growth of sessile and pedunculate oak was consistently good across all three sites but the other four species had varied survival and growth at Westonbirt and Mull. Only pedunculate and red oak at Westonbirt had very good survival and were well established.

Other broadleaves

The native broadleaves, silver birch and common beech, both performed well; sycamore (naturalised) showed variable growth and was constrained at Llandovery and Mull. Silver birch was consistently the best performer. Interestingly, oriental beech established and grew better than native beech. The non-native broadleaves were more variable: false-acacia generally did well but struggled on Mull; liquidambar was quite poor with low survival and moderate growth; the carob tree failed completely. The eucalypts used in the trials showed characteristically good survival and growth although blue gum failed at Westonbirt.

Table 6. Forest Research Trials (2012-13 plantings) mean survival and height for species ordered by mean survival. The colours relate to growth and survival as detailed in Table 3.

	Bramshill61			Glentress96			Llandovery52			Mull17			Westonbirt32			Mean overall	
	Prov[2].	Survival	Height	Prov.	Survival	Height	Prov.	Survival	Height	Prov.	Survival	Height	Prov.	Survival	Height	Survival[1]	Height
Pines																	
Weymouth pine	2	99	145.2	2	90	152.3	-	-	-	-	-	-	-	-	-	95	148.7
Maritime pine	2	96	318.9	3	77	243.5	-	-	-	-	-	-	-	-	-	84	273.7
Scots pine	3	97	190.8	3	82	206.5	3	82	192	3	46	94.5	3	87	229.5	79	182.1
Corsican pine	-	-	-	-	-	-	1	81	130.2	1	50	72.3	-	-	-	66	101.2
Radiata pine	2	86	336.7	2	22	255.2	2	40	320.3	2	14	176.3	2	54	368.3	44	291.4
Other Conifers																	
Japanese red-cedar	-	-	-	-	-	-	2	76	98.2	2	75	107.5	3	82	207.9	78	147.9
Oriental spruce	1	82	39.4	1	56	56.6	2	81	74.8	2	64	59.4	2	84	47.8	75	57.5
Sitka spruce	-	-	-	2	40	208.8	2	80	277.1	-	-	-	2	94	298.5	71	261.5
Douglas fir	3	60	153.1	3	74	237.6	3	88	289.1	3	39	248.7	3	78	312	68	248.1
Western red-cedar	-	-	-	-	-	-	1	66	116.5	-	-	-	1	67	143.8	67	132.9
European larch	1	78	306.6	1	35	325.3	1	50	389.2	1	57	210.5	1	86	592.5	61	364.8
Cedar-of-Lebanon	-	-	-	1	59	154.6	-	-	-	-	-	-	-	-	-	59	154.6
Hybrid larch	2	70	228.9	1	42	345.7	2	46	479.4	2	68	374.9	-	-	-	59	358.8
Coast redwood	-	-	-	-	-	-	-	-	-	-	-	-	1	47	143.5	47	143.5
Atlantic cedar	1	75	84.1	1	5	14.5	-	-	-	-	-	-	-	-	-	40	49.3
Broadleaves																	
Red oak	1	99	86.8	1	78	145.5	-	-	-	-	-	-	-	-	-	88	116.1
Silver birch	1	95	337.5	1	92	479.2	2	82	411.6	1	29	187.4	1	92	592.4	79	403.3
Pedunculate oak	-	-	-	-	-	-	1	78	141.6	1	50	15.4	2	76	204.3	71	141.4
Pyrenean oak	-	-	-	-	-	-	1	86	55.9	1	55	49.9	1	66	118.9	69	74.9
Bigleaf maple	1	7	43.1	-	-	-	2	15	56.9	2	46	79.6	1	38	191	28	84.5

1 – Species are listed in order of their mean overall survival in each species group.

2 – Prov. – number of provenances of each species planted at site.

