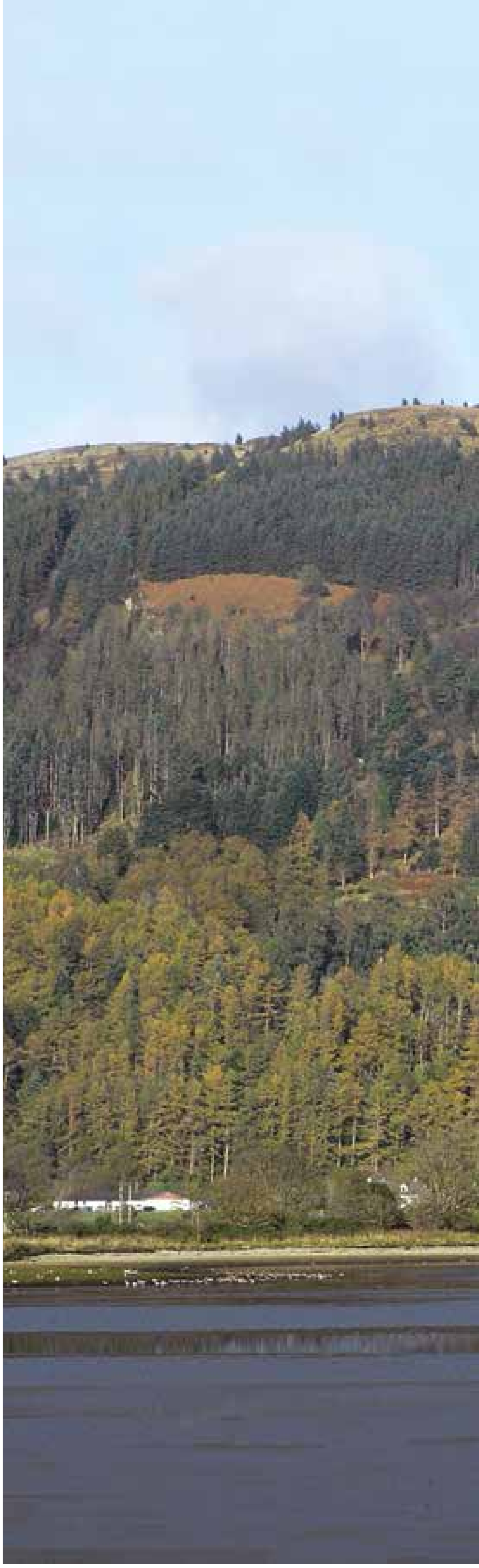
By W.L. Mason, F. MacDonald, M. Parratt and J.P. McLean

What alternative tree species can we grow in western Britain? 85 years of evidence from the Kilmun Forest Garden



Summary

Nearly 300 tree species have been planted at Kilmun Forest Garden in Argyll since 1930, mostly in small plots allowing the collective performance of an individual species to be evaluated. Results from the mid-1990s showed that about 60 species had formed productive closed canopy stands, with a number of conifers all showing health and potential productivity equivalent to that of Sitka spruce, the major species grown in the forests of western Britain. Since 2000, there has been increased interest in the collection at Kilmun, partly because it allows the comparison of long-term growth of a wide range of species at a time when species diversification is being encouraged as a means of adapting forests to climate change. Accordingly, existing plots have been remeasured, some have been sampled for their timber properties and a number of new plots have been established. There are now around 200 different species in the collection, of which 145 are in good health. Growth measurements show the continuing good performance of about 18 conifer and broadleaved species at between 45 and 85 years of age: these species would be prime candidates for use in diversifying spruce dominated planted forests in western Britain.

Introduction

Recent years have seen increasing awareness of the potential impacts of both projected climate change and a range of pests and diseases upon the long-term sustainability of British forests (Read *et al*, 2009). One concern is the low numbers of species in our forests, for example in 2005 around 55% of UK forests were single species stands (Forest Europe, 2011). In addition, the British timber industry is dependent on very few species with Sitka and Norway spruce accounting for over 55% of softwood timber production in 2012, a figure projected to increase to nearly 70% by 2030 (Forestry Commission, 2014). Single species stands can be vulnerable to the impact of biotic and abiotic hazards, a recent example in Britain being the extensive mortality of Japanese larch (*Larix kaempferi*) and other larch species caused by the pathogen *Phytophthora ramorum* (Webber *et al*, 2010).

Awareness of a lack of species diversity has resulted in renewed interest in other tree species that could be used to diversify British forests, either as

THE AUTHORS

W.L. Mason*, F. MacDonald, M. Parratt and J.P. McLean

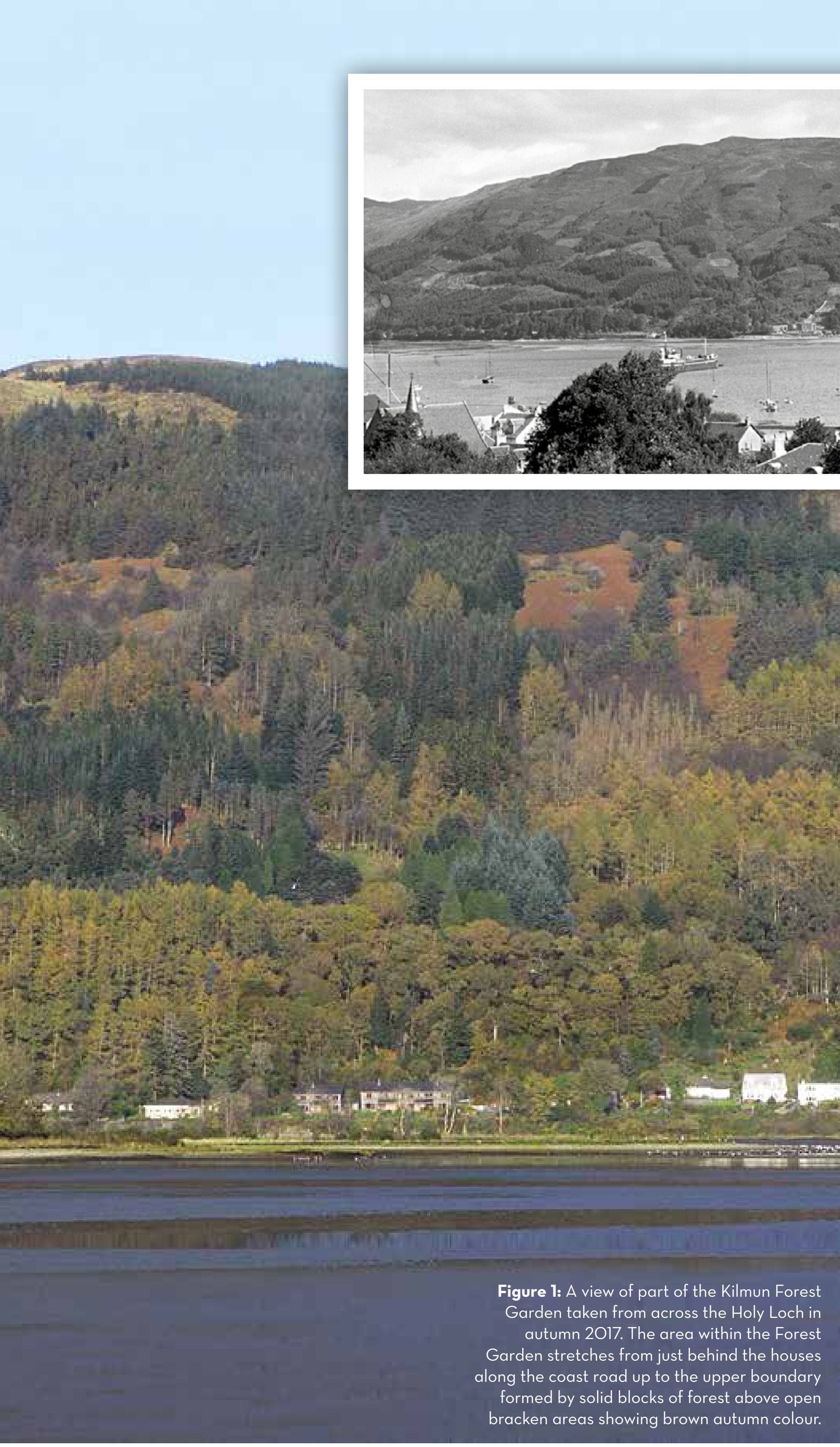
*Corresponding author. Email: Bill.Mason@forestry.gsi.gov.uk. Forest Research, Northern Research Station, Roslin, Midlothian, Scotland. EH25 9SY.

Bill Mason is a Research Fellow of Forest Research (FR) based at the Northern Research Station near Edinburgh. He has been responsible for the FR involvement with Kilmun for 20 years.

Fraser MacDonald is a Forest Management forester in Forest Enterprise Scotland, based at the Glenbranter office of Cowal and Trossachs Forest District. He has been involved with Kilmun for over 15 years and has been responsible for operational work there for the last 7-8 years.

Matt Parratt is a silviculturist based at FR's Northern Research Station with a special interest in tree species and their identification.

Paul McLean is a research scientist based at FR's Northern Research Station where he leads the Tree and Wood Properties research programme.



Left: General view of Forest Garden in 1962.

Figure 1: A view of part of the Kilmun Forest Garden taken from across the Holy Loch in autumn 2017. The area within the Forest Garden stretches from just behind the houses along the coast road up to the upper boundary formed by solid blocks of forest above open bracken areas showing brown autumn colour.

alternative production species or to increase the resilience of single species stands to pests and diseases. Examples of this interest include recent articles describing a range of alternative conifers and broadleaves that might be grown in different parts of Britain (e.g. Wilson, 2007; Bladon and Evans, 2015; Savill, 2015; Wilson *et al*, 2016). However, owners and managers are often reluctant to plant lesser known species for which there is limited silvicultural guidance and little knowledge of their timber properties and potential markets. In such circumstances, comparison of candidate species in long-term trials can provide valuable information. Such long-term trials include the 'forest gardens' established in the early decades of the last century, defined as sites where a wide range of species are trialled in small plots prior to large-scale operational testing of a few, selected species (MacDonald *et al*, 1957).