Figure 5. Oriental spruce at Llandovery 52 FR trial. A healthy tree but it is five years old and still under 1m in height. The recent leader extension would suggest it is now becoming established. (Photo: © Forest Research)

Results – Forest Research trials

Twenty-one of the 24 species planted had five years of measurements (Table 6). Variation between the sites followed a decreasing success trend Westonbirt (7) > Bramshill (4) > Llandovery/Glentress (2 each) > Mull (0) where species had both very good survival and were well established (Table 6).

Most of the species performed well and showed fair/good survival and were considered established four-five years after planting. The exceptions were bigleaf maple, Atlantic cedar and radiata pine that showed poor survival and oriental spruce that had not yet established.

The FR trial results have been grouped into 'pines', 'other conifers' and 'broadleaves'.

Pines

Where planted maritime and Scots pine performed well. All pines at Bramshill had very good survival and all were established. Radiata pine had poor survival except at Bramshill, but the survivors were generally well established. Three of the four pines at Glentress grew and survived well; the exception was radiata pine which had the highest growth rate but very poor survival. The pines planted on Mull generally did not do well.

Other conifers

The four Principal species planted all showed satisfactory performance. Douglas fir showed good growth and survival at all sites. Sitka spruce where planted showed good survival and growth except at Glentress where a late spring

Figure 6. Good establishment of red oak at Glentress 96. (Photo: © Forest Research)

frost in 2013 affected survival. The two larches where planted performed well but there were occasional problems with survival.

Emerging Species conifers had mixed results. The true cedars performed poorly although they were not planted everywhere. Japanese red cedar was variable at Llandovery and Mull but showed its potential at Westonbirt. Oriental spruce showed good or very good survival on all sites but was not yet established anywhere; recent observations indicate growth is improving (Figure 5). Coast redwood at Westonbirt demonstrated poor survival, but the surviving trees did become established; western red cedar at Llandovery and Westonbirt performed satisfactorily.

Broadleaves

Silver birch on all sites was well established with very good survival except on Mull. Pyrenean and English oak were planted on three sites including Mull and demonstrated good survival although establishment was variable. Red oak (Figure 6) where planted had very good survival but variable growth. Big-leaf maple was consistently poor.

Figure 7. A French provenance of European larch at the Westonbirt 32 FR trial. Phytophthora ramorum now dictates a restricted use but we should always think about where larch might still grow successfully and not abandon it all together. (Photo: © Forest Research)

Discussion

There has been little recent work evaluating tree species for use in British forestry. This paucity of up-to-date knowledge has meant many decisions are based on information that predates current issues. The trials described here represent a major step towards rectifying that gap and will help forest managers make more informed decisions in these ever more challenging times.

Enhancing our silvicultural knowledge

Biotic factors – the living influences

Dothistroma needle blight (DNB) was the main disease present and the potential impact on pines was planned for. This included a DNB-resistant provenance of radiata pine from New Zealand and at present the surviving trees of that provenance visually appear uninfected. Some species planted on the REINFFORCE sites were badly affected particularly ponderosa and Calabrian pine at Westonbirt. Differences were also apparent between species and among provenances of the same species. An example was the heavily infected Turkish provenance of Scots pine at Llandovery with adjacent provenances from Scotland and Slovakia appearing less affected.

The trials included hybrid and European larch, which have been affected by *Phytophthora ramorum* throughout western Britain. A plot at Glentress was felled under a Statutory Plant Health Notice and the Llandovery site is surrounded by confirmed *Phytophthora* infections. Despite this both are consistent performers and the trials are a reminder that we should strive to define a place for larch in our future silviculture, maybe focussed on less humid, warmer and drier areas as part of mixed-species stands (Figure 7).

The western red cedar at Westonbirt appeared to be heavily infected in Spring 2017 with Thuja blight. This disease is mainly a nursery issue where ‘crowding’ causes high humidity and persistent water on the foliage (CABI, 2020). The issue may have been the heavy woody weed growth; after cleaning in 2017 the symptoms disappeared. A reminder of something we already know but need to relearn.