A forest garden differs from an arboretum in that the focus is on evaluating the collective growth of trees in a stand rather than on the development of individual specimens. Amongst the forest gardens that still survive in Britain are those at Bedgebury (Kent), Brechfa and Vivod (Wales), Crarae, Kilmun, Kirroughtree and Lael (Scotland). Of these sites, Kilmun on the Cowal peninsula near Dunoon in Argyll probably has the largest collection of tree species plots (as opposed to individual specimen trees) in the British Isles. At the beginning of this century, about 50% of the conifers planted at Kilmun were classed as 'Rare' or 'Very Rare' elsewhere in Britain, while 30% of the conifers were 'Threatened' in the wild (*pers. comm.* Dr Richard Jinks, Forest Research).

Kilmun Forest Garden was established in 1930 to test and demonstrate the performance of tree species in the west of Scotland. In 1950 the overall objective for the forest garden was defined as: "[the growing of] stands of timber trees (of a wide range of species) under forest conditions in a high rainfall area of western Scotland".

"A forest garden differs from an arboretum in that the focus is on evaluating the collective growth of trees in a stand rather than on the development of individual specimens"

A previous report (Mason *et al*, 1999) described results from the first 65 years of the collection, based on plots that were established either in the 1930s or between 1950 and 1971. This had involved planting 482 plots of 260 species from 50 different genera; a survey in 1995 found that 110 different conifers and 52 broadleaves still survived. Particular features included successful plots of a wide range of *Abies* species, the healthy state of a wide range of species from north-west America and eastern Asia, and the large size attained by surviving trees of a number of *Eucalyptus* species (Mason *et al*, op.cit.).

Since 2000, there has been renewed investment in Kilmun with new plots established and older plots remeasured: Kilmun has also served as a 'safe site' for *ex situ* plantings of endangered conifers collected by the International Conifer Conservation Programme (ICCP) (Gardner, 2014). This paper summarises recent developments and relates the results to the current interest in diversifying the species composition of Scottish forests as a means of increasing their resilience against abiotic and biotic hazards.

Site details

Kilmun Forest Garden covers about 50ha on steep slopes overlooking the Holy Loch in Argyll where elevation ranges from about 20m on the lower slopes to about 300m asl at the top of the site. Several streams and steep-sided gorges run though the site, which combined with the steep terrain, have influenced both plot layout and access. Soils are mainly upland brown earths although gleys and wet flushes occur wherever the ground flattens out. This gives a soil moisture regime of 'fresh-moist' and a 'poor-medium' soil nutrient regime in the Ecological Site Classification (ESC) terminology (Pyatt *et al*, 2001). Average annual rainfall is around 2,100mm and accumulated temperature is around 1,410 degree days >5.60°C at the bottom of the site and around 1,150 degree days at the top of the site. Exposure varies from DAMS 10.5 at the bottom of the site to nearly 14 at the upper margin (all values derived from ESC: v 3.0).

Recent history

Revised Objectives

The policy for Kilmun was revised in 2009 as part of a wider review of the tree collections owned and managed across Great Britain by the (then) Forestry Commission. This identified four main objectives for Kilmun:

- To provide a unique display of an extensive range of the world's trees arranged in 'miniforests'
- To become an important resource for science, conservation and education during an era of adapting forests and society to climate change
- To support national and international policies on forestry and conservation of biodiversity
- To provide a year-round destination for visitors to the Loch Lomond and Trossachs National Park, linked to the Royal Botanic Gardens Edinburgh (RBGE) at Benmore.

These objectives are implemented through a strategy based on planting and management of small plots (i.e. 50-200 plants = 'mini-forests') of species likely to be adapted to the current and future climate of western Scotland. This is guided by an accessions list of around 140 species (approximately 55% conifers) suitable for future planting at Kilmun. The list concentrates on species threatened in the wild, of particular landscape or cultural value, which might be adapted to a future climate, and which have the potential to produce utilisable timber.

Management

Since the early 1990s, management of the collection has been guided by a partnership between staff from the local Forest District of Forest Enterprise Scotland and from Forest Research (FR). The former have overall responsibility for the site including establishing new plots and maintaining old ones while the latter are responsible for assessments, providing material for new plantings, and providing advice on other specialist aspects. In 2012, Kilmun became a founder member of the National Tree Collections of Scotland (NTCS, http://www.ntcs.org.uk/).

The steepness of the ground plus limited access for modern harvesting machinery has largely precluded regular thinning of plots. However, plots were thinned to waste in earlier decades, especially on the lower slopes.

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New plot establishment

Most species have been raised in containers (normally in 175-300 cm^3 cells) in the glasshouses at FR's Northern Research Station and are supplied to Kilmun as two to three year-old plants depending on growth rate. Sometimes plants are potted into one-litre pots to improve size and vitality. Occasionally species have been obtained from other bodies such as the RBGE or from commercial nurseries. In the late summer or autumn, potential areas for planting are identified and cleared. Planting normally takes place in the following March or April and all plots are protected against browsing using a temporary deer fence. Plots may be hand weeded for two-three years after planting and failures are beaten-up with plants of the same species if these are available.

Assessments

Forest Research staff carried out a quinquennial inspection of all plots (and other specimen trees) within the collection in 2004, 2010 and 2015. Plots are scored visually on a simple 1-4 system where 1 indicates all trees in a plot are healthy, 2 indicates that most trees are healthy but some dieback is apparent, 3 indicates that most trees are unhealthy, while score 4 indicates that most trees in the plot are dead or dying. This scoring system differs from that used in the 1995 survey when trees were scored 1-3; dead-healthy.

The previous paper (Mason *et al*, 1999) described the growth and yield of 44 older plots of conifers and broadleaves based on permanent assessment plots of 0.02 to 0.06ha in size. Further assessments of 38 of these plots were made between 2000 and 2004, while in 2015, 41 plots were assessed. However, this last assessment used temporary circular plots of 0.02ha because the markers identifying the permanent assessment plots had often decayed and the plot boundaries were sometimes unclear. Assessments involved measuring all live stems >7cm dbh plus the height of the largest dbh tree in each plot (used to provide a measure of top height).

Climatic damage

Although sheltered by higher ground to the east, Kilmun is fully exposed to

Figure 2: An internal view within Kilmun Forest Garden in autumn 2017. In the foreground are young plants of maritime pine (*Pinus pinaster*) within a fenced enclosure. In the background are older plots of *Abies lasiocarpa*, Sitka spruce, and grand fir.

prevailing winds from the south-west with sporadic wind damage a feature of recent decades. Severe wind damage was recorded in 1998, while a major storm in 2012 followed by further gales over the winter of 2014/15 eliminated a number of plots. The maritime climate means that severe frosts are rare, and although -15°C was recorded in the hard winter of 2010, there was little damage to trees in the collection.

Pests and pathogens

A number of disease outbreaks have affected species within the collection. Several pines (e.g. Corsican pine (*Pinus nigra* subsp. *laricio*), ponderosa pine (*P. ponderosa*), and Jeffrey pine (*P. jeffreyi*)) have been badly affected by Dothistroma needle blight. In 2004, the plot of mountain hemlock (*Tsuga mertensiana*) had extensive shoot dieback, subsequently found to be caused by the shoot blight *Sirococcus tsugae*, responsible for the shoot dieback recently found on Atlas cedar (*Cedrus atlantica*) in various parts of Britain (see https://www.forestry.gov.uk/forestry/beeh-a6seme). In 2010, two mature plots of Nothofagus species (roble – *N. oblique*; rauli – *N. alpine* (syn. *N. nervosa, N. procera*)) were found to be suffering from *Phytophthora pseudosyringae*; most trees died within 12 months and the plots were felled with the timber destroyed. In 2016, a few trees in an isolated plot of western larch (*Larix occidentalis*) with a history of poor growth were found to be infected with *Phytophthora ramorum*; this plot and other larches in the immediate vicinity were felled and destroyed while standard biosecurity precautions were put in place. One impact of the clearance of plots following windblow or disease outbreaks has been an increasing incidence of damage to young plants by *Hylobius* weevils.

Timber properties

When considering tree species diversification, the merchantability of the timber of alternative species should also be evaluated. Some information can be gained from earlier studies (e.g. Lavers, 2002), but often these studies used small defect free wood samples, not necessarily representative of the sizes of timbers employed in construction. In the Kilmun plots, it is possible to visit and assess trees of a candidate alternative species exactly as one would in a stand of Sitka spruce. Timber studies use measures of stem size and form to obtain an estimate of merchantable volume for both sawn timber and chip purposes. Sample trees are then felled and processed in a small scale operation that replicates current sawmilling practice. Thus at Kilmun, it has been possible to test timber and small wood samples of both Japanese red cedar (*Cryptomeria japonica*) and Pacific silver fir (*Abies amabilis*) which are both being considered for use in upland forests. Logs were collected in 2015, cut into structural sized battens, kilned and then tested at Edinburgh Napier University to current European standards (CEN, 2016). This allows a direct assessment of the suitability of the timber from these species to meet current market requirements. In addition, these studies investigated the evolution of the important grade determining wood properties throughout the growth of the stand. This will facilitate recommendations about the length of rotation required to produce structural timber with these species.

Results

Overall survival

In 2015, 263 plots had surviving trees, 179 were conifers and 84 broadleaves. This was a slight increase over 1995 (248 plots with surviving trees), reflecting recent plantings. Since some species were planted in more than one plot, the actual number of species is less, being 131 conifers (110 in 1995) and 67 broadleaves (52 in 1995). However, these figures make no allowance for the number of surviving trees on a plot and in some cases there may be only one or two survivors. A better indication of overall performance is given by noting only those plots awarded the top two health scores in 2015; this suggests that only 83 conifer species (63%) were in good health compared to 62 broadleaves (93%). 17% of surviving plots dated from the period 1930-1949 (nearly all from the 1930s), 42% from the 1950s, 16% from 1960-1979 and the remaining 25% had been planted since 2000. Brief details about some genera are given below, concentrating on aspects that have changed since the previous paper (Mason *et al*, 1999). We also note some of the new species that have been planted, although these are too young to have provided useful growth data.