Hylobius damage was an issue for most of the conifers on Mull and had an impact. This highlights the continuing need for good protection against Hylobius, particularly with the requirement to diversify our range of conifers.

Figure 8. Radiata pine generally performed below expectations across the five FR trial sites. This plot at Bramshill 61 was the exception being well established and showing very good survival. (Photo: © Forest Research)

A minor issue for birch at the Westonbirt FR trial in 2014 was bark stripping by European hornets. They ring-barked stems leading to top breakage over that winter. The damage had generally healed by the autumn of 2015. The result is a slight reduction in the average height of some blocks but there is no apparent long-lasting effect.

Abiotic factors – the non-living influences

At the Westonbirt REINFFORCE site, winter snow in 2017/18 caused toppling of some maritime, loblolly and radiata pine. The cause could be a number of factors but mainly appear attributable to an imbalance between rapid shoot growth and slow root development (Burdett, 1979).

Atlantic cedar and cedar of Lebanon both performed poorly against expectations (particularly on the English sites). Site records and notes indicate plants for both species were possibly too small (<10cm height) when planted and struggled to establish. These examples highlight that if Emerging Species are to be more widely planted understanding how to produce a quality plant is essential to maximize survival and growth when planted.

Soils and site conditions varied as would be expected based on the sites' geographic distribution. Observations suggest soils and site are having an impact, for example apparent chlorosis, possibly due to heather check on the sandy heaths at Bramshill and rampant bramble and willow-herb on the fertile soils of Westonbirt. Further analysis is required to attribute the site effects on the different species.

> "It is vital that species which performed below expectations are not dismissed based on these trials."

The main influence missing from the results is the weather data. Although Table 2 provides some information these represent climatic means. Comparing the actual temperature and precipitation over the life of the trials may reveal differences that could have had an influence on growth and survival. Some weather events had an obvious influence (heavy snow at Westonbirt, frosts at Glentress), but these do not represent extreme events (storms, drought) against which the species planted would be truly tested. When considering climate change the importance of long-term monitoring over many years to fully test a species is essential.

How do we evaluate the results?

To date only short-term survival and growth are assessed and our findings need to be carefully interpreted. The main reason for this is that the potential of any species could be obscured by other factors such as management issues, pests and diseases, weed competition, weather, plant quality and other local factors.

We have presented the main results by using a 'traffic light' colour coding (Table 3) for survival and growth in Tables 5 and 6 to visualise early performance. This approach has its limitations. One issue is the favouring of species that naturally grow quickly; some species take time to establish and may demonstrate good survival but apparent poor growth. For example, Oriental spruce showed good survival but was consistently 'not yet established' and author experience suggests that slow establishment is a species characteristic. Another issue is the hard boundary between classes where a matter of a centimetre in growth can for example push a result from 'established' down to 'not yet established'.

A second way in which we have evaluated the results is shown in Table 4. For each of the Emerging Species categories (Table 1) the existing knowledge of a tree species has been used to rate each of the species in terms of how it has performed in relation to expectations. This shows that nine species have performed below expectations and seven have been classed as above expectations. Although helping with the bigger picture and contributing to our knowledge further research is essential to confirm these assessments.

Together these observations, data and opinions can help us to identify what species could be planted more widely. Our aim is to seek evidence to 'promote' species from their existing category to a higher one, for example, justifying moving red oak from Secondary to a Principal species. In addition, the trials provide an initial screening of species for

further research, including incense-cedar, oriental beech, loblolly pine, Japanese red cedar and holm oak.

It is vital that species that performed below expectations are not dismissed based on these trials. The early results may have been negatively influenced by other factors and future performance could be improved with better understanding of the species' requirements. All nine species listed as performing below expectations (Table 4) have either demonstrated their potential in past trials e.g. coast redwood (Savill, 2019) or like radiata pine would be suited to our warming climate in some areas of the country (Figure 8).

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