Abies

The collection of silver firs on the middle slopes was a feature of Kilmun with 26 *Abies* species represented in 1995. Most plots have remained healthy and vigorous with the exception of high elevation species and/or those from more continental climates (e.g. *Abies concolor*, *A. lasiocarpa*, *A. sibirica*). Unfortunately, there have been losses to windblow following clearance of adjacent plots, including *Abies alba*, *A. fraseri*, *A. lasiocarpa*, *A. pinsapo*, and *A. sachalinensis*. While a number of new species have been planted in recent years (e.g. *A. borisii-regis*, *A. bornmuelleriana*, *A. squamata*), it will take a decade or more until they contribute to the collection. There has been no evidence of damage by the *Neonectria* spp. canker which has damaged silver fir species in Scandinavia and in Christmas tree plantations in Britain (see https://www.forestry.gov.uk/forestry/beeh-a6seme)

> "Although 42 pine species have been planted at Kilmun, survival has been lower than in the other major conifer genera with only 26 species surviving in 1995"

Cedrus

The vitality of all true cedars (*Cedrus atlantica*, *C. deodara*, *C. libani*) has declined substantially. In 1995, these were all assessed as having moderate health, but many trees have died in subsequent years. While this most likely indicates that these species are not suited to the oceanic climate of Kilmun, there is also a possible link to the outbreak of shoot blight *Sirococcus tsugae* on the plot of mountain hemlock which is 100m away.

Figure 3: 56 years-old plot of coast redwood (*Sequoia sempervirens*).

Picea

There were more than 15 successful plots of spruces in 1995, but since they were scattered across the site, they had less visual impact than the silver firs. Sitka spruce, oriental spruce and Serbian spruce are still vigorous and healthy while species from more continental or higher elevations have declined in vitality over the last 20 years (e.g. *Picea asperata*, *P. breweriana*, *P. glauca*, *P. pungens*).

Pinus

Although 42 pine species have been planted at Kilmun, survival has been lower than in the other major conifer genera with only 26 species surviving in 1995. There have been further losses due to the impacts of Dothistroma needle blight (see above) and of windblow (e.g. plots of *Pinus contorta*, *P. radiata* and *P. strobus*). The healthiest pine plot is that of Macedonian pine (*Pinus peuce*) which continues to flourish towards the top of the site. The main plot of Scots pine (a provenance from a planted stand in west Argyll) is suffering slightly from exposure but is otherwise satisfactory.

Other conifers

Attractive plots of mature European and Japanese larch are a feature of the lower slopes of the collection, although their future is uncertain because of *Phytophthora ramorum* in the surrounding area. Plots of western hemlock, coast redwood, Leyland cypress, western red cedar and Japanese red cedar continue to impress, while individual specimens of Douglas fir are 40m tall. By contrast, the plot of giant redwood has shown shoot dieback in recent years, suggesting that it is less suited to the oceanic climate – a similar trend has been recorded at Brechfa in mid-Wales (Forest Research, unpublished data). More unusual features include a striking 60-year-old plot of monkey puzzle (*Araucaria araucana*) and a healthy small group of Chinese fir (*Cunninghamia lanceolata*). Recent plantings include plots of endangered South American conifers such as

Table 1: Growth performance of a range of different conifer species at Kilmun Forest Garden. Data are for 2015 except for four plots where data are from 2006. Two plots with species names in brackets have been windblown since the last measurement.

SPECIES	AGE AT TIME OF MEASUREMENT (YEARS)	STANDING BASAL AREA (M^2 HA^{-1})	TOP HEIGHT (M)	ESTIMATED GEN.YIELD CLASS(YC)[1]	CHANGE IN YC FROM 1997[3]
[Abies alba] [4]	50	64.8	ND	18 [2]	NC
Abies amabilis	57	135.1	34.5	24	NC
[Abies cephalonica] [4]	57	99.3	ND	16 [2]	NC
Abies delavayi	83	63.4	20.6	12	ND
Abies grandis	60	79.5	33.6	20	-
Abies homolepis	57	91.1	26.1	20	ND
Abies nordmanniana[4]	54	68.9	ND	ND	ND
Abies pindrow	55	93.2	22.6	16	ND
Abies procera	45	110.0	29.7	24	+
Abies veitchii	59	92.5	28.5	22	ND
Araucaria araucana	61	67.9	ND	ND	ND
Chamaecyparis lawsoniana	61	88.6	25.7	18	ND
Cryptomeria japonica	61	57.6	33.8	20	-
Cupressus x leylandii	56	122.8	28.0	22	-
Larix kaempferi	81	33.8	36.1	16	+
Picea abies	62	107.5	28.1	16	ND
Picea glehnii	55	85.6	14.5	8	ND
Picea omorika	62	120.0	29.0	18	+
Picea orientalis	62	152.5	28.1	18	+
Picea rubens	61	110.3	25.8	14	NC
Picea sitchensis	85	123.7	41.3	24	+
Pinus nigra subsp. laricio[4]	76	65.1	26.3	12	ND
Pinus peuce	56	121.8	21.6	12	+
Pinus monticola	61	38.2	21.6	10	-
Pinus sylvestris	63	64.7	21.6	10	+
Pseudotsuga menziesii	62	129.6	39.6	24	+
Sequoia sempervirens	61	214.8	33.5	22	NC
Sequoiadendron giganteum	55	136.5	29.1	18	+
Thuja plicata	85	148.4	24.9	14	ND
Tsuga heterophylla	85	135.0	38.2	22	+
Tsuga mertensiana	56	89.9	22.0	12	+

Notes:

1. Yield Class estimates for species without published tables are based on the recommendations by Anon. (2016 b, Appendix 1) outlining suggested tables for use with other species (e.g. grand fir tables for use with coast redwood).
2. These values are taken from Table 1 in Mason *et al* (1999).
3. This column gives an indication of any changes in estimated Yield Class between 1997 (i.e. Mason *et al* 1999) and the most recent measurement. NC – no change; '+' = an increase; '- ' = a decrease; ND – no data.
4. The values for these species are from 2006.

Fitzroya cuppressoides and *Prumnopitys andina*: plants for these plots were provided by the ICCP.

Acers

The main feature of the various maples continues to be the impressive vigour of the old stand of big-leaf maple (*Acer macrophyllum*), also evident in a younger plot established a few years ago. Norway maple is also healthy, but the poor growth of sycamore (of south Scotland provenance) has been surprising. Small groups of Japanese and other specimen maples have been established in recent years and provide attractive patches of autumn colour.

Betula

In 1995, the most impressive birch plots were an adjacent pair of cherry birch (*B. lenta*) and yellow birch (*B. lutea*) located towards the southern end of the collection. These continue to look healthy, while recent plantings include plots of silver birch sourced from the Tayside regional collection of the Future Trees Trust breeding programme, and of monarch birch (*B. maximowicziana*).

Eucalyptus

Recent years have seen a resurgence of interest in *Eucalyptus* species in Britain, partly because of the potential use of some species in short-rotation forestry (Purse and Leslie, 2016). Six new plots of a range of eucalypts have been established including *E. glaucescens*, *E. nitens* and *E. regnans*. Individual survivors of plantings in the 1950s and 1960s continue to be a feature of the lower slopes of the forest garden, while natural regeneration of *E. gunnii* and possibly other eucalypt species can be found on disturbed ground adjacent to the mature trees.

Nothofagus

Recent felling of the two mature plots of rauli and roble damaged adjacent groups of other southern beech species, so the impact of this genus in the collection is diminished compared to 20 years ago. However, there are impressive mature specimens of the evergreen species coigue (*N. dombeyi*) and *N. menziesii* in different parts of the site, while younger healthy plots of rauli, roble, and *N. pumilio* can be found in the less visited southern part of the site. Natural regeneration of both evergreen and deciduous *Nothofagus* species can be found within fenced exclosures protecting new plantings of other species.

Quercus

Unfortunately, the mature plot of pedunculate oak (*Q. robur*) was severely damaged by windthrow in 2012, while a nearby plot of red oak (*Q. rubra*) appears to have suffered from exposure. The healthiest mature plot is the one of sessile oak (*Q. petraea*), while a new plot of *Q. pyrenaica* is part of an attempt to increase the number of oak species present in the collection.

Other broadleaves

A mature plot of Italian alder (*A. cordata*) continues to impress while plots of European (*Fagus sylvatica*) and oriental beech (*F. orientalis*) are in good health, even if the trees in the former are of poor form. A plot of whitebeam (*Sorbus aria*) is healthy with nice straight stems while most ashes (*Fraxinus* spp.) are of poor form and have little vigour. Recent plantings include several new broadleaves such as sweet chestnut and hybrid aspen (*Populus tremula x tremuloides*).

Tree Growth

Performance of 31 different conifer species at between 45 and 85 years of age is summarised in **Table 1**. This highlights the generally good growing conditions found at Kilmun, where over 60% of species had estimated Yield Classes in excess of 14m^3 ha^{-1} yr^{-1}, the average productivity for conifer stands in Britain (Anon., 2016 a, Table 10). The highest Yield Classes occurred in Pacific silver fir, noble fir, Sitka spruce and Douglas fir, but several other species had productivities greater than 20m^3 ha^{-1} yr^{-1}. Estimated productivity of the pines was lower than for the spruces or the silver firs.

> **"Therefore, on current evidence from Kilmun, there are 18 potential alternative species that could be considered for the diversification of spruce-dominated forests in western Britain"**

Evaluation of standing basal area is complicated by the variable thinning history, while the small plot size used in the latest measurements may have masked within-plot variation in growth. In general, the higher basal areas were from those species which had higher estimates of Yield Class, but there were interesting variations. Thus, the highest basal area was in coast redwood, while there were relatively more high values recorded in spruce species and relatively fewer in silver firs. One or two species with relatively low Yield Classes had comparatively high basal areas, such as western red cedar and Macedonian pine.

Table 2 provides information on the growth and productivity of 15 broadleaved species at between 46 and 81 years of age. In most cases the estimated yield classes were quite low <10 with the only exceptions being the plots of big-leaf maple (*Acer macrophyllum*), Italian alder (*Alnus cordata*), and the two *Nothofagus* species (now felled) where productivity ranged between 10 and 20m^3 ha^{-1} yr^{-1}. In general, there was little change in estimated yield class between 1997 and 2015: where changes had occurred these involved an increase in estimated yield class. Standing basal areas tended to be lower than in the conifers with most values being between 40 and 70m^2 ha^{-1}.

Timber properties

At the time of writing, timber testing has only been completed for Pacific silver fir. Provisional figures (Dr Steven Adams, Edinburgh Napier University, *pers. comm.*) have shown that structural timber of this species, from this site, can easily meet requirements for C16 and could potentially grade at C20, though this will need to be verified. Preliminary indications for Japanese red cedar suggest that the timber of this species may come out at a lower grade.

Discussion

The previous report on the Kilmun collection (Mason *et al*, 1999) concluded that the species which had performed well were those adapted to the oceanic climate, characterised by high rainfall and a cool growing season, while being cold hardy to below -15°C to -20°C. When combined with results from the Forest Garden at Brechfa in mid-Wales (Danby and Mason, 1998), there were considered to be more than a dozen 'minor' species which could be used to diversify planted forests in western Britain while providing adequate timber volumes. Recent assessments summarised in **Tables 1 and 2** support the general conclusion from the previous paper. Although a few species previously favoured such as *Nothofagus alpine, N. oblique*, and *Sequoiadendron giganteum* have suffered declining health or mortality, all the other species previously listed remain healthy and vigorous while other species not mentioned previously (*Abies homolepis, A. veitchii, Picea orientalis*) show good health and vigour after 55-65 years of age.

Therefore, on current evidence from Kilmun, there are 18 potential alternative species that could be considered for the diversification of spruce-dominated forests in western Britain (**Table 3**). Most originate either from the Pacific North-West of North America (e.g. grand fir, noble fir, coast redwood, Douglas fir and western hemlock) or from Japan (*Abies homolepis, A. veitchii*, Japanese red cedar). The high productivity of some of these North American conifers in relation to Sitka spruce has been examined previously (Aldhous and Low, 1974). We have separated the conifers into two categories, the first comprising those of high productivity at Kilmun and elsewhere in western Britain. The second category contains those conifers with either slightly lower productivity but good performance elsewhere in Britain or those for which we have only limited other data (e.g. *Abies homolepis, A. veitchii*). In the broadleaved category we have only listed two species (*Acer macrophyllum, Alnus cordata*) where the productivity substantially exceeds

Table 2: Growth performance of plots of a range of different broadleaved species at Kilmun Forest Garden. Data are for 2015 except for three plots where data are in italics, which are from 2006. Two *Nothofagus* plots in brackets were cleared because of pathogen attack after the last measurement – see text for details.

SPECIES	AGE AT TIME OF MEASUREMENT (YEARS)	STANDING BASAL AREA (M^2 HA^{-1})	TOP HEIGHT (M)	ESTIMATED GENERAL YIELD CLASS (YC)[1]	CHANGE IN YC FROM 1997[3]
Acer macrophyllum	81	64.8	32.7	>14	NC
Acer platanoides	62	38.7	15.1	4	+
Alnus cordata	81	68.9	26.2	12	NC
Alnus glutinosa	46	40.2	14.9	4	NC
Betula lenta	64	23.5	14,4	2	NC
Betula lutea	65	44.9	15.4	4	+
Fagus orientalis	55	48.3	23.6	8	+
Fagus sylvatica	62	67.6	22.2	8	+
[Nothofagus obliqua]	50[2]	48.6	26.3	16	+
[Nothofagus alpina]	50[2]	82.2	-	18	NC
Quercus petraea	56	31.9	20.3	8	NC
Quercus robur	49[2]	31.6	-	-	ND
Quercus rubra	59	25.0	21.0	8	NC
Sorbus aria	60	43.3	19.9	6	ND
Tilia cordata	80	55.1	24.2	6	NC

Notes:

1. Yield Class estimates for species without published tables are based on the recommendations by Anon. (2016 b, Appendix 1) outlining suggested tables for use with other species (e.g. grand fir tables for use with coast redwood).
2. The values for these species are from 2006.
3. This column gives an indication of any changes in estimated Yield Class between 1997 (i.e. Mason *et al*, 1999) and the most recent measurement. NC – no change; '+' = an increase; '- ' = a decrease; ND – no data.

Table 3: A list of potential alternative tree species that have performed well at Kilmun and could be considered for use in planted spruce forests in western Britain as part of a strategy of diversification to enhance resilience against climate change.

CONIFERS		BROADLEAVES
Category 1 – Productivity 20-24m^3 ha^{-1} yr^{-1} and good growth in other trials	**Category 2 –** Productivity 16-20m^3 ha^{-1} yr^{-1} and/or reasonable growth in other trials	**Productivity** > 10m^3 ha^{-1} yr^{-1} and/or reasonable growth in other trials
Abies amabilis	***Abies alba***	***Acer macrophyllum***
Abies grandis	***Abies homolepis***	***Alnus cordata***
Abies procera	***Abies veitchii***	
Cupressus x leylandii	***Picea abies***	
Cryptomeria japonica	***Picea omorika***	
Pseudotsuga menziesii	***Picea orientalis***	
Sequoia sempervirens	***Pinus peuce***	
Tsuga heterophylla	***Thuja plicata***	

that of a range of native broadleaved species. It is probable that productivity of recently planted broadleaves such as various *Eucalyptus* species and aspen hybrids will also exceed that of native broadleaves, but at present the evidence is lacking.

Inevitably, the categories in **Table 3** are somewhat arbitrary and species performance at Kilmun may have been affected by the use of a less productive provenance. Thus, the plot of *Abies alba* was of a Danish provenance from outwith the natural distribution of the species and the height at year 41 was less than in the best treatments of a nearby provenance experiment (Kerr *et al*, 2014). Similarly, the provenance of *Picea abies* was from Switzerland whereas the current recommendation is for the use of seed sources from Romania or Poland (Lines, 1987). Further details of many of these alternative species can be found in an ongoing series of articles published in the *Quarterly Journal of Forestry* (e.g. Savill, 2015; Wilson *et al*, 2016).

Given discussion about deploying alternative species in Scottish forests as part of a climate change adaptation strategy (Beauchamp *et al*, 2016), the fact that over 140 tree species are growing healthily at Kilmun should offer reassurance that there would be viable alternatives available for planting in western Britain if a major species was affected by a pest or pathogen. However, species selection is not just a function of tree health and productivity, but also depends upon the properties of the timber that is produced. Although the wood properties of material cut from British stands of several of the candidate alternative species listed above are relatively little known, recent work has suggested that home-grown timber of both noble fir and western hemlock is capable of meeting the strength requirements for use in construction

(Gil-Moreno *et al*, 2016). Cameron and Mason (2013) had previously suggested that British-grown western hemlock could have desirable timber properties, especially when grown in mixture in irregular silvicultural systems. While the results from timber samples of Pacific silver fir from Kilmun are promising (i.e. potentially grading at C20) good stands of Sitka spruce can grade at C24 (Moore *et al*, 2013), and more importantly range between C16 and C24. Therefore, evaluating timber from one stand alone is not enough to judge the suitability of an alternative species, but it does show the potential.

One factor that can influence the use of an alternative species is the ease of establishment, including the relative palatability to browsing by animals such as deer and rabbits. In this respect, results from Kilmun can only give partial information since the trees were established within fenced exclosures and have been regularly weeded. However, experience suggests that many alternative species are not well suited to being grown in the open ground conditions characteristic of larger patch clear-felling coupes (Cameron and Mason, 2013). Instead, deployment of these species could make use of their shade-tolerance by underplanting them in protected gaps in mature stands (Kerr and Haufe, 2016). Regimes used to produce these alternative species in forest nurseries may also need to be adjusted. For example, Macedonian pine needs a much lengthier stratification period than Sitka spruce (Mason *et al*, 1995) while nursery regimes used for producing Sitka spruce planting stock need to be modified to produce quality Douglas fir plants (Mason *et al*, 1989).

The data outlining the growth performance of different species (**Tables 1 and 2**) are based upon small plots located in the centre of stands that have had a differential history of partial thinning and occasional mortality. For these reasons the values presented should be considered as a relative indication of biological potential rather than a definite statement of performance. Some of the basal areas may seem high, but appear to fall within the upper range of other values reported for some of these species in the literature. Thus the value of 215m² ha⁻¹ for coast redwood is less than the 250m² ha⁻¹ reported from a plot (admittedly with older trees) in the Welsh Borders (Wilson *et al*, 2016). In New Zealand, Nicholas (2010) reported basal area values ranging from 101 to 213m² ha⁻¹ for 23 stands of coast redwood at 29 to 47 years of age. Similarly, Franklin (1981) reported an average basal area of 100m² ha⁻¹ for a number of noble fir dominated stands in the western USA with an upper figure of 161m² ha⁻¹. Kuiper (1988) carried out studies in Douglas fir stands of different ages in Oregon, finding basal areas ranging from 57 to 210m² ha⁻¹.

Figure 4: An 85 years-old plot of Japanese red cedar (*Cryptomeria japonica*), one of the original plantings in Kilmun Forest Garden.

One of the values of Kilmun is that it offers a visual demonstration of the comparative performance of a tree species on a single site. Thus of 70 alternative species listed on the SilviFuture website (http://www.silvifuture.org.uk/species), at Kilmun there are plots of 12 species in the ‘high-priority’ category (63%) and of 11 in the ‘medium’ category (40%). No other site in the British Isles provides such a breadth of species comparisons within a small area. Any extrapolation of species performance from the comparatively favoured environment at Kilmun to the more exposed conditions and wetter soils prevalent in other forests in western Britain should be done with care. However, the advent of more sophisticated decision support tools such as ESC (Pyatt *et al*, 2001) will make it easier for managers to judge how far site limitations might constrain the deployment of an alternative species. In addition, as noted above, these long-term plots can also provide useful samples for destructive timber testing and, if required, the plots could be used to see if particular species had effects upon wider aspects of the forest ecosystem such as soil properties or vegetation development.

“…recent work has suggested that home-grown timber of both noble fir and western hemlock is capable of meeting the strength requirements for use in construction”

As with any long-term forest trial, the survival of Kilmun Forest Garden will depend upon formulating a clear vision for its purpose that meets current and future needs, ensuring that adequate funding is available to support the delivery of that vision, communicating the importance of the results to interested parties, while maintaining the existing collection and establishing new plots so that its unique demonstration and educational value can be retained. With increasing awareness of the potential hazards and challenges that our forests may experience as a result of climate change, arguably the value of a collection such as Kilmun is greater than ever.

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